

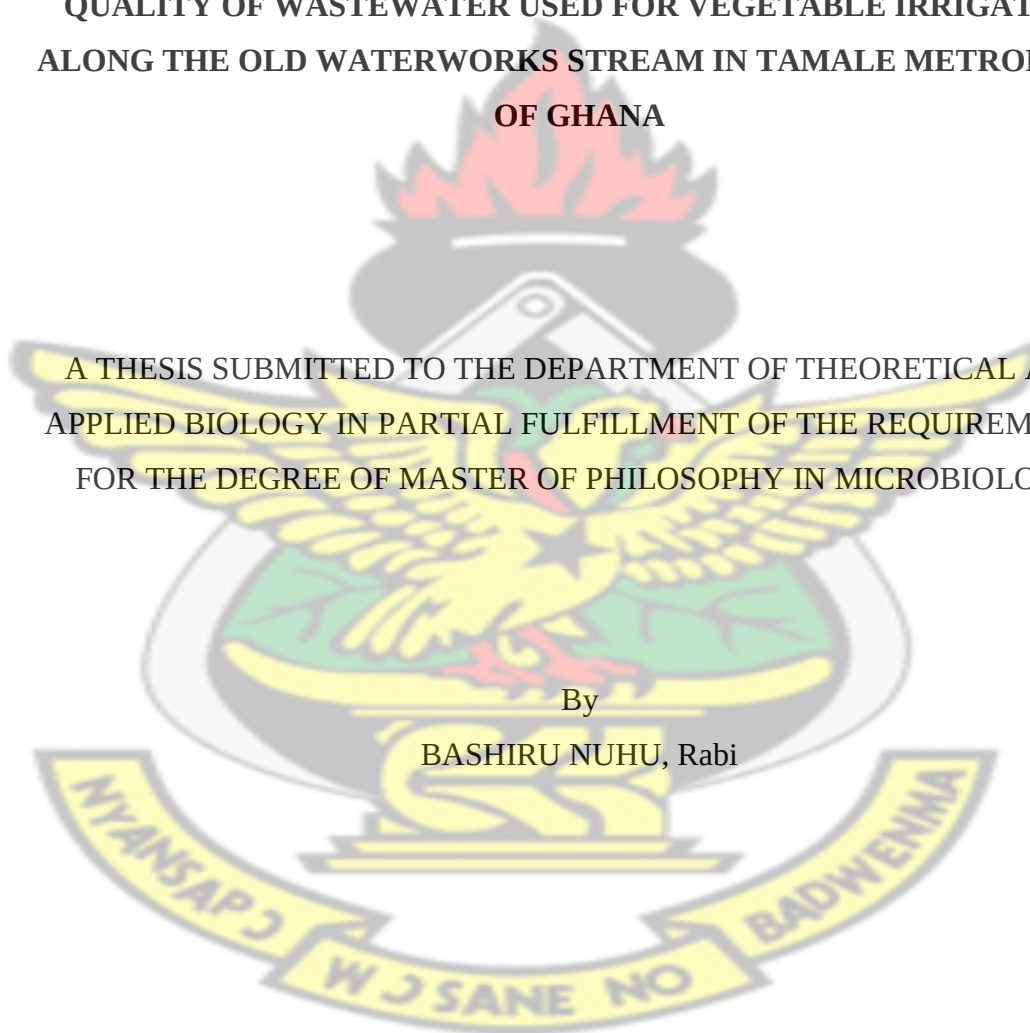
KWAME NKRUMAH UNIVERSITY OF SCIENCE AND TECHNOLOGY,
KUMASI
COLLEGE OF SCIENCE
DEPARTMENT OF THEORETICAL AND APPLIED BIOLOGY

**ASSESSMENT OF MICROBIOLOGICAL AND PHYSICOCHEMICAL
QUALITY OF WASTEWATER USED FOR VEGETABLE IRRIGATION
ALONG THE OLD WATERWORKS STREAM IN TAMALE METROPOLIS
OF GHANA**

**A THESIS SUBMITTED TO THE DEPARTMENT OF THEORETICAL AND
APPLIED BIOLOGY IN PARTIAL FULFILLMENT OF THE REQUIREMENTS
FOR THE DEGREE OF MASTER OF PHILOSOPHY IN MICROBIOLOGY**

By

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JUNE, 2018

DECLARATION

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

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DEDICATION

To my children: Rahamatu and Nurudeen Adam

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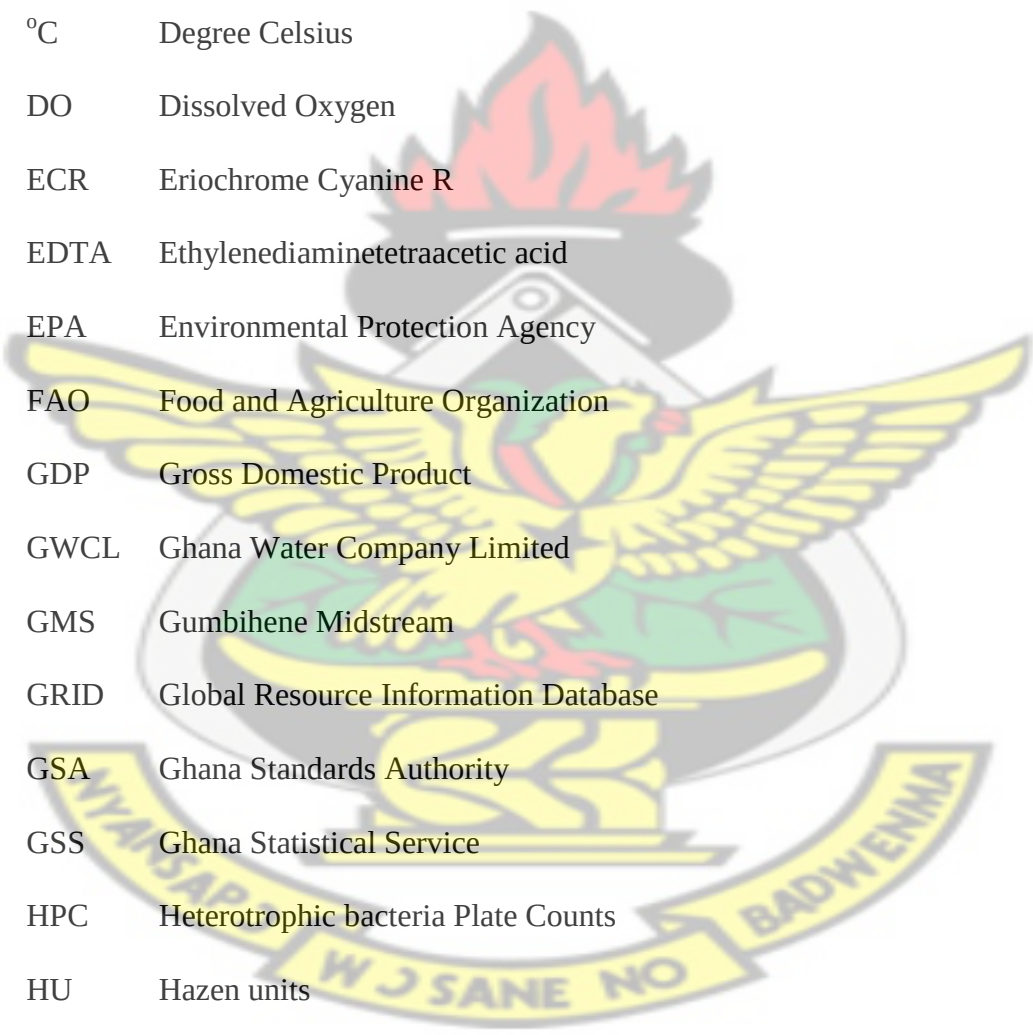
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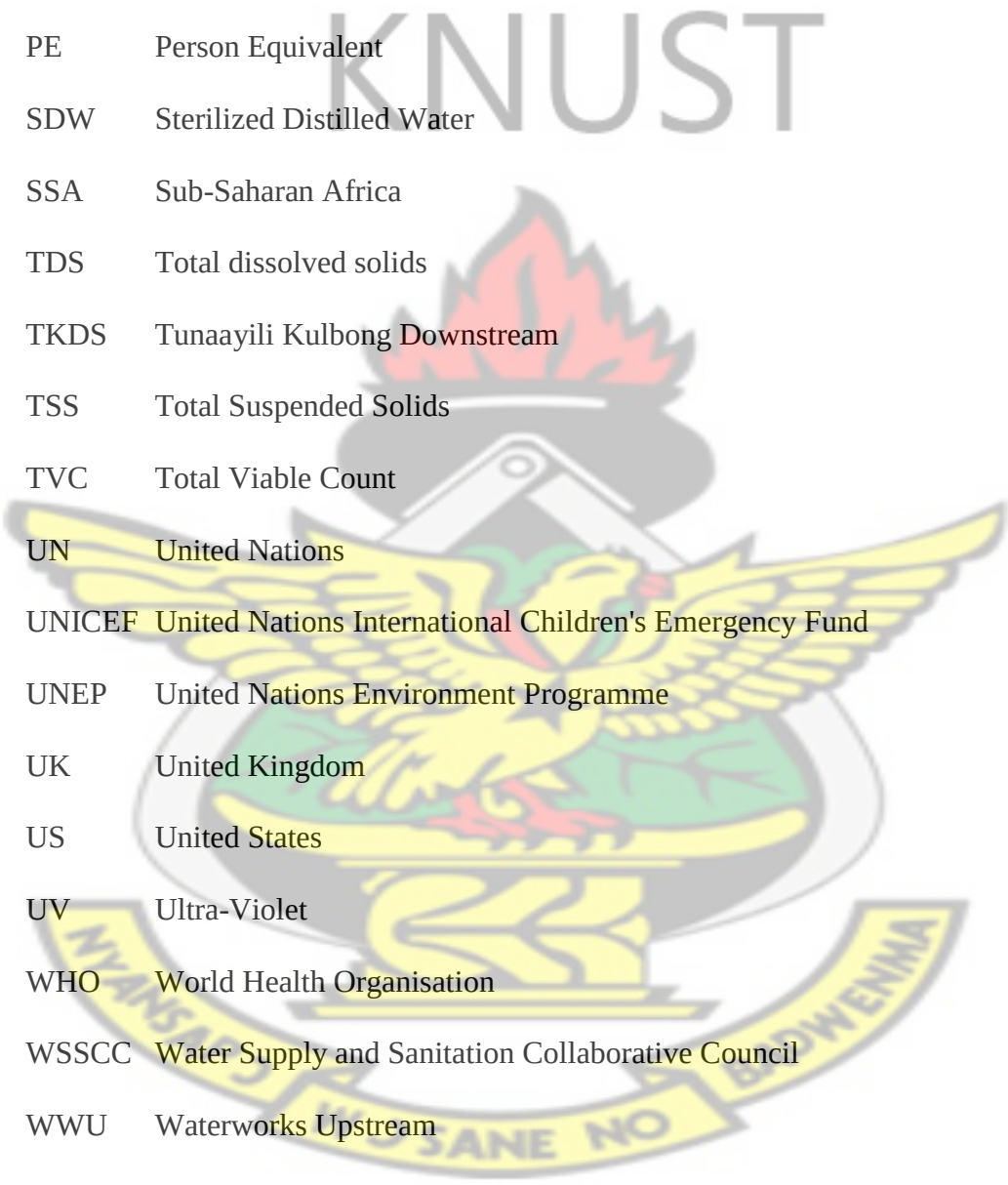
ABSTRACT

Worldwide, several million hectares of farmland in estimated 50 countries are used to cultivate agricultural produce by farmers who have adopted the application of untreated and or partially treated wastewater from various sources. The application of untreated wastewater which are contaminated with microbes and chemicals including heavy metals poses serious public health threat on the vegetable farmers, vendors and consumers of vegetables cultivated using such untreated wastewater. This study assessed the microbiological, physical and chemical qualities of wastewater used for vegetable irrigation along the Tamale old waterworks stream in the Tamale Metropolis of Ghana. Two wastewater samples each were collected from the four sampling sites: Waterworks upstream (WWU), Gumbihini midstream (GMS), Nyanshagu midstream Gardens (NMS) and Tunayili Kulbong Downstream Gradens (TKDS) along the stream monthly for six consecutive months for microbial and physicochemical parameters for dry and rainy seasons. A total of forty-eight water samples were collected and analysed for their microbiological, chemical and physical qualities using standard protocols adopted by the American Public Health Association (APHA, 1998). The results obtained showed consistent increase in the bacterial and physicochemical load for both irrigation seasons. The bacterial parameters studied include total coliform, faecal coliform, *E. coli*, *Staphylococci*, *Enterococci*, *Pseudomonas* and total heterotrophic bacteria. The statistical analysis on the microbials gave a weak correlation ($r=0.24$) among the individual sampling sites for microbial statistics. More so, there is a significant difference between the wastewater samples for dry and rainy season irrigation of microbial parameters with ($p = 0.005$) from the pairwise sample test. Results obtained showed consistent increase in the bacteria load for both seasons with the rainy season recording higher loads than the dry season except for total heterotrophic bacteria which was rather higher in the dry season as compared to rainy season. Overall, bacterial count recorded was lowest at GMS1 and highest at NMS2 for both seasons. The physicochemical parameters include, pH, conductivity, total alkalinity, total hardness, calcium hardness, magnesium hardness, carbonate hardness, bicarbonate hardness, calcium, magnesium, chloride, fluoride, sulphate, sulphide, phosphate, ammonia-nitrogen, nitrate-nitrogen, nitrite-nitrogen, aluminium, total iron, manganese, copper, zinc, cyanide, total chromium and potassium. There is strong correlation ($r=0.99$) among the individual sampling sites for physicochemical parameter analysis of wastewater samples during dry and rainy season irrigation schemes. More so, pairwise analysis indicates that there is no significant difference ($p= 0.41$) among the sampling sites for physicochemical wastewater samples for dry and rainy season irrigation of physicochemical parameters. Overall, physicochemical values recorded were lowest at GMS1 and highest at NMS2 for both the dry and rainy season samples. More so, bacterial counts recorded for all the microbial parameters exceeded the WHO (2006b) guideline of 1×10^3 cfu/100ml for unrestricted irrigation of crops likely to be eaten raw whilst the physicochemical parameters determined were found to be within FAO/WHO guidelines for irrigation water except for colour, total alkalinity, chloride, zinc and cyanide. Most of the chemicals had levels above WHO guidelines and are potential health threat especially high nitrate concentration in irrigation water causes blue baby syndrome. The application of untreated wastewater poses serious public health threat on the vegetable farmers, vendors and consumers of vegetables cultivated using such untreated wastewater. It is therefore recommended that wastewater for irrigation of ready-to-eat vegetables be treated using biological nutrient removal system and wastewater stabilisation ponds to reduce and or eliminate contaminants before irrigating vegetables.

ABBREVIATIONS



APHA	American Public Health Association
BOD	Biological Oxygen Demand
BNR	Biological Nutrient Removal
CDC	Centre for Disease Control and Prevention
COD	Chemical Oxygen Demand
CSIR	Council for Scientific and Industrial Research
°C	Degree Celsius
DO	Dissolved Oxygen
ECR	Eriochrome Cyanine R
EDTA	Ethylenediaminetetraacetic acid
EPA	Environmental Protection Agency
FAO	Food and Agriculture Organization
GDP	Gross Domestic Product
GWCL	Ghana Water Company Limited
GMS	Gumbihene Midstream
GRID	Global Resource Information Database
GSA	Ghana Standards Authority
GSS	Ghana Statistical Service
HPC	Heterotrophic bacteria Plate Counts
HU	Hazen units
ICMSF	International Commission on Microbiological Specifications for Foods
ICP	Inductively Coupled Plasma
ISSER	Institute of Statistical, Social and Economic Research
IWMI	International Water Management Institute



KDS	Kanvili Tunaayili Kulbong Downstream
MF	Membrane Filtration
NMS	Nyanshegu Midstream
NTU	Nephelometric Turbidity Units
PAHO	Pan American Health Organization
PE	Person Equivalent
SDW	Sterilized Distilled Water
SSA	Sub-Saharan Africa
TDS	Total dissolved solids
TKDS	Tunaayili Kulbong Downstream
TSS	Total Suspended Solids
TVC	Total Viable Count
UN	United Nations
UNICEF	United Nations International Children's Emergency Fund
UNEP	United Nations Environment Programme
UK	United Kingdom
US	United States
UV	Ultra-Violet
WHO	World Health Organisation
WSSCC	Water Supply and Sanitation Collaborative Council
WWU	Waterworks Upstream

CHAPTER ONE

INTRODUCTION

1.0 Background to the study

Worldwide, countries are competing daily for increased water resources as a result of the compound consequences of urbanization, population growth, economic development and climate change. The sustainability of water supplies is a challenge especially as sources of freshwater becomes scarce coupled with the increased use of wastewater for urban agriculture, aquaculture, landscape irrigation, urban and industrial uses (Asano *et al.*, 2007). Consequently, most urban cities are vulnerable to domestic water shortage (Toze, S. 1997). Water however is not always available in sufficient quantity and quality when and where it is needed. There is intense need for fresh potable water thus making the application of polluted industrial and domestic wastewater a common activity worldwide (Ensink *et al.*, 2002; Sharma *et al.*, 2007). Worldwide, it is projected that approximately 18% farmlands are cultivated with dirty or wastewater accounting for 40% of all the food crops (Gleick, 2000 and Amoah, 2008). It is also estimated that, a tenth or more of people in the world one way or the other eat food that has been cultivated with wastewater (Jiménez and Asano, 2008; Raschid-Sally and Jayakody, 2008). Global estimates of irrigated lands using different forms of wastewater (raw, diluted or partially treated) in fifty countries is 20 million hectares and there is the possibility to increase significantly in the next ten years because of the increasing need for water (Hussein *et al.*, 2001; Scott *et al.*, 2004; Hamilton *et al.*, 2007). This practice is especially high particularly in areas lacking sufficient water or rainfall and urban places where potable clean water is a scarce commodity and wastewater containing lots of plant nutrients

provides sufficient water supply for farming activities in times of drought (WHO, 2006).

In the developing and under-developed countries, the application of wastewater in crop farming is regarded an unavoidable condition in order to make-up for the shortage of water in these countries. For this reason, the practice of irrigating or cultivating crop plants with untreated wastewater is observed widely in these countries (Sou *et al.*, 2011). The application of untreated wastewater in the cultivation of food crops is a practice that has been around for ages which is getting more attention nowadays as a result of the lack of freshwater resources especially in arid or semi-arid areas or drought-prone regions (Ackerson *et al.*, 2012).

The use of wastewater to irrigate gardens and farmlands during dry season provides water to many including alefu (*Amaranthus cruentus*), tomato, carrot, spinach, ayoyo (*Corchorus olitorious.*), lettuces, cabbage and onion, which serves a means of livelihood for a significant number of people in under-developed and developing countries. Even in some developed states, wastewater is sometimes reused in the cultivation of certain vegetable farms (Aljaloud, 2010, Sarkinnoma *et al.*, 2013; Wajahat *et al.*, 2006).

According to Veenhuizen *et al.* (2007), for many agricultural purposes or reasons, farmers of different kinds or groups both in the urban and peri-urban areas in Africa and Asia apply wastewater in their daily activities on their farms. The activities may include the production of cereal, fodder for dairy, aquaculture, agroforestry, floriculture or keeping of orchard. In Nagpur, India, significant increase in crop yield of about 35% has been reported for the application of untreated wastewater when compared to freshwater with application of chemical fertilizer (Shende, 1985).

According to the Ghana Statistical Services (2002), there is lack of wastewater treatment plants in most urban centres, however, sewer networks in the whole of Ghana connects approximately 4.5% households. Most of this wastewater, which are mainly generated from domestic sources, finds their way into city drains, as well as streams, rivers and other waterbodies found in the cities (Obuobie *et al.*, 2006). Reports have estimated that around 85% of these untreated wastewaters produced in urban centres finally end up in the environment in its raw untreated form. In urban vegetables agricultural farms, some of these wastewaters are applied to the land and crops in the form of irrigation (Obuobie *et al.*, 2006). This kind of dirty water plays an important role in serving as a source of water for irrigation practice for most farmers involved in vegetable cultivation in the urban and peri-urban areas throughout the year helping them to cultivate their crops both in the dry and wet season. According to reports, agriculture is the backbone of Ghana's economy, hence contributes around 36% of the country's Gross Domestic Product (GDP) and provide employment for 60% of her labour force (ISSER, 2013; IWMI, 2002).

Wastewater use in urban agriculture provides a vital nutrient source especially including phosphorus, nitrogen and organic matter that improves the soil's physical properties in addition to its fertility (Nauman and Khalid, 2010; Gibbs *et al.*, 2006) for improved crop yield. Even though wastewater provides these benefits directly to the soil and indirectly to plants, the presence of appreciable quantities of both organic and inorganic toxic substances cannot be downplayed. They may also contain pathogens such as bacteria, intestinal and blood helminth and protozoa parasites, viruses, toxic chemicals from industries, business centres, agriculture and domestic sources (Keraita *et al.*, 2003; Amoah, 2008; Feachem *et al.*, 1983). Although the application of wastewater in agriculture provides a means of supporting

the livelihood of a significant number of people involved in the practice mostly in the urban and peri-urban areas, the health and environmental risks expose to farmers and non-farmers calls for serious public health attention (Asano and Levine, 1996).

After Accra and Kumasi, Tamale is considered the third largest city in Ghana, and in this city, wastewater is employed for both agricultural and non-agricultural use. It is used by car drivers for washing their cars and by farmers for irrigating their vegetable crops like cabbage, green pepper, spring onions and lettuce. Unfortunately, with the increasing number of people or inhabitants coupled with industrialisation and urbanisation, the volume of clean potable water supply available per capita annually is on rapid decline. Consequently, the quality of water in this region has significantly decline due to high pollution activities and has hence reduced the amount of water available for use domestically and for irrigation of farms. Most of these vegetable farming is usually done along streams, wastewater drains, earth-dams with small reservoirs, near dug-outs and broken-down sewers or sewers deliberately channelled into drains and streams. This condition is as a result of the fact that the Tamale Metropolis lack perennial stream but rather streams that get filled with water during the wet season and dries-up during the prolonged dry season (IWMI, 2002). This condition is compounded by the nature of groundwater table within Tamale which is very low as a result of an underlying consolidated neo-proterozoic Voltaian sedimentary formation, which in Ghana is believed to be one of the least of groundwater potentials in Ghana (Gyau-Boakye and Dapaah-Siakwan, 2000).

Upstream, most rivers in the metropolis are mainly used for car washing and the same water is used downstream for vegetable cultivation. Additionally, most of the wastewater used in urban agriculture is from old broken dams, water hydrants, commercial water pump at the old water works and dug outs, untreated sewage from

worn-out sewer as well as liquid wastewater from domestic and industrial sources. The cultivation of fresh vegetable crops in Tamale has become a profitable business opportunity and a major means of income for most farmers in and around the Tamale Metropolis either in the dry and wet season. The use of this polluted wastewater along the Tamale old water works in the cultivation of raw edible vegetables is something of public health concern because the consumption of these ready-to-eat or raw edible vegetables has increased among people in the metropolis and this could lead to increased water and food borne diseases in the metropolis.

1.1 Problem statement

It has been reported that farmers in several countries worldwide have adopted the application of raw untreated and/or partially treated wastewater on several million hectares of farm land. This practice has been estimated to increase significantly by the next few decades because of high demand of water (Hussein *et al.*, 2001; Scott *et al.*, 2004; Hamilton *et al.*, 2007). In regions where there are long periods of drought like arid and semi-arid regions and particularly urban areas with high demand and scarcity of clean potable water, farmers tend to use partially treated or raw untreated wastewater which are enriched with plant nutrients in irrigating their crops a lot (WHO, 2006). This kind of raw wastewater from industry, agriculture and domestic source serve as a reservoir of many different kinds of microbial pathogens such as bacteria, intestinal helminth and protozoa parasites, viruses and toxic chemicals (Amoah, 2008).

Studies conducted in some urban and peri-urban regions in Ghana have indicated that the sources of water for vegetable crops irrigation may be heavily contaminated by microbes and chemicals, and this make them unsafe for irrigation and consumption of their farm products. The presence of high salt levels, hazardous chemicals and a

lot of other contaminants make such irrigation water extremely dangerous to the health of plants, animals and human (Mensah *et al.*, 2001; Cornish *et al.*, 1999). Apart from the cultivation of common vegetables like okra, lettuce, green pepper and spring onions in the Tamale Metropolis, farmers are also fond of growing traditional vegetable including ayoyo (*Corchorus olitorious.*) and alefu (*Amaranthus cruentus.*), and sometimes less perishable vegetables like tomatoes and garden eggs.

The Tamale Waterworks is originally named after a dam that was constructed to supply clean portable water for inhabitants of the Tamale township. With the collapse of the water station, the water has now become very polluted and it is now used by vegetable farmers who have sited farms near the waterbody. Majority of inhabitants in the Sanerigu district rely on the Tamale old water works stream as a source of water for their all year-round gardening, vehicle washing, domestic use and for livestock production.

1.2 General Objectives

The main objective of this study was to determine the microbiological, physical and chemical quality of wastewater used for vegetable irrigation along the Tamale old waterworks stream in the Tamale Metropolis.

1.3 Specific Objective

To evaluate:

- Physical parameters including temperature, colour, turbidity, total dissolved solids and total suspended solids of wastewater along the course of the waterworks stream.
- Chemical parameters including pH, conductivity, total alkalinity, total hardness, calcium hardness, magnesium hardness, carbonate hardness,

bicarbonate hardness, calcium, magnesium, chloride, fluoride, sulphate, sulphide, phosphate, ammonia-nitrogen, nitrate-nitrogen, nitrite-nitrogen, aluminium, total iron, manganese, copper, zinc, cyanide, total chromium and potassium of wastewater along the course of the water works stream.

- Microbial parameters including Total Coliform, Faecal Coliform, *E. coli*, *Staphylococci*, *Enterococci*, *Clostridium*, *Pseudomonas* and Total Heterotrophic Bacteria of wastewater along the course of the water works stream.

1.4 Hypothesis

1.4.1 Null Hypothesis (H_0)

H_{01} : There is no significant difference in microbial and physicochemical qualities of the Tamale old water works stream during dry and rainy season.

H_{02} : There is no significant difference in the physicochemical parameters between dry and rainy season irrigation along the Tamale old water works stream.

H_{03} : There is no significant difference in the microbial parameters between dry and rainy season irrigation along the Tamale old water works stream.

H_{04} : There is no significant difference in the physicochemical and microbial parameters between dry and rainy season irrigation among the sampling sites along the Tamale old water works stream.

1.4.2 Alternate Hypothesis (H_A)

H_{A1} : There is significant difference in microbial and physicochemical qualities of the Tamale old water works stream during dry and rainy season.

H_{A2}: There is significant difference in the physicochemical parameters between dry and rainy season irrigation along the Tamale old water works stream.

H_{A3}: There is significant difference in the microbial parameters between dry and rainy season irrigation along the Tamale old water works stream.

H_{A4}: There is significant difference in the physicochemical and microbial parameters between dry and rainy season irrigation among the sampling sites along the Tamale old water works stream.



CHAPTER TWO

LITERATURE REVIEW

2.1 Wastewater reuse in irrigated agriculture

World Bank estimated that the wastewater from about 4,000 million inhabitants globally do not undergo any form of treatment (Idelovitch and Ringskog, 1997). Similarly, the World Bank (2000) reported that Latin America alone produced more than 100 million cubic metres of wastewater generated domestically, which was discharged into drains on daily basis all over the region with over 90% reused for agricultural irrigation (PAHO, 2005). Official reports from World Bank (2000) show that estimated quantity of wastewater that has been treated in Asia is 35%, 10% in South America, 4% in Caribbean, and close to 0% in sub-Saharan Africa (SSA) with large quantities of raw wastewater released into drains, as well as other natural waterways that eventually get collected by vegetable farmer for irrigation purposes.

The application of raw or partially treated wastewater in agricultural practices is an ancient custom that has gained considerable attention as a result of the growing demand and scarcity of freshwater resources in many drought-prone regions. Additionally, urban sprawl coupled with growing volumes and cost of treatment, where wastewater is usually used for irrigation as a means of cutting down the cost of water supply as compared to conventional irrigation water may be a contributory reason. Further, the reason attributed to the benefits wastewater used for irrigation supports livelihoods through the generation of considerable income derived from urban and peri urban agriculture. These kinds of ascribed reasons have the tendency of mitigating the extent of risks linked with application of wastewater. Even though use of wastewater is widespread, the practice is not checked or controlled particularly in low-income nations and its economic value is not well understood (Scott *et al.*,

2004). It is reported by WHO, UNICEF and WSSCC (2000) that most under-developed and developing countries lack adequate facilities or resources for treating wastewater, and this has had significant impact in generation of large volumes of wastewater particularly in urban areas.

In most under-developed and developing countries, there is application of wastewater in various agricultural practices either directly or indirectly. Direct wastewater irrigation practices are normally centred near large metropolitan areas (Wescott, 1997), but only a small percentage of the wastewater produced is used directly. Rather, indirect use of wastewater prevails in most developing countries (Wescott, 1997). Indirect use of wastewater said to have occurred when raw, partially treated or treated wastewater contaminate surface water that serve as a source of irrigation water for agricultural practices. Either direct or indirect application of wastewater in agriculture, both health and environmental issues of similar magnitude can come-up (Wescott, 1997). As a result of increasing rate of modernisation and urbanisation, there is realization that the volumes of wastewater produced will continue to increase. Therefore, water resource management systems need to incorporate the application of wastewater in the management of all water resources of a state (WHO, 2006).

2.2. Wastewater qualities for irrigated agriculture

In order to ensure that human health and wellbeing is well protected, the Food and Agriculture Organization (FAO) in 1992 recommended that certain factors or conditions be well considered in the application of raw untreated or partially treated wastewater. The conditions included: wastewater treatment that employs single or combined approaches, restriction of crops and control of the use of wastewater, control of human contact with wastewater and encouraging good hygiene practices in

the use of wastewater. As a result, a study by Hespanhol and Prost (1994) revealed that based on epidemiological and microbiological factors, different countries may have or adopt different guidelines for effective reuse of wastewater particularly in agriculture. Besides, WHO and FAO subsequently came out with guide lines as standard for checking the microbial and physicochemical qualities if irrigation water. This paved the way for Blumenthal *et al.*, (2000) to review different research works from other countries on the basis of their guidelines on the use of wastewater. The outcome revealed that there are a lot of health-related risks in the application of wastewater in either restricted or unrestricted irrigation systems, as a result of high risks of farmers and residents who live close-by acquiring infections such as bacterial and viral infections. Blumenthal *et al.*, (2000) have recommended therefore that it is necessary to revise guidelines for microbiological treatment of wastewater and its application.

Despite WHO and FAO recommended standards for safe reuse of wastewater in agriculture, many countries tend to set and adopt their own standards. For instance, in developing countries, there are a number of differences in microbiological guidelines for the proper and safe application of treated or untreated wastewater in agriculture (PAHO, 2005). Policies for checking and correcting indiscriminate use of wastewater and its potential negative effects on both the health of individuals and the environment are limited, while many countries do not have any standards. Brazil for instance does not have such legislation. In the legislature of South American countries like Chile and Argentina, there exist some general law governing water systems and the main purpose is to prevent them from contamination, but the application or reuse or treatment of wastewater was not been specifically outlined. Few countries that have established strict regulations have difficulty with

enforcement. Example is Peru, where legislation encourages primary, i.e. physical-sedimentation and secondary, i.e. biological treatment, but does not outline guidelines for checking bacterial and nematode contamination (PAHO, 2005).

2.3 Characteristics of Wastewater Effluents

2.3.1 Microbial characteristic

Bacteria, helminth eggs, protozoa, fungi and viruses commonly occur in influents of wastewater. Different kinds of microorganisms play critical roles in outbreaks of waterborne diseases, and these organisms are beneficial wastewater effluent (Kris, 2007). In wastewater treatment, microorganisms are employed in the removal of dissolved organic matter. Based on a wastewater treatment plant's preference, microorganisms are either used in lagoon systems, fixed film systems or suspended film systems. The presence of these microorganisms at different phases of wastewater treatment helps improve the breakdown of solids leading to the production of less sludge (Ward-Paige *et al.*, 2005a). Besides breakdown of solids, microorganisms found in wastewater are capable of recycling of certain nutrient chemical substances like heavy metals, nitrogen and phosphate. Until nutrients in the form of chemical substances or molecules trapped inside deceased materials of animal and plants broken down are released by microbes, the chemical nutrients cannot be made available, and when they are released the life of other organisms are sustained.

The activities of microorganisms play important role in the removal of toxic waste in acid mine drainage (Ward-Paige *et al.*, 2005b). The presence and load of microbial pathogens is also a sign of degree of pollution by microorganisms in a waterbody. Nonetheless, the task of detecting and characterising various kinds of microbial pollutants in wastewater is invariably cost involving, difficult and time-consuming.

To this effect, indicator microbes are always used as a sign of possible risk of the presence of some set of microbial pathogens in wastewater (Paillard *et al.*, 2005). For example, to determine the level of faecal contamination in water sources, enteric bacteria including total coliform, faecal coliform, faecal *Streptococci* and *E. coli* are measured (DWAF 1996; Momba and Mfenyana, 2005). On the other hand, to determine the presence of viral pathogens, somatic and F-RNA coliphages are employed. Also, as an indicator for the presence of disease pathogens like protozoa, viruses as well as helminth eggs, *Clostridium perfringens* is used as a test organism. *Clostridium perfringens* is a faecal bacterium which form spore that enable it to survive harsh environmental conditions and is sustained for a relatively long period of time (Payment and Franco, 1993; Grabow *et al.*, 1997). Furthermore, the level of diatoms with respect to nutrient enrichment of a water system is used to test its general quality, and this information provides valuable interpretations about changes in water quality with regard to conductivity, chloride, COD, BOD and turbidity water (Dela *et al.*, 2002).

2.3.2 Physico-chemical characteristics

Among all the physical and chemical features of wastewater, important quality parameters of special concern include its pH, chemical and biological oxygen demands, dissolved oxygen (DO), total suspended and dissolved solids, phosphate, nitrogen in the form of nitrite, nitrate and ammonia, as well as metals (DeCicco, 1979; Larsdotter, 2006). Since the hydrogen-ion concentration of a liquid medium for determining the level of acidity or basicity, it is important in analysing both natural and waste waters.

2.3.2.1 pH Indicator

When the range of pH values of wastewater flowing inward is below 7, it shows that there are microbial pathogens present, while pH ranges less than 5 and/or greater than 10 shows that there is industrial activities generating waste which is non-compatible with prevailing biological operations. The concentration of pH within which the existence of biological life is favoured occurs in a quiet narrow range, usually between pH of six and nine. When the pH value is extreme, it has been reported to cause damage to biological or physiological processes or systems (EPA, 1996; Gray, 2002).

2.3.2.2 BOD and COD indicator

Oxygen demand may be observed in the form of biological or chemical, respectively known as Biological Oxygen Demand and Chemical Oxygen Demand. The oxygen demand of a particular system is defined as the quantity of oxygen required or used by microorganisms as they consume organic solid substances in a given wastewater system (Water Environmental Federation, 1996; Gray, 2002; FAO, 2007). The biodegradable organics of a wastewater medium is used to determine the BOD, and measuring this parameter is relatively time-demanding (Gray, 2002; Metcalf, 2003).

In a similar way, the COD is used to determine the oxygen equivalent of the organic material in wastewater that can be chemically broken down by the process of oxidation. Comparing COD and BOD of a system, the COD is relatively always higher than BOD. This is due to the fact that in measuring COD, substances that are both biologically and chemically oxidised are taken into account. Although COD and BOD measure the oxygen requirement, their ratio (COD: BOD) provides useful guide to the amount or fraction of organic materials present in a given wastewater system. In the estimation of BOD, certain polysaccharides including cellulose is not

catered for since because it can be broken down without the presence of oxygen (Metcalf, 2003).

2.3.2.3 TDS and TSS indicator

Even though the concentration of solids in wastewater make-up roughly 0.1% and the rest being water, the quantity of solids present in drinking water has important effects on the total amount of solids in raw sewage (Water Environmental Federation, 1996). The plant influent of waste has been known to come from industrial and domestic discharges. Under normal circumstances, sedimentation and floatation processes employed in wastewater treatment processes is only able to remove solids in suspension but not dissolved ones (APHA, 2001; Larsdotter, 2006; Water Environmental Federation, 1996). Treatment systems used in biological treatments of wastewater including activated sludge and trickling filters are capable of converting dissolved solid into solids that can settle down and be removed by sedimentation tanks (Eckenfelder and Grau, 1992). Other different ways of classifying solids in wastewater are settling ability, organic and inorganic, colloidal solids and floatable (EPA, 1996).

2.3.2.4 Heavy metals presence

In water quality systems, both heavy and trace metals are of major importance. The important ones with respect to water quality and wastewater treatment include the following: Arsenic, Cadmium, Calcium, Chromium, Cobalt, Copper, Iron, Lead, Magnesium, Manganese, Mercury, Molybdenum, Nickel, Potassium, Selenium, Sodium (Na), Vanadium and Zinc. Metal like calcium, cobalt, chromium, copper, iron, potassium, magnesium, manganese, sodium, nickel and zinc. These are required by living organisms in varying amounts as either macro or micro nutrients for their physiological processes and proper growth, functioning and development. Other

metals do not have any biological function and as such classified as non-essential metals. These include aluminium, cadmium, lead, silver, gold and mercury (Metcalf, 2003; Hussein *et al.*, 2005). Different complex methodologies are employed in detecting the presence of these metals depending on substances that may be interfering. Common methods used in detecting the presence and concentrations of these metals include atomic absorption (electro-thermal), flame atomic absorption and inductively coupled plasma (ICP) mass spectrometry (APHA, 1998).

2.4 Empirical studies on Health impacts of Wastewater reuse for Agricultural irrigation

Bacterial, viral and protozoa infections are among the most common health problems that are linked with the intake of untreated water, as well as recreational waters. Waste from human and animals form the primary source of these microbial pathogens that contaminate drinking and recreational water (WHO, 1997; Environmental Canada, 1997; 2003 EPA, 2000; WHO, 2006). These human and animal waste serve as a reservoir or supply of different kinds of microbial pathogens including intestinal helminth eggs and protozoa, bacteria and viruses that can be carried by certain environmental and human factors and eventually end up in natural water bodies or drinking water supplies (Kris, 2007). Disease-causing microorganisms are believed to be significant or important leading factors of numerous reported and unreported waterborne outbreaks. Certain chronic disease conditions whose treatment is long-term and costly like ulcer of the stomach or certain heart diseases such as endocardities can result from many pathogenic microorganisms that contaminate wastewater (Paillard *et al.*, 2005).

Among all the microorganisms that are found contaminating wastewater, the viral group is one of the most significant and possibly the most hazardous microbial

pollutants of wastewater. Resistance to treatment is generally observed with these kinds of viruses and they are very infectious, relatively more difficult to find and their infective dose is usually little for disease condition establishment (Toze, 1997; Okoh, *et al.*, 2007).

In contamination of wastewater, bacteria are most common microbes found polluting water. Several disease conditions are attributed to bacterial infections, and among them are skin or tissue infection, diarrhoea, dysentery and others. Pathogenic bacteria that occur in water include several different kinds of bacteria species and among them are *Escherichia coli* O157:H7, *Salmonella*, *Shigella*, *Listeria*, *Leptosporosis*, *Campylobacter* and *Vibrio*. (CDC, 1997; Absar, 2005).

Even though wastewater is considered a haven of several different kinds of bacteria, most of these bacteria found in wastewater are harmless and incapable of causing diseases. Yet, pathogenic bacteria that are responsible for disease conditions such as dysentery, typhoid and other forms of intestinal disorders may also be found in wastewater. The various test procedure used in the detecting the presence and load of coliform, i.e. either total or faecal or non-pathogenic bacteria provide an indication about the presence of pathogenic bacteria may be present (EPA, 1996; APHA, 1998).

Due to the affordability and relative ease of performing coliform test, faecal coliform testing has become the gold standard for detecting contamination by faecal source or origin. In testing for the presence and quantity of faecal contamination in untreated domestic sewage, faecal coliform load of 100 million per 100 millilitres may be observed. Total coliform load or counts of between 2300 to 2400 per 100 millilitres of recreational water have been reported to cause health implications. Methods of

disinfection, especially by chlorination are generally done to reduce microbial pathogens (EPA, 1996; Absar, 2005).

Bacterial microbes are often implicated causal agent of most gastroenteritis waterborne disease. Some possible disease-causing agents of gastroenteritis include *E. coli* and other strains of *Pseudomonas*, which may even affect new born babies and have also been reported to be leading cause of gastrointestinal disease outbreaks (Metcalf, 2003). Although only a small number of aquatic protozoa are pathogenic, species that are very adaptable are widely distributed in most natural water systems. Compared to bacterial infections of the gastrointestinal tract, protozoa infections which are normally disorders of the gastrointestinal tract are often milder than their bacterial counterparts (Ingraham and Ingraham, 1995).

Due to the disease impact on individuals whose immune response is relatively compromised like young children and the elderly, protozoa infections caused by *Cryptosporidium parvum*, *Cyclospora* and *Giardia lamblia* are of significant health concern (Sperling, 2007). Even though not all the *Cryptosporidium* and *Giardia* oocysts that are present in untreated sewage or wastewater are viable or able to cause disease, large numbers of these oocytes can be found in raw sewage (Ingraham and Ingraham, 1995; Metcalf, 2003). With regards to drug resistance, oocysts of *Crptosporidium parvum* and *Giardia lamblia* have been reported to be more difficult in terms of drug treatment. Nonetheless, chlorination of water as a means of conventional disinfection has been very effective in the removal or inactivation of *Crptosporidium parvum* and *Giardia lamblia*. The application of radiations like ultra-violet (UV) in recent years has proven to be effective in inactivating *Crptosporidium parvum* and *Giardia lamblia*(Metcalf, 2003; Absar, 2005).

Nematodes and flatworms can cause infection in humans while segmented worms associated with human infections include leaches, which are ectoparasites (Metcalf, 2003). The human infectious or disease-causing helminths are classified into three phyla: Nematodes, Platyhelminthes and Annelida. While the Nematodes are roundworms, the Platyhelminthes are flatworm and the Annelids are segmented worms. In the growth and development of helminth, two animal hosts or sometimes more animal hosts are required; one of which can be the waste of animal or human host. Insects and aquatic animals like snails can also serve as a means of contamination of water. Helminth pathogens can be transmitted through aquatic means, but current water treatments adopted can also be very efficient in removing or significantly reducing these kinds of pathogens. Such current methods include chemical precipitation, filtration, chlorination and sedimentation (EPA, 1996; Absar, 2005).

Cyanotoxin is also another chemical poison that has been reported by several countries worldwide to cause health problems through wastewater contamination (Department of Natural Science, 2006; WHO, 2006). Many reports have associated cancer of the human liver with exposure to the cyanotoxin produced by algae through drinking water or contact with recreational water (Chorus and Bartram, 1999; WHO, 2006; Runion, 2008). In the process of eutrophication, the cyanobacterial toxins can increase to undesirable concentrations. Unfortunately, the concentrations get worse in the food chain as shellfish as well as other aquatic organisms feed on the algae. Infections with toxic algae can lead to disease conditions including diarrhoeal, paralytic or amnesic shellfish poisoning (Chorus and Bartram, 1999; EPA, 2000; WHO, 2006).

Due to the carcinogenic nature of nitrosamines which are formed from nitrites and amino acids, nitrates and nitrites are also considered important in health concerns of wastewater (Fraser, 1995; El-Bahri *et al.*, 1997; Runion, 2008). Even though chlorination treatment of water plays an important role in the destruction and inactivation of disease-causing microbes, chlorine in wastewater is a significant health risk to humans, animals and the environment at large (EPA1996).

Ammonia occurs in the natural environment in varying concentrations which do not pose any risk to human health. On the other hand, exposure to ammonia in aquatic systems can pose several health problems to humans. Reports indicate that the most common danger associated with contact with ammonia at high concentrations is usually pulmonary edema, after which severe irritation to moist tissue surfaces is observed (WHO, 1997; Health Canada, 1998; WHO, 2006).

2.5 Types of Irrigation Methods in Wastewater Reuse for Agriculture

Different methods of irrigation are adopted by farmers all over the world for crop irrigation. Ranging from a can of water to highly technologically automated watering systems such as the centre pivot system, water is delivered to individual crops in so many different ways. Based on delivering water to wet the soil, five major applied kinds of irrigation can be classified, and among them are furrow irrigation, sub-irrigation, flood irrigation, sprinkler irrigation and localised irrigation (FAO, 1992).

2.5.1 Flood Irrigation

Irrigation by flooding is an irrigation process whereby water is supplied over the whole field to pass through or penetrate the soil. Some common methods of flood irrigation include contour flooding, wild flooding and border and basins (FAO, 1992).

2.5.2 Furrow Irrigation

The application of water between ridges is known as furrow irrigation. Common examples are corrugations, contour furrows, level and graded furrows. In this process of water delivery to soil, the water reaches the ridge, where the plant roots are concentrated as a result of capillary rise processes (FAO, 1992).

2.5.3 Sprinkler Irrigation

In sprinkler irrigation, water is sprayed and as a result, the irrigation water reaches the ground soil just like rain water. Various kinds of sprinkler irrigation are practiced. These include spray guns, solid set sprinklers, travelling sprinklers and centre-pivot systems. In the application processes, it is important that the rate of application of water is monitored in order to prevent collections of small ponds of water on the surface (FAO, 1992).

2.5.4 Sub Irrigation

The sub-irrigation method of water supply provides water to the plant at just beneath the root zone thereby wetting the root zone by water capillary rise of the water. The types of methods that are employed in this case to supply water just beneath the root zone include deep surface canals or buried pipes and sub-surface irrigation canal systems (FAO, 1992).

2.5.5 Localised Irrigation

In the localized irrigation method, water that is applied is received around the plant or group of plants thereby wetting the individual plant or group of plants locally and also the root zone. Irrigation systems that usually deliver this kind of irrigation include drips, bubblers and micro-sprinkler irrigation systems (FAO, 1992; Smith, 2009).

2.5.6 Factors that influence selection of irrigation methods type

A number of factors come to play when considering which kind of irrigation method to adopt. Evapo-transpiration is an important physiological need of the plant that needs to be considered. Therefore, there is the need to control the rate of application of water to the plant in order to reduce passage of water through the soil to the plant (FAO, 1992). Some primary factors include weather or climate conditions, the types of crops grown or to be grown, cost of the type of irrigation, conditions of favourable water supply and the farmer's capability of managing the irrigations system. Other equally important factors to consider for choosing wastewater as a source of irrigation water include salinity level of the water, the presence of hazardous chemicals, likelihood of contamination of plants and its products, as well as workers on the farm (Abdulai, 2014). As a result, a number of technical factors need to be taken into consideration when choosing the right irrigation system for using wastewater as a source of irrigation water. Among them are: effectiveness of the application of water; the kind of plant, the likelihood of contaminating farm workers or polluting the environment; wetting of leaves, fruits and other exposed parts of the plant; the ease with which water potential of high soil could be achieved and maintained, and the distribution of water, salts and contaminants in the soil (FAO, 1992).

Among all the various kinds of irrigation systems furrow, drip, border and sprinkler irrigation practices are the most widely used (Pescod, 1992). The border form of irrigation is also known as flood or basin irrigation. In this kind of irrigation, treated wastewater is used to cover surface of the soil where a plant or crop is grown completely. Beside the inefficiency of this type of irrigation practise, root crops and vegetables growing nearby are at a great risk of being contaminated, as well as the

farm workers (Hamilton *et al.*, 2007; Keraita *et al.*, 2003a). Consequently, the application of water by the border irrigation techniques is not the best option when considering the health conservation of water and health of the farmer and the safety of the crop irrigated (FAO, 1992; Keraita *et al.*, 2003a). Despite the fact that health risk is relevant, the effect of the water quality does not affect the other surface irrigation methods. Usually, when the wastewater contains larger number of suspended solids, easy flow of the effluent through pipes or gates or channels or appurtenances are greatly hampered (FAO, 1992).

The sprinkler irrigation system may be affected by the quality of water as a result of any of the following reasons: orifices in sprinkler heads becoming clogged, burning of leaves or phytotoxic effect on the leaves as a result of saline and other excessive toxic compounds, as well as aggregation of sediment in valves, pipes and distribution systems. (FAO, 1992; Keraita *et al.*, 2003a).

In order to prevent the effect of water quality on the sprinkler irrigation method, there is the need to take advanced measures like enlargement of sprinkler nozzle diameter ($\geq 5\text{mm}$) and application of micro-strainers or granular filters. Compared with automated or mechanised irrigation systems, the sprinkler irrigation method is relatively cheaper since the capital and labour cost of the automated and mechanised systems are costly (FAO, 1992).

2.6 Wastewater Treatment in Ghana

Management of wastewater especially in urban regions mostly involves treatment of municipal and domestic wastewater. In Ghana, industrial activities are concentrated most in urban and municipal regions of Takoradi, Accra and Tema, where industrial and domestic wastewater are either directly discharged into the ocean or into

peripheral waterbody. In reference to reports by the Global Water Supply and Sanitation Assessment (WHO, UNICEF and WSSCC, 2000), 63% of the population of Ghana have access to improved sanitation facilities, while in countries like Benin and Niger, approximately 25% of their populations have access to improved sanitation. Comparably, among most countries in West Africa, Ghana has a good balance of provision and availability of sanitation services of approximately 62% in urban areas and 64% in rural areas (FAO, 1992; Sou *et al.*, 2011). Other countries including Senegal (94% urban, 48% rural), Benin (46% urban, 6% rural) and the like show high disparity. Overall, analysis of sanitation levels at regional basis in Africa shows that the extent of sanitation coverage in West Africa is very deplorable (48%) with Central Africa (29%) having the worst state of sanitation coverage, while the best coverage has been reported for Northern African states (74%), which is followed by South Africa (63%) and East Africa (62%) (WHO, 2010; WHO, UNICEF and WSSCC, 2000).

2.6.1 Wastewater Treatment Systems

According to the United Nation (UN), urbanised environment would cover most parts of the world by the year 2025 (UN, 2013). In the era of urbanisation, the provision of municipal services including facilities and resources for fresh water supply, sanitation and management of wastewater systems are common hurdles (Rose, 1999; WHO, 2010). The essence of wastewater treatment has been an old practice that dates back in time to the biblical days as a means of preventing the spread of certain diseases, which is now practiced worldwide as a normal way of life (Amos, 2003). The main objective of wastewater treatment is to reduce the spread of water-borne diseases as a result of contamination by pathogens of sewage. In effect, the treatment would reduce the risk or chance of surface and ground water getting

polluted to make safe for domestic and other uses, and eventually maintain the integrity of the environment (Pescod and Arar, 1985; Alnos and Ashraf, 2010).

All over the world, several different kinds of systems are in use for the treatment of wastewater. The treatment process of sewage or wastewater consists of three main processes: the physical, also known as the mechanical process; the biological process and the chemical process, which is usually considered the tertiary stage (WHO, 2010). Municipal sewage treatment usually involves the conventional treatment systems, which is a common practice. This process involves preliminary treatment, sedimentation (primary), biological process, sedimentation (secondary) and sludge treatment process (Metcalf, 2003; WHO, 2010).

After the conventional secondary treatment process, additional treatment process that is applied in the removal of suspended and dissolved substances is termed advanced wastewater treatment. In order to get this process dry season accomplished, targeted pollutants are gotten rid of through several different kinds of processes including biological, physical and chemical treatments. Some of the common properties usually by Advanced treatment include organic chemical substances, colour, nutrient materials in the form of nitrogen and phosphorus and metal substances colour, metals, organic chemicals, and nutrients (Metcalf, 2003; World Bank, 2013).

An example of the non-conventional treatment system is waste stabilisation pond, while the use of activated sludge and trickling filter form part of the conventional treatment systems. Due to their special spatial requirements, mechanised treatment ($0.5\text{-}1\text{m}^2/\text{Person Equivalent (PE)}$) systems are considered more efficient than counterpart natural treatment systems ($5\text{-}10\text{m}^2$ (PE)). For efficient and high reduction in BOD, conventional aerobic treatment is usually the best option (Rose, 1999;

World Bank, 2013). In Ghana, some of the treatment systems commonly used include waste stabilisation ponds, trickling filter systems and activated sludge. On the other hand, in most low-density areas of cities and rural areas, septic tank systems are common.

2.6.2 Biological nutrient removal system (BNR)

Among various sewage treatment systems, the Biological nutrient removal is the most widely used compact technology for the treatment of waste liquid, which involves the application of activated sludge system (Mara, 1976; World Bank, 2013) due to its ease of use and applicability in different systems with regard to degree of operational flexibility. In this process, as wastewater passes through an aerated tank, microbial organisms held in suspension are involved in a wide range of biological activities in the removal of some waste substances. While the wastewater passes, it becomes exposed to aerobic, anoxic and anaerobic conditions in the treatment system, and this promotes different microbial activities on the sewage leading to the removal of waste from the sewage (World Bank, 2013).

The activated sludge system confines natural processes to specific limits while the processes are compounded substantially. This phenomenon is possible by producing and sustaining a very high saprophytic concentration, as well as that of other microorganisms in the operation tank while constantly supplying oxygen through aeration to maintain efficient running of the system. While BNR is effective as part of the processes of municipal wastewater or sewage treatment, it does not usually produce effective results in the treatment of industrial wastewater influent. This is due to the toxic nature of the influent and its lack of phosphates and nitrates substances eventually leading to bulking of sludge in the treatment system (Lever, 2010; Mara, 1976).

2.6.3 Waste Stabilisation Ponds

Many different kinds of ways (natural or artificial) are employed by different groups of people to partially or wholly treat wastewater before they are applied for specific purposes, and among them, wastewater stabilisation pond technology is one of the most common and significant natural means of treating wastewater by many local folks. This kind of pond is usually shallow artificial basins in nature which consist of a single or in other cases various series of anaerobic, facultative or maturation ponds. The anaerobic pond stage is where the main treatment of the wastewater occurs. Here, the primary role is to get rid of materials including suspended solids, as well as other soluble materials that are organic in nature. The secondary treatment stage takes place in the facultative pond where coordinated actions of heterotrophic bacteria and algae help in the removal of excess BOD from the wastewater. The removal of pathogens, nitrogen and other nutrient materials occurs in the maturation pond which is the tertiary phase of the treatment process. Among all treatment systems, the removal of pathogenic microbes is comparably best achieved with the waste stabilisation pond system, and it is also the most economical in terms of cost (Campos *et al.*, 2000b). This is as a result of the natural means by which disinfection is achieved. Since sunlight and relatively high temperature play a major role in achieving this, waste stabilisation pond treatment system is well suited for folks in the tropical and sub-tropical regions of the world especially sub-Saharan Africa (Mara 1976; Pescod and Arar 1985; Blumenthal, *et al.* 2000, Lever, 2010).

The simplicity in the design and construction of the waste stabilisation pond is one notable advantage, as well as little maintenance that is required to keep it running. There is no need for electricity. The ponds are capable of absorbing hydraulic in addition to organic shock loads, and therefore capable of removing substantial

amount of waste. On the other hand, a major disadvantage of this system is intense odour produced from the anaerobic pond and the large area required for operation (Blumenthal, *et al.*, 2000; Veenstra and Polprasert, 2000; Sperling, 2007; World Bank, 2013). Since the outcome waste stabilisation pond system is usually of low quality, hence further treatment is required to improve its quality.

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CHAPTER THREE

MATERIALS AND METHODS

3.1 Study area

3.1.1 Location

The study was carried out in Sagnerigu district which is one of the newly created districts and amongst the twenty-six districts in the Northern Region of Ghana, with Tamale being the regional capital. For the purpose of this study, three communities were selected purposively out of the 81 communities that make up the Sagnerigu district, because there are several riparian activities in these communities including vehicle washing, fishing and vegetable gardening. These communities are Gumbihene, Nyanshagu and Tunaayili. Geographically, Sagnerigu district lies between latitude 9°16' and 9°34' North and longitude 0°36' and 0°57' West (Figure 3.1). Sagnerigu district was carved out of the Tamale metropolis and shares boundaries with four districts: Tolon to the west, Kumbungu to the north-west, Savelugu/ Nanton municipality to the north and Tamale metropolis to the south-east. Sagnerigu district has a total land area of about 20,041,901km² and a total human population of about 181, 011 (Ghana Statistical Services, 2014). About 60% of its population are Muslims. The dominant ethnic group is Dagomba with Dagbani the widely spoken local language.

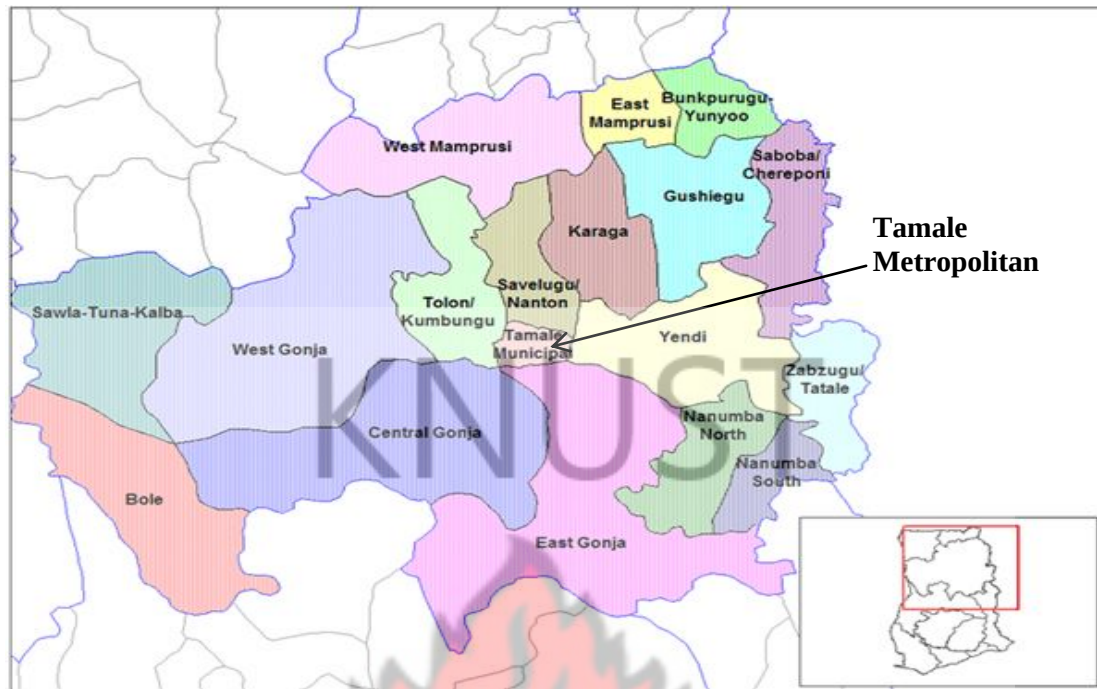


Figure 3.1: Map of the Northern Region showing Tamale Metropolitan and other districts in the region (Ghana Statistical Services, 2002)

3.1.2 Vegetation and topography

The vegetation of the study area is guinea savanna wood land characterised with tall grass land, shrubs and drought resistant trees such as Neem, Dawadawa, Acacia, Shea tree, Baobab and Mahogany (Dickson and Benneh, 1995). The topography is predominantly flat and rolling with some shallow slopes less than 5% which serve as stream channels with few isolated hills. The common soil type is sandstone, gravel, mudstone and sahel that have weathered into different soil grades. This phenomenon has made some parts of the soil sandy, clayey and lateritic ochrosols (Anim-Gyampo *et al.*, 2012).

3.1.3 Relief and Drainage

There is only one distinct rainy season starting from March/April to September/October which peaks between July and August each year with a prolonged dry season from October to February. The annual rainfall ranges from

600mm to 1100mm (Agodzo *et al.*, 2003). The district is poorly drained with few water bodies and few natural seasonal streams, one of which is the waterworks stream (Fig 3.2). The waterworks stream originates from the Tamale waterworks reservoirs and its spill ways which was built to supply the Tamale Metropolis with potable drinking water but was abandoned and later the dam failed with all the water spilling into the stream. The waterworks stream flows through Gumbihene, Sakasaka, Nyanshagu, Gumani, Tunayili, Foo and finally to Pasam River. It usually has water all year round though in reduced quantities during the dry season starting from October to February. This stream serves as source of drinking water for livestock, vegetables irrigation or gardening sites, small scale fishing activities, point and non-point waste disposal site and vehicle washing bay.

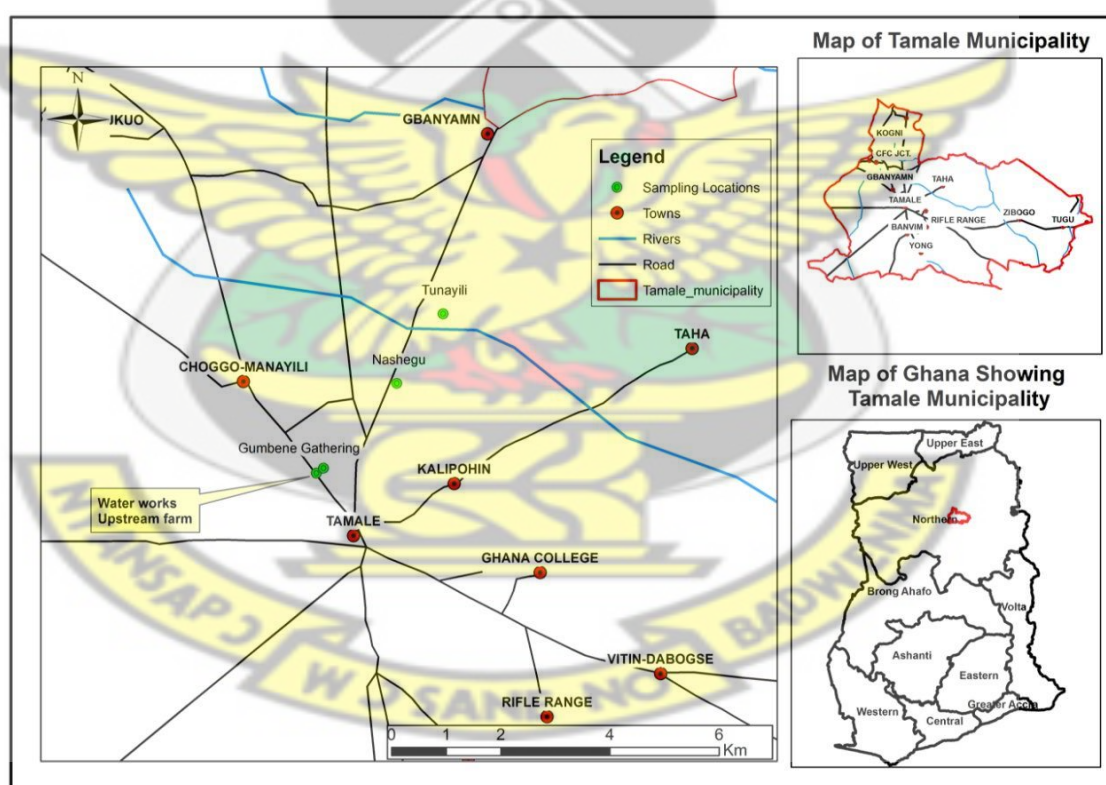


Figure 3.2: Wastewater sampling sites along the Tamale old water works

3.2 Sampling Areas

Wastewater used for irrigation was collected from four sampling sites along the Tamale old waterworks stream: water works upstream (WWU), Gumbihini midstream 1 (GMS1), Nyanshagu midstream2 (NMS2) and Tuunaayili kulbung downstream (TKDS). For every month, eight water samples were collected from the stream for bacteriological and physicochemical analysis over a period of six months starting from December to May 2013 and grouped into two schemes to represent dry and rainy seasons; sampling for dry season irrigation (dry season) was from December to February and rainy season irrigation (rainy season) was from March to May.



Plate 3.1: Farming behind an in-take tower at the Tamale old waterworks



Plate 3.2: Water tanker drawing water from water filling point



Plate 3.3: Vehicle washing along the stream (WWU)



Plate 3.4: Bridge across WWU



Plate 3.5: Gumbihene Midstream 1(GMS1) showing sampling point and path to vegetable farms



Plate 3.6: Old water treatment clarifier used for vegetable farming



Plate 3.7: GMS1 cabbage and lettuce Gardens



Plate 3.8: Dug Out and sampling point At NMS2



Plate 3.9: Vegetable garden at NMS2 Showing buckets used for water sprinkling



Plate 3.10: TKDS plantain plantation downstream (TKDS) sampling site

3.3 Sampling Techniques

3.3.1 Pre-treatment of apparatus

Water sampling bottles were washed with liquid soap, rinsed with distilled water and then soaked in 10 % HNO₃ solution for 24 hours (Todorovi *et al.*, 2001). They were then rinsed with distilled water before used in sampling to ensure that they are cleaned from 10% HNO₃.

3.3.2 Samples Collection, Pre-treatment and Preservation

Water samples were collected from the four sampling points along the Tamale waterworks stream monthly over a six-month period (December 2013 to May 2014). Sampling was done between 8:00 and 10:00am in the morning in line with the farmers routine irrigation schedules (APHA, 1998). Temperature, conductivity and pH were measured in situ using the multi-parameter kit. Samples were transported to the Water Research Institute of the Council for Scientific and Industrial Research (CSIR) laboratory in Tamale in cool box with ice for bacteriological analysis and the Ghana Water Company Ltd (GWCL) for physicochemical analysis.

3.4 Laboratory analysis of Samples

3.4.1 Enumeration of Microorganisms

Microorganisms were enumerated using the Membrane Filtration Technique (MF) according to standard procedures (Anon, 1992). Serial dilutions of 10⁻¹ to 10⁻⁶ were prepared from each of the different water samples collected. Using the three-set filtration system (Plate 2), the receptacle was sterilised with 96 % alcohol, flamed and allowed to cool. A Millipore HA-type cellulose filters with pore size of 0.45µm was gently placed on it and a filter funnel fitted unto it. Ten millilitres (10 ml) of distilled water was first placed in the funnel and into each of the 10ml distilled water in the funnel, one millilitre aliquots of the 10⁻¹ to 10⁻⁶ dilutions were inoculated

separately. Each dilution was analysed in triplicate. Prior to this, 5 ml of sterilized distilled water (SDW) was used to prime the membrane filter. Samples were filtered using a vacuum pump at a pressure of 65kpa (500mmHg) (Millipore, Bedford, UK).

The filter was then picked gently using a sterile forceps and placed in a petri dish containing Hicrome medium, M-FC agar, Cetrimide agar, Gelatin Mannitol Salt Agar and Slanetz and Bartley medium for the enumeration of total coliforms and *E.coli*, faecal coliform, *Pseudomonas* spp, *Staphylococcus* spp, and *Enterococci* spp respectively. The inoculated plates were incubated in inverted position at 37°C for 24 hours. However, faecal coliform and *E. coli* were incubated at 44°C for 24 hours and *Enterococcus* spp. were incubated initially at 37°C for 4 hours and at 44°C for 44 hours.

3.4.2 Enumeration of Total Heterotrophic Bacteria or Total Viable Count (TVC) and *Clostridium*

The total heterotrophic bacteria plate counts (HPC) in the water samples were obtained using the pour plate technique according to Anon (1994). Dilutions of 10^{-1} – 10^{-6} of water samples were prepared in 0.1% buffered peptone water and triplicate 1ml aliquots of each dilution inoculated into 10 ml molten standard plate count agar in universal bottles. After thorough mixing, these were poured into sterile Petri dishes and incubated for 48 hours at 37°C. For *Clostridium* spp., 10ml of sample was pipetted into a test tube/boiling tube. It was warmed for 15 minutes at 80°C in a water bath. One millilitre aliquot was transferred onto a sterilized petri dish and 10-15 ml of nutrient agar added to it. This was uniformly mixed for a minute and allowed to solidify. The inoculated plate was placed into an anaerobic chamber and incubated at 37 °C for 48 hours. Colony growth on the plate after the incubation period was then counted using the colony counter.



Plate 3.11: (Left) Instrument for Membrane Filtration (Right) The suction filter

3.4.3 Bacteria identification and counting

After the incubation period, faecal colonies were identified by their blue distinct colour, a combination of blue and red colonies depicted *E. coli* and Total coliform respectively (Plate 3.12), creamish colour depicted total heterotrophic bacteria (Plate 3.13), and pink-maroon colour was *Enterococci* (Plate 3.14).

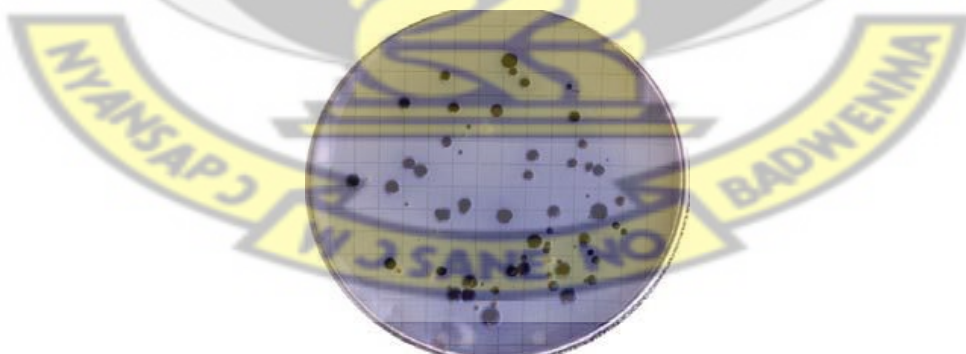


Plate 3.12: Faecal coliform bacteria on M-FC medium

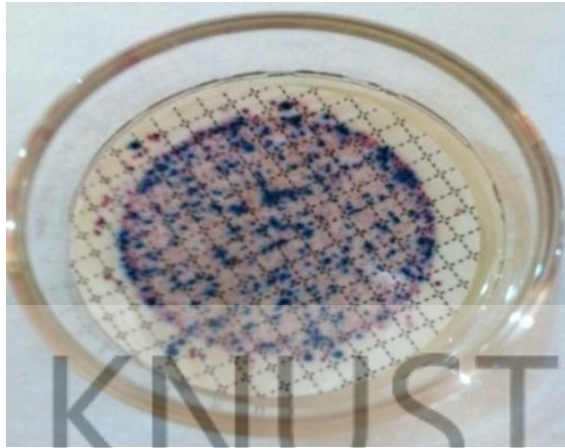


Plate 3.13: Total coli and *E. coli* on Hicrome Agar



Plate 3.14: *Enterococci* on S&B agar



Plate 3.151: THB on Nutrient Agar

3.5 Determination of Physical and chemical Parameters

3.5.1 Temperature, Conductivity and Total dissolved solids (TDS)

Temperature, conductivity and total dissolved solids were read directly using the multi parameter kit (conductivity meter with a thermometer and a TDS probe). Temperature was measured in degrees Celsius ($^{\circ}\text{C}$) while conductivity was measured in microsiemen per centimetres ($\mu\text{S}/\text{cm}$). Total dissolved solids were measured in milligrams per litres (mg/L).

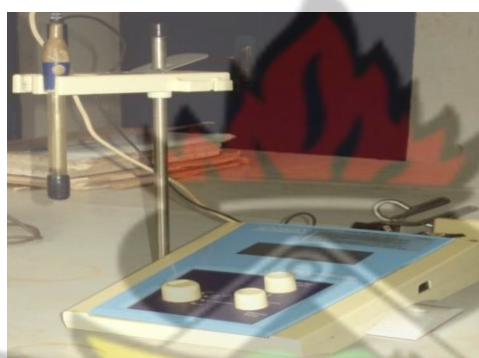


Plate 3.16 2: Conductivity meter

3.5.2 pH

The pH was measured using a pH meter (CyberScan CON 410 by Eutech Instruments, USA) and a combination electrode (a set of glass electrode and a reference electrode). The electrode was first calibrated against a pH buffer 7 and 9 at a temperature of 25°C to adjust to the response of the glass electrode. The pH was measured at the sampling site using the pH meter by dipping the electrodes into the water and reading off the values which appeared on the pH meter screen.



Plate 3.17 : pH meter

3.5.3 Colour

Visual comparison method was used in the colour determination by means of Lovibond Nesslerizer Comparator 2000 (Fisher Scientific, USA). A 10ml comparator tube was filled with the water sample and placed in the right groove of the comparator. Then another 10ml of comparator tube was filled with distilled water and placed in the left groove. The Lovibond Nesslerizer colour disc was then inserted into the comparator and rotated whilst observing through the eye piece until comparable colours were achieved on both sides (right and left side of comparator). The figure that appeared on the comparator was read off as the colour of the sample. With this method colour was expressed in Hazen units (HU).



Plate 3.18: Comparator

3.5.4 Turbidity

The portable hand held 2100 Turbidimeter (Hach, USA) was used in determining the turbidity of the sample. Distilled water was used as a standard reference for measuring the turbidity. The distilled water was first used to calibrate the turbidimeter device. The distilled water was then replaced by the wastewater samples and the level of turbidity of each sample tested and recorded in Nephelometric Turbidity Units (NTU).



Plate 3.19: Turbidity Meter

3.5.5 Total suspended solids

The DR 2800 Spectrophotometer (Hach, USA) was used in the determination of total suspended solids. Using the wave length of 810nm, 500ml of the sample was blended at high speed for two minutes and poured into a 600ml beaker and stirred before immediately being poured into a sample cell to serve as the prepared sample.



Plate 3.20: DR2400- spectrophotometer

3.5.6 Total Alkalinity

Fifty millilitres (50ml) of the sample was taken into a clean Erlenmeyer flask and two (2) drops of methyl orange indicator was added. Upon turning yellow, the sample was titrated with 0.02N H₂SO₄ and swirled gently until the colour changed to orange. The titre value, was then recorded at the end point in milligram per litre calcium carbonate (mg/L CaCO₃). Total alkalinity titration was then calculated using the formula:

$$\text{Total Alkalinity as mg/L CaCO}_3 = \frac{A \times t \times 1000}{\text{Sample Volume}}$$

Where;

A = ml standard acid used

t = titre of standard acid

3.5.6.1 Phenolphthalein Alkalinity

Fifty millilitres (50ml) of the sample was taken into a clean Erlenmeyer flask and two (2) drops of phenolphthalein indicator was added. The sample turned pink and was titrated with 0.02N H₂SO₄, swirling gently until the pink colour disappeared. The titre value, was recorded at the end point for total alkalinity. The unit for measuring phenolphthalein alkalinity is milligram per litre calcium carbonate (mg/L CaCO₃). Phenolphthalein alkalinity was then calculated using the formula:

$$\text{Phenolphthalein Alkalinity as mg/L CaCO}_3 = \frac{T_v \times 1000}{\text{Sample Volume}}$$

3.5.7 Total hardness

Complexometric titration using Ethylene Diamine tetra acetic acid (EDTA) was used in the total hardness determination. Fifty millilitres (50ml) of the sample was measured into a clean Erlenmeyer flask and 1ml of buffer solution added. A few grams of the Eriochrome Black T indicator was added and titrated against 0.01N EDTA solution, mixing gently until the colour changed from red to blue. The unit for measuring total hardness is also milligram per litre calcium carbonate (mg/L CaCO₃). The titre value was recorded and the concentration computed using the formula:

$$\text{Total Hardness as mg/L CaCO}_3 = \frac{A \times B \times 1000}{\text{Sample Volume}}$$

Where;

A = titre value for sample

B = ml CaCO₃ equivalent of EDTA

3.5.8 Calcium hardness

Fifty millilitres (50ml) of the sample was measured into a clean Erlenmeyer flask and 1ml of 1N NaOH solution was added. This was followed with a few grams of powdered ammonium murexide indicator. The solution was then titrated against 0.01 M EDTA solutions, mixing gently until the colour changed from pink to purple. The unit for measuring calcium hardness is also milligram per litre calcium carbonate (mg/L CaCO₃). The titre value, was then computed as follows with the formula below:

$$\text{Calcium Hardness as mg/L CaCO}_3 = \frac{A \times B \times 1000}{\text{Sample Volume}}$$

Where;

A = titre value for sample

B = ml CaCO₃ equivalent of EDTA

$$\text{mg Ca}^{2+}/\text{L} = \frac{A \times B \times 400.8}{\text{Sample Volume}}$$

3.5.9 Magnesium hardness

Magnesium hardness was estimated as the difference between total hardness and Calcium hardness. The unit for measuring calcium hardness is also milligram per litre calcium carbonate (mg/L CaCO₃).

Formula:

$$\text{Mg Hardness as mg/L CaCO}_3 = [\text{Total Hardness} - \text{Calcium Hardness}]$$

$$\text{Mg}^{2+} (\text{mg/L}) = [\text{Total Hardness} - \text{Calcium Hardness}] * 0.243$$

3.5.10 Carbonate Alkalinity and Bicarbonate Alkalinity

From the phenolphthalein and the total alkalinity results above the carbonate and bicarbonate alkalinity were calculated using the alkalinity relationship table below.

Table 3.1: Alkalinity Relationships

RESULT OF TITRATION	CARBONATE ALKALINITY AS CaCO_3	BICARBONATE ALKALINITY AS CaCO_3
$P = 0$	0	T
$P < \frac{1}{2} T$	2P	$T - 2P$
$P = \frac{1}{2} T$	2P	0
$P > \frac{1}{2} T$	$2(T - P)$	0
$P = T$	0	0

(Source: APHA, 1998)

Key: P— phenolphthalein alkalinity

T— total alkalinity

3.5.11 Calcium

From the Calcium hardness results above Calcium concentration was determined by calculation from the formula below;

$$\text{Ca}^{2+} \text{ as mg/L CaCO}_3 = \text{mg/L Ca Hardness} \times 0.40$$

The unit for measuring of calcium is milligram per litre.

3.5.12 Magnesium

From the Magnesium hardness results above Magnesium concentration was also determined by calculation from the formula below;

Mg Hardness as mg/L CaCO_3 = [Total Hardness – Calcium Hardness]

Mg^{2+} (mg/L) = [Total Hardness – Calcium Hardness] * 0.243. The unit for measuring of magnesium is milligram per litre.

3.5.13 Chloride

Fifty millilitres (50ml) of the sample was measured into a clean Erlenmeyer flask and 5% Potassium Chromate (K_2CrO_4) added as an indicator. This was then titrated against 0.0141N AgNO_3 solution, and swirled gently until the colour changed from yellow to brick red. The unit for measuring chloride is milligram per litre. The titre value, T_v was recorded and concentration were calculated using the formula:

$$\text{mgCl}^-/\text{L} = \frac{(A - 0.2) \times N \times 35450}{\text{Sample Volume}}$$

Note: 1ml of 0.0141N AgNO_3 solution = 0.5mg Cl^-

Where;

A = titre value; N = normality of silver nitrate

3.5.14 Fluoride

The DR 2800 Spectrophotometer (HACH, USA) was used in the determination of fluoride. The SPANDS method was used. Twenty-five millilitres of sample was emptied into a clean dry sample cell. Twenty-five millilitres (25ml) of demineralised water was measured into a second sample cell to serve as the blank. Sample cell of the device was filled with five millilitres aliquot of SPANDS reagent and swirled to mix the content. Finally, the cell containing the prepared sample was placed into the cell holder. The concentration of fluoride is in milligram per litre.

3.5.15 Sulphate

The DR 2800 Spectrophotometer (HACH, USA) was used in the determination of sulphate. The sulfaVer method was used. The device was first set to the required wavelength (450nm). A clean dry 1" sample cell was filled with the sample and placed into the cell holder. The cell was removed from the cell holder and the content of one sulfaVer reagent powder pillow added to the sample cell and swirled to dissolve the content. The sample was replaced into the cell holder. The concentration of sulphate is in milligram per litre.

3.5.16 Sulphide

The DR 2800 spectrophotometer (HACH, USA) was used in the determination of Sulphide by the Methylene Blue method. The required wavelength (665nm) of the device was first set. Twenty-five millilitres of the sample was emptied into a sample cell. Twenty-five millilitres of deionised water was added into a second sample cell to serve as blank and 1ml of sulphide reagent was added to each cell and swirled to mix the content. In addition, sulphide 2 reagent was added to each cell and immediately swirled to mix. The blank was then removed and replaced with the prepared sample. Sulphide concentration was recorded in milligram per litre.

3.5.17 Phosphate

The DR 2800 spectrophotometer was used in the determination of Phosphate by the PhosVer 3 or ascorbic acid method. The required wavelength (890nm) was first set. A cell was filled to 25ml mark with the sample. The content of one PhosVer 3 phosphate powder pillows was added to the sample cell and swirled to immediately mix to serve as the prepared sample. The prepared sample was then placed into the cell holder and the light shield closed. The concentration of phosphate was recorded in milligram per litre.

3.5.18 Ammonia-Nitrogen

The DR 2800 Spectrophotometer (HACH, USA) was used in the determination of Ammonia-Nitrogen by the Nessler method. The required wavelength (425nm) was first set. Twenty-five millilitres each of sample and deionized water were measured and emptied into different graduated cylinder. Three drops of mineral stabiliser were added to each cylinder. The cylinders were inverted gently several times to mix the content. Again, three drops of polyvinyl alcohol dispersing agent were added to each cylinder and held vertically. One millilitre aliquot of Nessler reagent added to each cylinder and the content inverted several times to mix. Each solution was then poured into a 25ml sample cell for 1 minute. The blank reagent was set. The blank was then removed and replaced with the prepared sample and the sample. The concentration of Ammonia-Nitrogen was recorded in milligram per litre

3.5.19 Nitrate-Nitrogen

The DR 2800 Spectrophotometer (HACH, USA) was used in the determination of Nitrate-Nitrogen by the Cadmium reduction method. The required wavelength (500nm) set. A clean sample cell was filled with the 25ml of sample and NitraVer 5 reagent powder pillows added. The content was then vigorously shaken gently for one minute to dissolve. A five-minute reaction period was again set and a second cell filled to 25ml of deionised water to serve as blank and placed into the cell holder. The prepared sample was then inverted twice and the stopper removed. The blank was then removed and replaced with the prepared sample containing the NitraVer5 reagent. The concentration of Nitrate-Nitrogen was recorded in milligram per litre.

3.5.20 Nitrite-Nitrogen

The DR 2800 Spectrophotometer (HACH, USA) was used in the determination of Nitrite-Nitrogen by the ferrous sulphate method. The required wavelength (585nm)

was first set followed by the 5-signal average. Twenty-five millilitres of each sample was emptied into a sample cell and NitraVer 5 reagent powder pillows was added to the sample. The content was then shaken gently to dissolve. The setup was allowed to stand for 1 minute. A blank sample was prepared and placed in the cell holder. The prepared sample was then inverted twice and the stopper removed. The blank was then replaced with the prepared sample containing the NitraVer5 reagent. The concentration of Nitrite-Nitrogen was recorded in milligram per litre read off.

3.5.21 Aluminium

The DR 2800 Spectrophotometer (HA, USA) was used in the determination of aluminium by the Eriochrome Cyanine R (ECR) method. The required wavelength (535nm) was first set. Fifty millilitres of each sample was measured and kept at 20-25°C. A content of ECR reagent powder pillows was added to the sample and the content inverted several times to dissolve the powder and the content was allowed to stand for thirty seconds. One gram of hexamethylenetetramine buffer reagent powder pillow was then added to the content and inverted several times to dissolve the powder. Two drops of ECR masking reagent solution was then emptied into a clean sample cell and filled to 25ml mark with prepared sample and content was mixed to serve as the blank sample. The remaining 25ml of the mixture was poured into another sample cell and allowed to stand for 5 minutes. The blank was then removed and replaced with the prepared sample containing the hexamethylenetetramine buffer reagent in the cell holder in an appropriate orientation. The concentration of Aluminium was recorded in milligram per litre.

3.5.22 Iron (Total)

The DR 2800 Spectrophotometer was used in the determination of total Iron by the iron phenantrolene (ferroVer) method. The required wavelength (510nm) was first

set for the determination. A clean sample cell was filled with 25ml of the sample and the content of one ferroVer iron reagent powder pillow added to the sample and swirled gently to mix the content. The content was allowed to sit for 3 minutes. Another sample cell was filled with 25ml of the sample to serve as blank. The blank was then removed and replaced with the prepared sample containing the ferroVer iron reagent. The concentration of total Iron was recorded in milligram per litre read off.

3.5.23 Manganese

The DR 2800 Spectrophotometer (HACH, USA) was used in the determination of Manganese by the periodate Oxidation method. The required wavelength (525nm) was first set. Different clean sample cell was filled with the 25ml of each sample and buffer pillows were added to each sample followed by sodium periodate powder pillow and gently swirled for two minutes. The blank was set in the cell holder in an appropriate orientation. The blank was then removed and replaced with the prepared sample containing the sodium periodate powder. The concentration of Manganese was recorded in milligram per litre.

3.5.24 Copper

The DR 2800 Spectrophotometer (HACH, USA) was used in the determination of copper by the colorimetric method. The required wavelength (810nm) was first set. Three millilitres of the bath sample and 2.0ml of deionised water were pipetted into a 16mm diameter screw-capped culture tube to serve as the prepared sample. A second culture tube was filled with 5.0ml aliquot of deionised water to serve as the blank. The content of one acid reagent powder pillow was added to each tube and mixed gently and all effervescence allowed to stop before the tube was capped. The

tube was then shaken to dissolve all of the powder and the blank was set. The setup was then ran and the concentration of copper was recorded in milligram per litre.

3.5.25 Zinc

The DR 2800 Spectrophotometer (HACH, USA) was used in the determination of zinc by the zinc on method. The required wavelength (620nm) was first set. One zincoVer5 reagent powder pillow was then added to 50ml of sample and the content was inverting several times to dissolve the powder completely. A sample cell of the device was filled with 25ml to serve as blank and 10ml of cyclohexanone were added to the remaining sample solution and the content was gently shook for 30 seconds to serve as prepared sample. The prepared sample was allowed to sit for 3 minutes and the solution was emptied into a sample cell. The blank was then removed and replaced with the prepared sample before being placed in the cell holder. The concentration of zinc was recorded in milligram per litre.

3.5.26 Cyanide

The DR 2800 Spectrophotometer (HACH, USA) was used in the determination of cyanide by the pyridine-pyrazolone method. The required wavelength (612nm) was first set. A clean sample cell was filled with 25ml of sample and oneferroVer iron reagent powder pillow added to it and swirled gently to mix the content. The content was allowed to stand for 3 minutes. Another sample cell was filled with 25ml of the sample without reagent to serve as blank. The blank was then removed and replaced with the prepared sample containing the ferroVer iron reagent. Concentration of cyanide was recorded in milligram per litre.

3.5.27 Chromium (Total)

The DR 2800 Spectrophotometer (HACH, USA) was used in the determination of chromium by the 1, 5-Diphenylcarbohydrazide method. The required wavelength (540nm) was first set. Twenty-five millilitres of sample was mixed with one chromaVer chromium reagent powder pillows and the content was gently swirled to mix well. The setup was allowed to stand for 5 minutes while a blank samples cell was being prepared. The concentration of chromium was recorded in milligram per litre.

3.5.28 Potassium

The DR 2800 Spectrophotometer (HACH, USA) was used in the determination of Potassium by the tetraphenylborate method. The required wavelength (650nm) was set. The content of one potassium I and potassium II reagent powder pillows were added to 25ml of sample and the content was gently inverted several times to mix. The content of one potassium III reagent powder pillow was added to the solution after the solution had cleared. The setup was allowed to stand for 30 minutes. Sample cells were filled with the prepared mixture and a blank sample cell was set. The concentration of potassium was recorded in milligram per litre read off.

3.6 Data Analysis

The data obtained was input into Microsoft Excel application and statistical analysis was performed using Statistical Package for Social Sciences (SPSS). The output was presented in the form of tables for discussions. Descriptive analysis together with inferential statistics was used to test the research hypothesis.

CHAPTER FOUR

RESULTS

4.0 Bacteriological and physicochemical indicator counts at the sampling site

4.1 Irrigation schemes used for categorizing Physicochemical and Bacteriological Characteristics of wastewater used for Irrigation

The mean bacterial counts and mean concentrations of physicochemicals obtained from the measurement and analyses of the wastewater samples are shown in Table 4.1 and Table 4.2.

4.1.1 Bacteriological quality of wastewater samples from the study area

This section presents the results obtained from the microbial analysis conducted on wastewater used for irrigation of some vegetables along the old waterworks stream. The level of microbial contamination of the wastewater used for the irrigation varied along the stream. The bacteria indicators tested were Total coliform, Faecal coliform, *E. coli*, *Staphylococci*, *Enterococci*, *Pseudomonas* and Total Heterotrophic Bacteria.

Among the microbial indicators or parameters studied, Total heterotrophic bacteria recorded the highest mean counts at all the sampling sites (4.9×10^5 cfu/100ml, 3.7×10^5 cfu/100ml and 3.2×10^5 cfu/100ml at WWU, GMS1 and TKDS respectively) with the exception of NMS2 where *Pseudomonas spp.* recorded the highest mean count (2.6×10^5 cfu/100ml) in the dry season. *E. Coli* on the other hand recorded the lowest mean counts in all the sampling sites (0.00, 2.5×10^4 and 1.6×10^3 cfu/100ml at GMS1, NMS2 and TKDS respectively) with the exception of WWU where *Enterococci spp.* recorded 3.3×10^2 cfu/100ml in the dry season (Table 4.1). During the rainy season, Total coliforms recorded the highest mean counts at all the sampling sites (2.1×10^7 cfu/100ml, 2.9×10^7 cfu/100ml, 5.2×10^7 cfu/100ml and 3.6×10^7 cfu/100ml at WWU, GMS1, NMS2 and TKDS respectively). On the other

hand, Total heterotrophic bacteria recorded the lowest mean counts at all the sampling sites (4.8×10^2 cfu/100ml, 4.1×10^2 cfu/100ml, 6.3×10^2 cfu/100ml and 4.3×10^2 cfu/100ml at WWU, GMS1, NMS2 and TKDS respectively) in the rainy season as compare to dry season counts of (4.9×10^5 cfu/100ml, 3.7×10^5 cfu/100ml, 1.3×10^5 cfu/100ml and 3.2×10^5 cfu/100ml) (Table 4.1).

Comparably, mean bacteria count recorded for all the indicator parameters were generally higher during the rainy season irrigation than mean bacteria count recorded during the dry season irrigation with exception of Total heterotrophic bacteria counts, which was relatively higher during dry season irrigation than that of rainy season irrigation.

Table 4.1: Mean bacterial counts (log10) for dry and rainy season irrigation schemes

Parameter	DRY SEASON(cfu/100ml)				RAINY SEASON(cfu/100ml)			
	WWU	GMS1	NMS2	TKDS	WWU	GMS1	NMS2	TKDS
Total Coliform	2.4×10^5	2.0×10^4	3.2×10^5	2.0×10^5	2.1×10^7	2.9×10^7	5.2×10^7	3.6×10^7
Faecal Coliform	1.1×10^4	4.3×10^3	6.8×10^4	4.4×10^4	6.9×10^6	5.7×10^5	1.8×10^7	1.6×10^6
<i>E. coli</i>	6.0×10^3	0.00	2.5×10^4	1.6×10^3	3.0×10^5	6.7×10^4	1.0×10^7	3.7×10^5
<i>Staphylococci</i>	1.4×10^5	8.3×10^3	5.3×10^3	1.4×10^4	7.0×10^5	1.5×10^6	1.7×10^6	1.6×10^6
<i>Enterococci</i>	3.3×10^2	3.3×10^2	4.1×10^4	6.7×10^3	1.3×10^5	1.7×10^5	2.8×10^6	4.0×10^5
<i>Pseudomonas</i>	2.0×10^5	3.6×10^4	2.6×10^5	5.9×10^4	9.7×10^6	1.5×10^6	1.4×10^7	4.7×10^5
Total Heterotrophic Bacteria	4.9×10^5	3.7×10^5	1.3×10^5	3.2×10^5	4.8×10^2	4.1×10^2	6.3×10^2	4.3×10^2

No *Clostridium* spp. were detected during dry and rainy irrigation

The faecal coliforms counts of all the sampling sites in both the dry (1.1×10^4 cfu/100ml, 4.3×10^3 cfu/100ml, 6.8×10^4 cfu/100ml and 4.4×10^4 cfu/100ml) and rainy (6.9×10^6 cfu/100ml, 5.7×10^5 cfu/100ml, 1.8×10^7 cfu/100ml and 1.6×10^6 cfu/100ml) seasons were higher when evaluated against the World Health

Organization (WHO, 2006) guideline of 1×10^3 cfu/100ml of faecal coliforms which is equivalent to $\log_{10} 3$ cfu/100ml for unrestricted irrigation of crops likely to be eaten raw. More so, all the microbial parameters analysed had numbers higher than WHO recommended levels upon evaluation with the exception *Clostridium* spp. which was not detected in all the sampled wastewater from all the various study sites during both dry and rainy season irrigation schemes.

4.1.2 Multiple Comparison for Microbial Parameters during Dry and rainy season Irrigation Scheme

To investigate the association of the bacteria counts within the sampling site for all the irrigation schemes of the water in the study area, multiple comparisons were performed and the coefficient were used to analyse the bacteria counts at the sampling sites. The multiple comparison observed for the bacteria counts for the dry season irrigation scheme at the sampling sites were: WWU and GMS1 ($p=0.27$), WWU and NMS2 ($p=0.788$), WWU and TKDS ($p=0.45$), GMS1 and WWU ($p=0.27$), GMS1 and NMS2 ($p=0.18$), GMS1 and TKDS ($p=0.72$), NMS2 and WWU ($p=0.79$), NMS2 and GMS1 ($p=0.18$) and NMS2 and TKDS ($p=0.31$), TKDS and WWU (0.45), TKDS and GMS1 (0.721), TKDS and NMS2 (0.31) (Appendix XXVII).

On the other hand, bacteria counts for the rainy season irrigation scheme are: WWU and GMS1 ($p=0.90$), WWU and NMS2 ($p=0.23$), WWU and TKDS ($p=0.98$), GMS1 and WWU ($p=0.90$), GMS1 and NMS2 ($p=0.18$), GMS1 and TKDS ($p=0.88$), NMS2 and WWU ($p=0.23$), NMS2 and GMS1 ($p=0.18$) whilst that of NMS2 and TKDS ($p=0.24$) on the other hand TKDS and WWU (0.98), TKDS and GMS1 (0.88) and TKDS and NMS2 (0.25) (Appendix XXXI).

These gave a weak correlation ($r=0.24$) (Appendix XXXIII) among the individual sampling sites for microbial statistics of wastewater samples during dry and rainy season irrigation schemes. More so, there is a significant difference between the wastewater samples for dry and rainy season irrigation of microbial parameters with ($p = 0.005$) (Appendix XXXIV) from the pairwise sample test. We therefore reject H_{03} (Null hypothesis) so we fail to reject H_{A3} (Alternate hypothesis). This gives strong evidence that microbial parameters for dry and rainy season irrigation are different.



Table 4.2: Mean concentration of some physicochemical parameters for dry and rainy season irrigation schemes

Para Meter		Temperature (°C)	pH	Colour (Hazen)	Turbidity (NTU)	Conductivity (µS/cm)	TDS (mg/L)	TSS (mg/L)	Total Alkalinity (CaCO ₃) (mg/L)	Total Hardness (CaCO ₃) (mg/L)	Cal. Hardness (CaCO ₃) (mg/L)	Magnesium Hardness (MgCO ₃) (mg/L)	Carbonate Alkalinity (CO ₃ ²⁻) (mg/L)	Bicarbonate Alkalinity (HCO ₃ ²⁻) (mg/L)
WWU	D	19.33	6.83	5.17	6.22	257.47	298.10	9.00	67.33	36.33	29.00	6.67	44.67	22.67
	R	28.43	6.57	50.67	80.57	178.40	89.17	34.00	96.33	27.00	22.67	4.33	23.33	73.00
GMS1	D	18.73	6.63	7.60	11.75	828.33	415.67	7.67	46.67	25.33	23.67	1.67	18.00	19.00
	R	27.97	6.57	21./23	34.66	1025.00	512.33	37.67	62.00	20.67	17.67	3.00	25.33	44.00
NMS2	D	18.23	7.34	42.30	52.03	1559.33	782.33	58.67	515.00	202.00	90.67	111.33	104.67	410.33
	R	28.97	7.23	80.07	64.00	1354.00	677.00	191.00	554.67	376.33	60.67	315.67	85.33	469.33
TKDS	D	18.43	7.36	30.57	33.32	1537.33	772.03	46.33	436.33	90.33	71.67	19.33	90.67	345.00
	R	28.63	7.67	62.87	82.93	1428.33	714.00	147.00	475.00	85.33	58.33	27.00	80.00	396.67

D-Dry Season, R-Rainy Season –

Table 4.2 continuation.

Parameter		Ca ²⁺ (mg/L)	Mg ²⁺ (mg/L)	Cl ⁻ (mg/L)	Fl ⁻ (mg/L)	SO ₄ ²⁻ (mg/L)	S ²⁻ (mg/L)	PO ₄ ³⁻ (mg/L)	NH ₃ -N (mg/L)	NO ₃ -N (mg/L)	NO ₂ -N (mg/L)	Al (mg/L)	Tot. Fe ^{2+/3+} (mg/L)	Mn ²⁺ (mg/L)	Cu ³⁺ (mg/L)	Zn ²⁺ (mg/L)	CN ⁻ (mg/L)	Cr ⁻ (Total) (mg/L)	K ⁺ (mg/L)
WWU	D	11.60	1.62	56.67	0.03	57.23	0.07	0.87	3.69	2.25	0.01	0.02	0.52	0.22	0.53	0.04	0.13	0.04	5.80
	R	9.07	1.05	50.67	0.00	50.57	0.10	12.22	10.25	3.00	0.01	0.04	1.39	0.04	0.16	0.07	0.12	0.04	13.77
GMS1	D	9.47	2.51	29.00	0.00	40.00	0.05	0.55	1.66	1.92	0.01	0.02	0.55	0.07	0.05	0.04	0.04	0.01	5.37
	R	7.07	0.73	26.67	0.00	37.75	0.04	10.65	15.46	1.92	0.00	0.03	1.02	0.02	0.16	0.09	0.27	0.00	8.30
NMS2	D	36.27	27.05	365.00	0.18	30.00	0.54	7.25	57.31	4.75	0.01	0.06	1.64	0.30	0.13	0.01	0.02	0.01	88.47
	R	24.27	76.71	294.00	0.00	9.47	2.54	37.16	14.83	12.83	0.03	0.05	2.29	0.53	0.01	0.01	0.03	0.00	36.07
TKDS	D	21.02	8.35	381.67	0.20	20.57	0.15	1.47	51.45	2.08	0.01	0.03	1.53	0.30	0.09	0.02	0.01	0.03	72.00
	R	23.33	6.56	344.33	0.00	43.31	0.35	18.45	12.87	11.17	0.03	0.42	2.11	0.51	0.48	0.03	0.01	0.01	40.50

D-Dry Season, R-Rainy Season

4.2 Physicochemical Concentration of Wastewater Samples from the Study

Area

Wastewater samples were collected along the Tamale Old Tamale Waterworks stream and analysed for physicochemical parameters from the following sampling points WWU, GMS1, NMS2 and TKDS during dry season and rainy season irrigation. The results obtained are shown in Tables 4.2. The reported concentrations are averages of the analysed physicochemical parameters for both dry and rainy season irrigation from the four sampling sites along the Tamale old waterworks stream.

4.2.1 Mean Concentration for Physicochemical parameters for Dry and Rainy Season Irrigation Scheme along the Tamale old Waterworks Stream

Among the physical parameters (temperature, pH, colour and turbidity), turbidity was highest during rainy season at 82.93NTU at TKDS and lowest during dry season at WWU (6.22NTU). Meanwhile, conductivity is the highest chemical parameter. It counted up to 1559.33 μ S/cm at NMS2 during dry season and lowest at WWU with a count value of 178.40 μ S/cm (Table 4.2).

The mean temperature recorded for the four sampling sites ranged from 18.23°C to 19.33°C during dry season irrigation and 24.90°C to 25.73°C during rainy season irrigation respectively (Table 4.2). Even though there is no recommendation guideline for irrigation water on temperature in Ghana, temperature values obtained from the test during dry season and rainy season irrigations fall within room temperature value of 25°C, which is a conducive temperature for the cultivation, growth and development of most edible crops.

The mean pH of the wastewater samples measured ranged from 6.63 to 7.36 during dry season irrigation and 6.67 to 7.47 during rainy season irrigation (Table 4.2). Meanwhile, the mean pH for both dry and rainy season irrigations was within the Ghana guideline for wastewater used in irrigation of vegetables at 6.5 to 8.4 (Appendix XVII).

The level of turbidity of the wastewater recorded ranged from 6.22 NTU to 52.03NTU for dry season irrigation and 34.66NTU to 82.93NTU (Table 4.2) for rainy season irrigation, which were below the Ghana irrigation water recommendation value of 1000NTU (Appendix XVII).

The level of conductivity recorded varied among the study sites and also between dry and rainy season irrigation wastewater samples. The level of conductivity recorded during dry season irrigation ranged from 257.47 μ S/cm at WWU to 1559.33 μ S/cm at NMS2 for dry season irrigation and 178.40 μ S/cm at WWU to 1428.33 μ S/cm at TKDS during rainy season irrigation. During both dry and rainy season irrigations, the level of electrical conductivity recorded in all the sampling sites were above the Ghana guidelines for irrigation water at $\leq 300\mu$ S/cm (Appendix F) except wastewater samples from WWU which is within the range for both dry and rainy season irrigation (Tables 4.2).

The levels of total dissolved solids (TDS) varied between both dry and rainy season irrigation periods. During dry season irrigation, TDS ranged from 298.10mg/L to 782.33mg/L and 89.17mg/L to 714.00mg/L for rainy season (Table 4.2). The concentrations of TDS recorded for wastewater samples during dry season irrigation from all the sampling sites were relatively higher than that of rainy season irrigation with exception of samples from study site GMS1, which was higher during rainy

season irrigation than during dry season irrigation. Also, all the counts of TDS exceeded the Ghana guideline value of ≤ 200 mg/L (Appendix XVII) for wastewater used for irrigation of crops except WWU which recorded 89.17mg/L during rainy season irrigation (Table 4.2).

The mean total suspended solids (TSS) concentrations ranged from 7.67mg/L at GMS1 to 58.67mg/L at NMS2 during dry season irrigation and 34.00mg/L at WWU to 191.00mg/L at NMS2 for rainy season irrigation. There is no set irrigation water guideline for total suspended solids.

The mean total alkalinity (TA) concentrations recorded for both dry and rainy season wastewater irrigations was less than the Ghana guideline for irrigation water which is $TA \leq 850$ mg/L (Appendix XVII). The mean total alkalinity therefore ranged from 46.67mg/L at GMS1 to 515.00mg/L at NMS2 for dry season irrigation and from 62.00mg/L at GMS1 to 554.67mg/L at NMS2 for rainy season irrigation (Table 4.2).

For total hardness (TH), calcium hardness (CH) and magnesium hardness (MH), the highest mean concentrations during the dry season irrigation were recorded at NMS2 (202, 90.67 and 111.33mg/L respectively) and the lowest mean concentrations were recorded at GMS1 (25.33, 23.67 and 1.67mg/L respectively). During rainy season irrigation, the highest mean concentrations of total hardness, calcium hardness and magnesium hardness were recorded at NMS2 (376.33, 60.67 and 315.67mg/L respectively) and the lowest mean concentrations were recorded at GMS1 (20.67, 17.67 and 3.00mg/L respectively) (Table 4.2).

Similarly, NMS2 recorded highest mean concentration of carbonate during dry season irrigation at NMS2 (104.67mg/L) of carbonate and lowest mean concentration

was recorded at GMS1 (18.00mg/L). During rainy season irrigation, highest mean concentration of carbonate was recorded again at NMS2 (85.33mg/L).

Whilst WWU recorded the lowest rainy season means (23.33mg/L) (Table 4.2).

The highest mean concentration of bicarbonate during dry season irrigation was recorded at NMS2 (410.33mg/L) and the lowest mean concentration was recorded at GMS1 (19.00mg/L). The highest mean concentration of bicarbonate during rainy season irrigation was recorded at NMS2 (469.33mg/L) and the lowest mean concentration was recorded at GMS1 (44.00mg/L) (Table 4.2).

During dry season irrigation, the highest concentrations were recorded by Ca^{2+} , Mg^{2+} , S^{2-} , PO_4^{3+} , $\text{NH}_3\text{-N}$, $\text{NO}_3\text{-N}$, Al^+ , $\text{Fe}^{2+/3+}$ and K^+ at NMS2 (36.67, 27.05, 0.54, 7.25, 57.31, 4.75, 0.06, 1.64 and 88.47mg/L respectively); Cl^- , F^- , SO_4^{2+} and Mn^{2+} at TKDS (381.67, 0.20, 20.57 and 0.30mg/L respectively); and Cu^{2+} , Zn^{2+} , CN^- and Cr^- at WWU (0.53, 0.04, 0.13 and 0.04mg/L respectively). On the other hand, Ca^{2+} , Cl^- , F^- , S^{2-} , PO_4^{3+} , $\text{NH}_3\text{-N}$, $\text{NO}_3\text{-N}$, Al^+ , Mn^{2+} , Cu^{2+} , Cr^- , K^+ recorded lowest concentrations at GMS1 (9.47, 29.00, 0.00, 0.05, 0.55, 1.66, 1.92, 0.02, 0.07, 0.05, 0.01 and 5.37mg/L respectively); Mg^{2+} , SO_4^{2+} , Al^+ and $\text{Fe}^{2+/3+}$ recorded lowest concentrations at WWU (1.62, 57.23, 0.02 and 0.52mg/L respectively); Zn^{2+} and Cr^- recorded lowest concentrations at NMS2 (0.01mg/L each) and CN^- (0.01mg/L) recorded lowest concentration at TKDS. The concentration of $\text{NO}_2\text{-N}$ in samples from all the study sites during dry season irrigation was 0.01mg/L (Table 4.2).

During rainy season irrigation, Ca^{2+} , Mg^{2+} , S^{2-} , PO_4^{3+} , $\text{NO}_3\text{-N}$, $\text{NO}_2\text{-N}$, Al^+ , and $\text{Fe}^{2+/3+}$ and Mn^{2+} recorded highest concentrations at NMS2 (24.27, 76.71, 2.54, 37.16, 12.83, 0.03, 0.05, 2.29 and 0.53 respectively); Cl^- , $\text{NO}_2\text{-N}$, Cu^{2+} and K^+ recorded highest concentrations at TKDS (344.33, 0.03, 0.48 and 40.50mg/L respectively);

NH₃-N, Zn²⁺ and CN⁻ recorded highest concentrations at GMS1 (15.46, 0.09 and 0.27mg/L respectively); and SO₄²⁺ and Cr⁻ recorded highest concentrations at WWU (50.57 and 0.04mg/L respectively). On the other hand, Ca²⁺, Mg²⁺, Cl⁻, S²⁻, PO₄³⁺, NO₃-N, NO₂-N, Al⁺, Fe^{2+/3+}, Mn²⁺ and K⁺ recorded lowest concentrations at GMS1 (7.07, 0.73, 26.67, 0.04, 10.65, 10.25, 0.00, 0.03, 1.02, 0.02 and 8.30mg/L respectively); Cu²⁺, SO₄²⁺, Zn²⁺ and Cr⁻ recorded lowest concentrations at NMS2 (0.16, 9.47, 0.01 and 0.00 respectively); and NH₃-N (10.25mg/L) and CN⁻ (0.01mg/L) recorded lowest concentrations at WWU and TKDS respectively (Table 4.2).

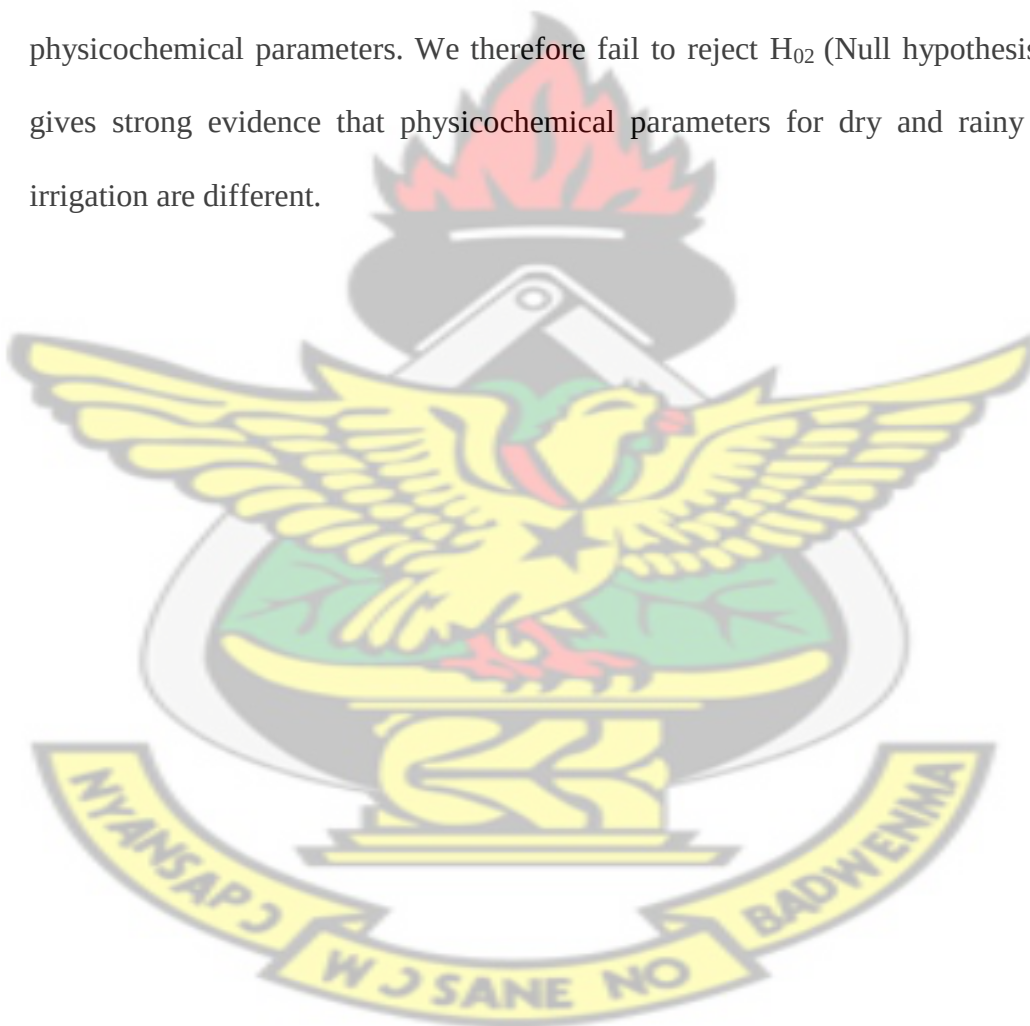
4.2.2 Multiple Comparism of Dry and Rainy Season Physicochemical Concentrations

To investigate the association of the physicochemical concentration within the sampling site for all the irrigation schemes of the water in the study area, multiple comparisons were performed and the coefficient was used to analyse the physicochemical concentration at the sampling sites. The multiple comparison observed for the physicochemical concentration for the dry season irrigation scheme at the sampling sites were: WWU and GMS1 (p=0.76), WWU and NMS2 (p=0.06), WWU and TKDS (p=0.10), GMS1 and WWU (p=0.76), GMS1 and NMS2 (p=0.11), GMS1 and TKDS (p=0.18), NMS2 and WWU (p=0.06), NMS2 and GMS1 (p=0.11) whilst that of NMS2 and TKDS (p=0.79), on the other hand TKDS and WWU (p=0.10), TKDS and GMS1 (p=0.18) and TKDS and NMS2 (p=0.79) (Appendix XXXIX).

Whilst the rainy season irrigation scheme gave: WWU and GMS1 (p=0.90), WWU and NMS2 (p=0.06), WWU and TKDS (p=0.20), GMS1 and WWU (p=0.90), GMS1 and NMS2 (p=0.08), GMS1 and TKDS (p=0.24), NMS2 and WWU (p=0.06), NMS2 and GMS1 (p=0.08) whilst that of NMS2 and TKDS (p=0.55) on the other hand

TKDS and WWU ($p=0.20$), TKDS and GMS1($p=0.24$) and TKDS and NMS2 ($p=0.55$) (Appendix XLIII).

There is strong correlation ($r=0.99$) (Appendix XLV) among the individual sampling sites for physicochemical parameter analysis of wastewater samples during dry and rainy season irrigation schemes. More so, pairwise analysis indicates that there is no significant difference ($p=0.41$) (Appendix XLVI) among the sampling sites for physicochemical wastewater samples for dry and rainy season irrigation of physicochemical parameters. We therefore fail to reject H_0 (Null hypothesis). This gives strong evidence that physicochemical parameters for dry and rainy season irrigation are different.



CHAPTER FIVE

DISCUSSION

5.1 Physicochemical parameters

The temperature of irrigation waters does not have any direct effect on the growth and development of crops but controls all the chemical reactions occurring within the irrigation waters, hence, affect all the other water quality parameters (Patil *et al.*, 2012; Farrell-Poe, 2000). Even though there is no temperature standard for irrigation waters in Ghana, temperature values obtained from the experiment during dry season and rainy season irrigations fall around the room temperature value of 25°C, which is the optimum temperature for the cultivation, growth and development of most edible crops in Ghana (Table 4.1). This means these wastewaters are suitable for the irrigation of raw edible vegetables in terms of temperature. The difference in the mean temperature values of the irrigation waters during the dry and rainy seasons may result from differences in the rate of chemical reactions occurring within these irrigation waters during these two different weather conditions (Mazari-Hiriart, 2014).

The pH values obtained from water samples collected from the sampling point along the stream for both dry and rainy season irrigation schemes were close to neutral. This created the optimum condition for the growth and development of most mesophilic bacteria. This must have supported the proliferation of heterotrophic bacterial count, Total Coliform, Faecal coliform, *E. coli*, *Staphylococci*, *Enterococci*, *Pseudomonas*. Temperature and pH have an effect on the level of faecal coliform and *Enterococci* in waterbodies (Abdulai, 2014; Pautshwa, *et al.*, 2009).

Electrical conductivity (EC) is one of the important parameter for water quality because when conductivity is high, the number of ions are said to have exceeded the recommended limit (Ayers and Westcot, 1985). Conductivity is directly proportional to parameters such as temperature, pH, alkalinity, total hardness and total dissolved solids (Patil *et al.*, 2012). Since conductivity determines the degree of salinity in water, it should be noted that high electrical conductivity above the recommended levels in the irrigation water may indicator high salinity, thus may be toxic to plants. High concentrations of salt in the soil can cause vegetables and other crops to lose more water through the process of osmosis thereby causing “physiological” drought condition. In this case, the farm land will appear to be very moist but the plants will wilt due to inability of the roots to absorb water efficiently (Fipps, 2003). The electrical conductivity recorded at all the sampling sites for the both dry and rainy season irrigation was above the Ghana wastewater use in irrigation recommended limit except for WWU in dry season irrigation scheme; high EC of soil could create be toxic for proper plant growth. The reason for the high counts at NMS2 and TKDS may be due to the pollution of the stream by the surrounding community and their waste management regime as well as animal and humans defecating into the stream point and diffused source of pollutants, the soil type, field slope and drainage, irrigation system type and management, high fertilizer and manuring practices, and other soil and water management practices. EC, affect crop yield and soil physical conditions (Bauder, *et al.*, 2011). However, EC was not significantly correlated with most of the physicochemical parameters.

A study by Sunitha, *et al.* (2005) showed that EC correlates with other water quality parameters like total alkalinity, sulphates, total hardness and magnesium. Higher concentrations of such chemical parameters above recommended limits may result in

poor growth of plants and when such plant produce are consumed without proper washing, humans could be accumulating these toxic chemicals in their system. Also, a study by Mahajan, *et al.* (2005) has also reported that almost all the physicochemical parameters in one way or the other are relate to each other when they performed correlation and regression analysis on the physicochemical parameters of ground water. A study by Kalyanaraman and Geetha (2005) identified that the water quality of ground and surface water can be predicted with sufficient accuracy by the measurement of EC alone. Therefore, the EC of a waterbody is a useful parameter in studying the quality of water, hence providing a means for easier and faster monitoring of water quality of a particular location.

The calcium and calcium hardness levels were proportional to each other with the calcium hardness level being higher than the calcium concentrations for both dry and rainy season irrigation. However, dry season irrigation recorded higher calcium and calcium hardness levels than the rainy season irrigation (9.07mg/L; 3.63mg/L and 5.30mg/L; 2.12mg/L for dry and rainy season irrigations respectively). In both cases the high calcium concentration occurred at NMS2 which can lead to an accumulation of calcium ions in the soil. This coupled with high counts of magnesium at NMS2 recording (2.71×10^1 mg/L and 2.05×10^2 mg/L) for dry and rainy season irrigation can result in imbalance of calcium and magnesium in vegetables which may also exhibit toxic symptoms. Also, the bicarbonate ions (total alkalinity and total hardness) present in soil solution can also affect absorption of mineral nutrient and metabolism of nutrients (Bauder, *et al.*, 2011).

The most important source of chromium in vehicle related wastewater analysis is the metal surface coating found on the bumper and wheels (Abagale, *et al.*, 2013). When steel is produced to manufacture metal parts of a vehicle, heavy metals such as

manganese and cast iron are used to improve strength, hardness and stiffness. Therefore, when these metal parts and engine blocks are washed near a waterbody like the Tamale old water works stream, high levels of manganese can be released into the stream that is used for the irrigation of vegetables leading to manganese contamination in high concentration beyond appreciable limits (Abagale *et al.*, 2013).

Chromium occurs in different oxidation states some of which have biological relevance (trivalent chromium (III) and hexavalent chromium (VI)). Chromium (III) is generally less toxic than chromium (IV), which has harmful effects on human health as it has been shown to cause irritation and cancer (Baysal *et al.*, 2013; Abagale *et al.*, 2013). Toxicity of chromium is also dependant on pH, temperature and salinity. As pH and salinity decreases, temperature was low during the dry season which happen to be cold due to harmattan season at a value of 19.33⁰C (Appendix XX) to as high as 25.75⁰C (Appendix XXII) in the rainy season which could be due to the warm weather. Moreso, toxicity of chromium also increases. in soft water than in hard waters (Frances, 2008). This was evident for both irrigation schemes for WWU and GMS1 (Table 4.2).

The mean copper for both dry and rainy season is 0.53ml/L and 0.16ml/L respectively (Table 4.2). This concentration is below the Ghana's recommended concentration of 2mg/L for irrigation water. ANOVA and pairwise statistics show no significant differences ($p=0.57$) between the mean concentrations during both dry and rainy season irrigation schemes. Copper is a heavy metal which may pose serious health risks not only to farmers of vegetable irrigated with wastewater but also to consumers, fast food sellers and to vegetable vendors since. Wastewater irrigation contaminates the soil and the leaves of the vegetables as indicated in the

findings of Alexander *et al.* (2006). They also emphasises that wastewater irrigated leafy vegetables contain more metal irons as compared to root vegetables. This is consistent with copper concentrations in wastewater irrigated vegetables Tamale (Anim Gyampo *et al.*, 2012). Copper is one of the heavy metals whose toxicity decreases especially in the presence of chelating agents such as zinc, sulphate, calcium, molybdenum, magnesium, suspended solids and amino acids but increases with a combination of other metals and at a point where there is dissolved oxygen and water hardness decreases (DWAF, 1996). Accumulation of copper in soil over a long period of time can affect the quality and quantity of crops and also affect some aquatic life such as larva of marine invertebrates (Abagale *et al.*, 2013). The effects of copper toxicity occur when concentrations are above 140mg/L (Frances, 2008).

The mean turbidity values of the wastewater were between 0.62×10^1 NTU to 5.20×10^1 NTU and 3.35×10^2 NTU to 1.34×10^3 NTU dry and rainy season irrigation scheme respectively with the rainy season irrigation recording higher turbidity counts but the values were below the Ghana's recommended value of 1000NTU for wastewater used for irrigation for all the four sampling site for both irrigation schemes which. The high turbidity level during the rainy season can be attributed to the fact that rain water increases the turbidity of water bodies because greater amounts of solid matter are washed into the water bodies (Patil *et al.*, 2012).

In the case of potassium, results obtained indicate that both NMS 2 and TKDS is not conducive for crop irrigation during the dry season irrigation scheme since the levels (88.47 and 72.00) are higher than the Ghana standard for irrigation levels of not more than 40mg/L (Table 4.2). Also, for rainy season irrigation, values obtained from NMS2 were also above the Ghana standard for irrigation (48.70) thus not suitable for irrigation of raw edible vegetables. However, Potassium concentration for TKDS

during the rainy season and that of GMS1 and WWU for both dry and rainy season were both within the recommended for Ghana standard for irrigation. Higher concentration for NMS2 and TKDS may be due to increased concentration of organic and inorganic fertilizer from a point source of pollution since there is more potassium in the water during dry season than there is during the rainy season, and as well from continuous accumulation along the stream. According to Stahl, (2009), potassium concentration from 0 to 10 mg/L or above poses no problems to the crops. However, potassium, irrespective of the concentration poses no threat to the development and growth of crops as well as on the health of humans and animals that depend on these crops (Stahl, 2009). By this statement, the presence or absence of potassium in irrigation waters does not affect the suitability of the irrigation waters for the irrigation of raw edible vegetables. It must be noted that with the exception of potassium and phosphate, seasonal variations do not have much significant influence on the presence of plant nutrients in surface waters. However, when the concentration of potassium in soil water is higher it introduces a magnesium deficiency and iron chlorosis in plants (Bauder, *et al.* 2011). More so, an imbalance of magnesium and potassium may be toxic, but the effects of both can be reduced by high calcium levels in the soil water as is the case.

The total hardness was higher in the rainy season irrigation scheme (258.90mg/L) (Appendix XXII) and lower in the dry season irrigation (202.00mg/L) (Appendix XX). The total hardness is below the Ghana guideline for irrigation water of 850mg/L (Appendix XVII) (IWMI, 2002). The presence of calcium (Ca^{2+}) and magnesium (Mg^{2+}) ions make major contribution to the total hardness of the wastewater along the stream. Maximum concentration of calcium 36.27mg/L (Appendix XX) was found in dry season irrigation and minimum of 6.8mg/L

(Appendix XXII) in rainy season irrigation. Similarly, maximum concentration of magnesium of 49.8mg/L (Appendix XXI) was found in the rainy season irrigation and minimum of 27.00 mg/L (Appendix XX) in dry season irrigation scheme. There is no known health risk associated with consuming vegetables containing high Mn concentrations but high concentration of Mn can be toxic to some plants (Pescod, 1992 and Ghesquiere, 1999). The calcium ions render the water impure, this affects human beings who use the water for, irrigation, domestic purpose as well as industrial use.

5.2 Plant Nutrients

The levels of phosphate are below the Ghana's recommended standard of 10mg/L for the use of wastewater in irrigation of vegetables that can be eaten raw for only dry season irrigation scheme but above the standard for rainy season irrigation scheme. Phosphates are one of the essential plant nutrients released from vehicle washing bay into the stream and it promotes plant growth, which can pose human health concerns (Alede *et al.*, 2011). On the other hand, when phosphate is not present in the required amount, both plant leaf expansion and leaf surface area are reduced, as well as the number of leaves. In most cases the shoot growth is most affected than the root growth. Phosphate deficiency on plant growth are delayed maturity, reduced for age quality of fruit, vegetable and grain crops, and decreased disease resistance (Better Crops, 1999). The presence of phosphate in the stream can be categorised into two: point and natural sources. The point sources of phosphate that may have contributed to the presence of phosphate in the stream are sewage, and also waste industrial products such as toothpaste, detergents, pharmaceuticals, and food-treating compounds containing phosphorus (Kotoski, 1997). Usually, detergents used in cleaning the exterior of vehicles contain both nitrogen and phosphorus and may have

adverse effects on the environment (Oknich, 2002; Smith & Shilley, 2009). Other sources of phosphate in the wastewater could be from natural sources such as phosphorus rich rocks which can release phosphate during weathering, leaching and erosion or from sediments at the bottom of the stream during seasonal overturn. That may explain why the phosphate levels were higher during rainy season irrigation scheme than there was during the dry season irrigation (Table 4.2).

The sulphate was highest in dry season irrigation (57.23mg/L) (Appendix XX) and lowest in the rainy season irrigation (42.78mg/L) (Appendix XXII). Sulphate count was above the Ghana guideline limit of 10mg/L (Appendix XXVII) (IWMI, 2002) for wastewater used in irrigation of vegetables for both irrigation schemes. Sulphate was especially highest at the upstream (WWU) but low at the other three sampling sites. This could be due to the surfactant from the vehicle washing bay close by (Nor Haslina and Nadzirah, 2016). Sulphate salts are detrimental to sensitive crops because they limit their absorption of ions such as calcium but increase the uptake of sodium and potassium, thereby causing cationic balance within the plant (Bauder, *et al.*, 2011). Based on these analogies, it can be inferred that the high presence of chemicals such as zinc, chromium, sulphate and iron at the WWU and GMS1 for both irrigation schemes may have been due to the high rate of the vehicle washing activities at these sampling sites while manganese is rather high at NMS2 and TKDS (Table 4.2).

The average values of nitrate and nitrite obtained for dry season irrigation scheme were very low while that of rainy season irrigation scheme were high but below the WHO guideline of 10mg/L for nitrate. This could be due to the activities of nitrifying bacteria, runoff, erosion and leaching processes along riparian region of streams and rivers (Stahl, 2009). Nitrate and nitrite levels for dry season irrigation were 4.75mg/L

and 0.01mg/L respectively. While that of the rainy season irrigation was 9.25mg/L and 0.2mg/L, respectively. The free range system of animal rearing in the Tamale metropolis, frequent open defecation, the use of organic and inorganic fertilizers for farming and indiscriminate disposal of human and animal excreta may contribute to high levels of nitrate in the rainy season irrigation scheme (Oyelude *et al.*, 2013). It can be said that sampling sites WWU and GMS1 had lower counts for nitrate and nitrite for both dry and rainy season irrigation scheme (Table 4.2) which can be attributed to the low activities of humans and animal at the riparian region for both sampling sites. In situations where the level of nitrates is higher than the WHO guideline of 10mg/L, continuous consumption of vegetables from the other sites could cause diseases such as methaemoglobinemia in young babies due to nitrate interfering with iron and, thus affecting oxygen transport in the blood stream (WHO, 2007). While direct ingestion of nitrate can lead to gastric cancer if some of the nitrates get converted into nitrosamine which is a carcinogen (Haiyan & Stuanes, 2003; Speijers, 1996). But this is not likely to affect farmers and vegetable vendors as well as the general public in this case since the nitrate counts are below the WHO guidelines and the Ghana standards for the use of wastewater in irrigation of vegetables likely to be eaten raw and for that matter such low levels of nitrate is not likely to cause eutrophication of the wastewater.

The order of nutrient concentration in the wastewater along the Tamale old water works is $SO_4 > PO_4 > NO_3 > NO_2$. High levels of physico-chemicals are likely to be present on the vegetable on which the water from the Tamale old water works stream is applied (Anim-Gyampo *et al.*, 2012). The use of this wastewater by farmers or people near the stream and by consumers who buy vegetables from such farmers may be exposed to potential health threats since wastewater from the stream is

contaminated by nutrients, heavy metals, salts, nitrates and other potentially harmful substances (Stagnitti *et al.*, 1998; Anim-Gyampo, *et al.*, 2012). More so, human health is also at risk as we consume contaminated vegetable and also from exposure to heavy metals or harmful organic chemicals as well as pathogenic microbe (Stagnitti, 1999; Anim-Gyampo *et al.*, 2012; Zurera *et al.*, 1989).

5.3 Bacteriological Parameters

The results of the study show that the wastewater sampled from the four sampling sites along the Tamale old waterworks used for irrigation during both dry and rainy season irrigation schemes is polluted with faecal material (Amponsah-Doku *et al.*, 2009). The bacteria count is above the ICMSF (1998) limit of 10^3 to 10^5 coliforms $100 \text{ mg}^{-\text{L}}$ and the World Health Organization (WHO, 2006) guidelines for faecal coliform bacteria limit ($1 \times 10^3 \text{ mg}/100\text{ml}$) of wastewater for irrigation of vegetables likely to be eaten raw. Cornish *et al.* (1999), Mensah *et al.* (2001), Keraita *et al.* (2003a and 2003b), Amoah *et al.* (2005) and Obiri-Danso *et al.* (2005) all earlier reported high bacteria counts in wastewater used for irrigating vegetable in farms within Kumasi. This is in agreement with the investigations conducted in Tamale and Kassena-Nankana East municipality which also indicates that most of the water sources for irrigation are polluted (Ataogyie, 2012; Abdul-Ghaniyu *et al.*, 2002). The high levels of pollutants can be attributed to diffused or non-point sources and point sources of pollution such as run-offs from agricultural lands, small scale food vendors, vehicle washing bays along the stream, faeces of free range domestic animals and wild birds, human excreta from open defecation, use of poultry manure as well as household waste finding their way into the stream. Soaps and detergents used in vehicle washing slowly biodegrade in the environment thus lowers the oxygen potential and kill water born organisms but on the other hand increases the

bacterial numbers and organic matter in the stream (Oknich, 2002; Nadzirah *et al.*, 2015).

5.3.1 Bacteriological parameters for rainy and dry season irrigation

The level of pollution was higher during the rainy season than the dry season irrigation along the stream, especially at NMS2 where higher mean microbial counts and physicochemical concentrations were recorded than the rest of the sampling sites. These values are probably due to both a higher contamination of the wastewater from diffused and point source of contamination.

On the contrary, the water used for dry season irrigation was less polluted compared to the rainy season irrigation. The microbial count in the rainy season irrigation was 98% higher than the dry season irrigation. The reason for lower bacterial count in dry season irrigation is that during this period there is no rainfall thus the other source of pollution is reduced to point source of pollution and is very much so due to die off effect of bacteria as they move from one sampling sites. Bacteriological pollution was significantly higher in the rainy season than the dry season; this is due to higher run-off-rate that washes faeces from human and animal sources as well as agricultural, chemical and industrial waste along the catchment area into the stream. This is a major problem in several tropical countries in the world and reports have indicated that this kind of water pollution is associated with high prevalence of diarrhoea (Musa *et al.*, 1999, Obiri-Danso *et al.*, 2005). According to the Environmental Protection Agency (EPA) Act the level of total and faecal coliforms present in any liquid waste discharged into waterbodies like streams should not exceed 400mg/100ml and 10mg/100ml respectively (EPA, 1994). Comparing this standard with results obtained in this study, the GEPA directive is violated and health of the people and animals which use the stream water one way or the other may be a

major concern. Therefore, attention has to be called on board and measures instituted to mitigate this phenomenon at the Tamale old water works stream.

The observed high levels of faecal coliform are an indication of faecal contamination in the wastewater during rainy season irrigation may be due to the following reasons. Firstly, a cluster of washing bay and mechanic shops are located along the stream. Their waste materials are washed into the streams. There is no proper sanitary system for the vegetable farmers and their families who also live nearby, residential houses, chop bars, hotels, corner shops, as well as basic schools thus they openly defecate and urinate into the stream directly during all day long. Secondly, the stream is a source of drinking water for cattle and other animals as well as faeces, household and commercial waste from the community end up in the stream. Additionally, the water from major gutters and drains within the heart of the metropolis flow directly into the stream and this could be a contributing factor to the high microbial load in the stream.

Since micro organisms survival in the soil is dependent on soil texture, organic matter moisture, irrigation regime, pH and chemical fertilizers, it is usually advisable that farmers are familiar with these factors before they engage in wastewater irrigation of ready-to-eat vegetable (Mawdsley *et al.*, 1995; Cools *et al.*, 2001; Ogden *et al.*, 2001; Estrada *et al.*, 2004; Nicholson *et al.*, 2005; Pourcher *et al.*, 2007; Bernstein, 2009). In some studies, drip irrigation with coliform contaminated wastewater on sandy loam soil was safer since the soil was able to reduce the faecal contamination (Campos *et al.*, 2000b; Palese *et al.*, 2009).

The quality of water used for irrigation purposes in Ghana is of a great concern because people have become more aware of the health benefits of consuming plant-

based food products like vegetables and fruits. Since demand for vegetables is increasing, the microbial, physical and chemical quality of materials applied in their cultivation can eventually determine the health status of consumers. The act of open defecation by both human and animals, release of physical and chemical waste into waterbodies by industries is not restricted to Tamale alone. In Kumasi, a study along the Subin river by Obiri-Danso *et al.*, (2005) implicated the high levels of microbial indicators (10^{11} of total coliforms, 10^{10} of faecal coliforms and 10^{10} of Enterococci) to the lack of proper latrines and sanitary facilities like dustbins and waste management plants. As a result, pupils from schools near the river openly defecate along the river banks, which eventually washes into the river. Also, the garbage generated from commercial activities of traders during the day is dumped into the Subin River.

Finally, isolation of *E. coli* from the water used for irrigation is of significant concern because strains of these bacteria may be pathogenic and are the most common cause of infantile diarrheal disease in many countries, specifically in the developing world. Many studies in different parts of the world have linked pathogenic *E. coli*, one of the most common pathogens associated with the endemic life-threatening diarrheal diseases in many countries (Black *et al.*, 1981; Guerrant *et al.*, 1983 and Feachem *et al.*, 1983). There is therefore the need to develop risk reduction strategies at the farm level to help safeguard the health of farm workers, vegetable vendors consumers and the general public.

CHAPTER SIX

CONCLUSION, RECOMMENDATIONS

6.1 Conclusion

This study was conducted to evaluate the microbial and physicochemical parameters of wastewater used for irrigation of vegetables including alefu (*Amaranthus cruentus*), tomato, carrot, spinach, ayoyo (*Corchorus olitorius.*), lettuces, cabbage and onion along the Tamale old water works stream. In this study, physicochemical evaluation of wastewater samples from the Tamale old water works stream generally exceeded both WHO (2006) and Ghana standards for wastewater used for irrigation of vegetables that are eaten raw or minimally processed. The concentrations of heavy metals including Fe, Mn, Cu, and Zn were found to be above the recommended concentrations set by WHO (2006). Even though most of the physicochemical parameters are not related to one another, conductivity is related to higher total dissolved solids, salinity, sodium, potassium and hardness, which rise as a result of the presence of Ca^{2+} and Mg^{2+} ions. The results obtained in this study also points to the fact that there is serious public health threat on the vegetable farmers, vendors and consumers of vegetables cultivated using such untreated wastewater, and so is the case of the Tamale old water works stream.

The bacteriological analysis of the wastewater during both rainy and dry season irrigation varied considerably and revealed the presence of bacterial pathogens including total coliform, faecal coliform, *E. coli*, *Staphylococci spp.*, *Enterococci spp.*, *Pseudomonas spp.* and total heterotrophic bacteria. The level of bacterial contamination of the wastewater used for irrigation from the Tamale old water works was above the WHO (1989) and ICMSF (1998) acceptable limits, making the

consumption of vegetables cultivated with such wastewater a serious public health threat.

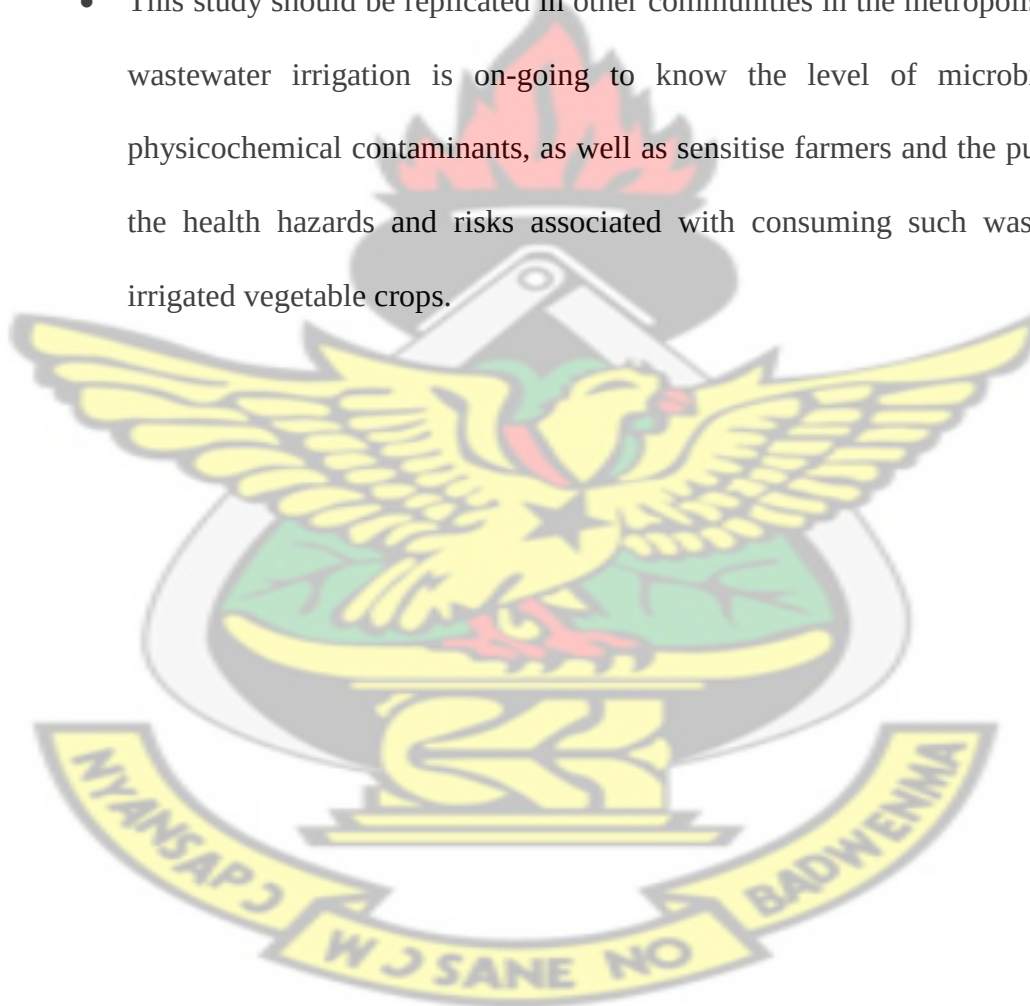
Generally, the bacterial pathogens identified in the wastewater samples are considered dangerous and can potentially cause diarrheal and other diseases of public health significance. This study shows that wastewater applied by irrigation farmers along the stream of the Tamale Waterworks is not suitable for cultivation of vegetables for consumption. Even though the levels of bacterial load and concentrations of physicochemical parameters detected in this study might not result in immediate illness, consumption of food materials irrigated with these levels or concentrations of contaminants would lead to their accumulation in trace amount in living organisms over a long period of time and eventually result in life-threatening disease conditions.

6.2 Recommendation

- Vegetable farmers should employ the use or application of irrigation water of good microbial and physicochemical quality in the cultivation of vegetable crops.
- The Tamale Metropolitan Assembly (TMA) should enforce by-laws to prevent open defecation and indiscriminate waste disposal of waste and other unsanitary practices along the stream. The TMA should provide adequate sanitary facilities for inhabitants, and also community leaders and inhabitants along these waterbodies should regularly organise communal labour to clean streams and their environments.
- Vegetable and other farmers along the stream should be regularly educated or enlightened about how to apply chemicals to vegetable crops and the disposal

of empty pesticide containers in order not to contaminate the crops and the stream with runoffs. Farmers should also be encouraged to wear safety gears when working and or applying such wastewater as irrigation water.

- The Tamale Metropolitan Assembly should promptly provide farmers with detailed annual assessment of the quality of the waterbodies in order to help inform farmers using this wastewater for irrigation when to apply and when not to apply such wastewater for irrigation of vegetable crops.
- This study should be replicated in other communities in the metropolis where wastewater irrigation is on-going to know the level of microbial and physicochemical contaminants, as well as sensitise farmers and the public on the health hazards and risks associated with consuming such wastewater irrigated vegetable crops.



REFERENCES

- Abagale, F. K., Kyei-Baffour, N., Ofori, E. and Mensah, E. (2013). Types and seasonal diversity of helminth eggs in wastewater used for peri-urban vegetable crop production in Tamale metropolis, Ghana. *International Journal of Current Research*; 5(11):3354–3359.
- Abdul-Ghaniyu, S., Kranjac-Berisavijevic, G. and Yakubu, I. B. (2002). Sources and Quality of Water for Urban Vegetable Production in Tamale, Ghana. *Urban Agriculture Magazine*; 8,10.
- Abdulai, A. K. A. (2014). Environmental assessment of the Kassena-Nankana irrigation scheme vis a vis microbial contamination of tomatoes produced from irrigated farms in the Kassena-Nankana East Municipality. http://ugspace.ug.edu.gh/bitstream/123456789/8079/1/abadi%20kwesi%20ABASS%20abdulai_environmental%20assessment%20OF%20THE%20kassena-nankana%20_2014.pdf. (Accessed 11/9/2012).
- Absar, A., Satyajyoti, S., Khan, M. I., Rajiv, K. and Sastry, M. (2005). Extra-intracellular biosynthesis of gold nanoparticles by an alkalo-tolerant fungus, *Trichothecium* sp., *J. Biomedical Nanotechnnology*; 1, 1, 47-53.
- Absar, A. K. (2005). Water and Wastewater Properties and Characteristics. In *water Encyclopedia: Domestic, Municipal and Industrial Water Supply and Waste Disposal*. Lehr, J. H., Keeley, J. (eds). *John Wiley and Sons, Inc.*, New Jersey, pp. 903-905.
- Ackerson, N. O. B. and Awuah, E. (2012). Microbial risk assessment of urban agricultural farming: A case study on Kwame Nkrumah University of Science and Technology campus, Kumasi, Ghana. *International Journal of Engineering and Technology*; 2(3): 356-363.
- Agodzo, S. K., Huibers, F. P., Chenini, F., van Lier, J. B. and Duran, A. (2003) Use of wastewater in irrigated agriculture. Country studies from Bolivia, Ghana and Tunisia, Vol. 2 (Ghana). WUR, Wageningen, The Netherlands. www.dow.wau.nl/iwe (Accessed 11/9/2012).
- Alede, A. O., Jameel, A. T., Muyubi, S. A., Abdul Karim, H. I. and Alam, M. Z. (2011). Removal of oil and grease as emerging pollutants of concern (ECP) in wastewater stream. *IIUM engineering journal: Special issue on biotechnology*, 12, 161-167.
- Alexander, P. D., Aloway, B. J., and Dourado, A. M. (2006). Genotype variations in the accumulation of Cd, Cu, Pb and Zn exhibited by six commonly grown vegetables. *Environ. Pollut.*, 144(3), 736-745. <http://dx.doi.org/10.1016/j.envpol.2006.03.001>
- Allen, J. M., Edberg, S. C., and Reasoner, D. J. (2004). Heterotrophic Plate Count Bacteria-What is their Significance in Drinking Water. *U.S. Environmental Protection Agency Papers*, 93, 1-11.

- Aljaloud, A. A. (2010). Reuse of waste water for irrigation in Saudi Arabia and its effect on soil and plant. World congress of Soil Science, Soil Solutions for a Changing World, pp. 163-166.
- Alnos E. and Ashraf A. R. (2010). Domestic wastewater effect on the pollution of the groundwater in rural areas in Egypt. Fourteenth International Water Technology Conference, IWTC 14, 2010, Cairo, Egypt.
- Amoah, P., Drechsel, P. and Abaidoo, R. C. (2005). Irrigation urban vegetable production in Ghana: sources of pathogen contamination and health risk elimination. *Irrigation and Drainage* 54, 49–61.
- Amoah, P. (2008). Wastewater Irrigated Vegetable Production: Contamination pathway for health risk reduction in Accra, Kumasi and Tamale – Ghana. CGSpaceA: Repository of Agricultural Research Outputs. <https://cgspace.cgiar.org/bitstream/handle/10568/17049/17049.pdf?sequence=1&isAllowed=y> (Accessed 10/09/20013).
- AMOS, A. (2003). Impact of land disposal of sewage sludge and effluent on groundwater at Crowborough farm, Zimbabwe. Unpublished MSc Thesis, Civil Engineering, University of Zimbabwe.
- Amponsah-Doku, F., Obiri-Danso, K., Abaidoo, R. C., Andoh, L. A., Drechsel, P. and Kondrasen, F. (2009). Bacterial contamination of lettuce and associated risk factors at production sites, markets and street food restaurants in urban and peri-urban Kumasi, Ghana. International Water Management Institute (IWMI), Accra, Ghana. University of Copenhagen, Denmark.
- Anderson, T.H. (2003). Microbial eco-physiological indicators to asses soil quality. *Agric. Ecosyst. Environ.* 98, 285–293.
- Andoh, L. A., Abaidoo, R. C., Obiri-Danso, K., Drechsel, P., Kondrasen, F. and Klank, L.T. (2009). Helminth contamination of lettuce and associated risk factors at production sites, markets, and street food vendor points in urban and peri-urban Kumasi, Ghana. *Research Journal of Microbiology* 4(1): 13-22.
- Anim-Gyampo, M., Ntiforo, A. and Kumi M. (2012). Assessment of Heavy Metals in Waste-Water Irrigated Lettuce in Ghana: The Case of Tamale Municipality. *J. Sustain. Dev.*, 5 (11) (2012), pp. 93-102.
- Anon, (1992). Standard Methods for the Examination of Water and Wastewater. 18th edition. Washington, D.C. USA. APHA/AWWA/WPCF. APHA-AWWA-WEF (2001) Standard Methods for the Examination of Water and Wastewater 22nd ed. Washington, DC.
- Anon. (1994). Centers for Disease Control and Prevention. Foodborne outbreaks of enterotoxigenic *Escherichia coli* Rhode Island and New Hampshire, 1993. *MMWR*. 43:81-89.

- APHA (American Public Health Association) (1998). Standard Methods for Examinations of Water and Wastewater, (20th ed., pp. 4-146). Washington D.C.
- Asano, T. and Levine, A. D. (1996). "Wastewater reclamation, recycling, and reuse: Past, Present and Future." *Water science and Technology* 33(10-11):1-14.
- Asano, T., Burton, F. L., Leverenz, H., Tsuchihashi, R. and Tchobanoglous, G. (2007). *Water Reuse: Issues, Technologies, and Applications*. New York: McGraw Hill.
- Ataogye, G. (2012). Microbial contamination of an indigenous leafy vegetable, roselle (*hibiscus sabdariffa*.) and associated risk factors on farm and market samples in the Kasena-Nankana East Municipality of the upper east region. <http://dspace.knust.edu.gh/handle/123456789/5810> (Accessed 11/9/2012).
- Ayers, R. S. and Westcot, D. W. (1985). Water quality for agriculture. FAO Irrigation and Drainage Paper No. 29, rev. 1. Rome: *Food and Agricultural Organization*.
- Bauder, T. A., Waskom, R. M., Sutherland, P. L. and Davis, J. G. (2011). Irrigation Water Quality Criteria. Colorado State University. Agriculture Publication No. 0.506 <http://www.ext.colostate.edu/pubs/crops/00506.html>.
- Baysal, A., Ozbek, N. and Akman, S. (2013). Determination of Trace Metals in Waste Water and Their Removal Processes. <http://dx.doi.org/10.5772/52025> INTECH.
- Better Crops (1999). Better Crops with Plant Food: Phosphorus for Agriculture. Vol. LXXXIII (83) 1999, No. 1.
- Bernstein, N. (2009). Contamination of soil with microbial pathogens originating from effluent water used for irrigation: in: *Contaminated soils: Environmental impact, disposal and treatment*, Nova science publishers, NY, USA.
- Bigdeli, M. and Seilsepour, M. (2008). Investigation of Metals Accumulation in Some Vegetables Irrigated with Waste Water in Shahre Rey-Iran and Toxicological Implications. *American-Eurasian J. Agric. & Environ. Sci.*, 4 (1): 86-92, 2008 –ISSN 1818-6769. IDOSI Publications.
- Black, R. E., Merson, M. H., Huq, I., Alim, A. R. M. A., Yunus, M. D. (1981). Incidence and severity of rotavirus and *Escherichia coli* diarrhea in rural Bangladesh: implications for vaccine development. *Lancet*, 1, 141-143.
- Blumenthal, U., Peasey, A., Ruiz-Palacios, G. and Mara, D. (2000). Guidelines for wastewater reuse in agriculture and aquaculture: recommended revisions based on new research evidence. WEDC, Loughborough University, UK, 42p.
- Campos, C., Oron, G., Salgot, M., Gillerman, L. and Casals, G. (2000b). Attenuation of microorganisms in the soil during drip irrigation with wastewater stabilisation pond effluent. *Water Sci. Technol.*; 10-11, 387-392.

- CDC (1997). Outbreaks of *Escherica coli* O157:H7 infection associated with eating alfalfa sprouts – Michigan and Virginia, June-July, 1997. *Morbidity and Mortality Weekly Report*; 46(32):741.
- Chorus, I. and Bartram, J. (eds) (1999). Toxic Cyanobacteria in Water: a guide to their public health consequences, monitoring and management. London E & Spon FN, on behalf of the World Health Organization, Great Britain, St Edmundsbury Press. ISBN 0-419-239.
- Cools, D., Merckx, R., Vlassak, K. and Verhaegen, J. (2001). Survival of *E. coli* and *Enterococcus spp.* Derived from pig slurry in soils of different texture. *Appl. Soil Ecol.* 17, 53-62.
- Dapaah-Siakwan, S. and Gyau-Boakye, P., (2000). Hydrological framework and borehole yields in Ghana. *Hydrogeology Journal* 8:405-416.
- DeCicco, B. T. (1979). Removal of eutrophic nutrients from wastewater and their bioconversion to bacterial single cell protein for animal feed supplements phase II. *Water Resources Research Centre Report* 15.
- Dela R, Taylor JC, Lass A, van Rensburg L, Vosloo O (2002). Determining the possible application of diatoms as indicators of general water quality: A comparison with South Africa. *Water SA*, 30(3): 1-11.
- Department of Natural Science (2006). Wastewater characterization for evaluation of biological phosphorus removal. Available from www.dnr.state.wi.us/org/water/wm/water/wm/ww/biophos/intro.htm. Accessed 13/6/2006.
- Dickson, K. B. and Benneh, G. (1995). A New Geography of Ghana, 3rd Edition, Longman Group Ltd, Essex, England.
- DWAF (1996). South Africa Water Quality Guidelines for Domestic Use, 2nd edition, Pretoria, South Africa.
- Eckenfelder, W. W. and Grau, P (1992). Activated Sludge Process Design and Control: Theory and Practice, volume 1. Technomic Publishing Inc, Pennsylvania, USA.
- El-Bahri, L., Belguith, J. and Blouin, A. (1997). Toxicology of nitrates and nitrites in livestock. *Compendium on Continuing Education for the Practicing Veterinarian* 19: 643-649.
- Ensink, J. H. J., van der Hoek, W., Matsuno, Y., Munir, S. and Rizwan Aslam, M. (2002). Use of Untreated Wastewater in Peri-Urban Agriculture in Pakistan: Risks and Opportunities (Research Report No. 64). Colombo: International Water Management Institute.
- Environmental Canada (1997). Review of the impacts of municipal wastewater effluents on Canadian waters and human health. Ecosystem Science Directorate, Environmental Conservation Service, *Environmental Canada*, p. 25.

- Environmental Canada (2003). Environmental indicator series. Available from <http://www.ec.gc.ca/soer.ree>. (Accessed 12/12/2007).
- EPA (1994). The effluent guidelines for discharges into natural waters. Environmental Protection Agency Act 490. Ghana, pp. 1–14.
- EPA (1996). U.S. Environmental Protection Agency, American Society of Civil Engineers, and American Water Works Association. *Technology Transfer Handbook: Management of Water Treatment Plant Residuals*. EPA/625/R-95/008. Washington DC.
- EPA (2000). Nutrient criteria technical guidance manual-rivers and streams. EPA-822-B-00-002. Washington DC.
- Estrada, I.B., Aller, A., Aller, F., Gomez, X. and Moran, A. (2004). The survival of *Escheichia coli*. Faecal coliforms and enterobacteriaceae in general in soil treated with sludge from wastewater treatment plants. *Bioresour. Technol.* 93, 191-198.
- FAO (1992). Wastewater treatment and use in Agriculture. Pescod MB. Irrigation and Drainage Paper 47. *Food and Agricultural Organization* (FAO), Rome.
- FAO (2007). Wastewater characteristics and effluents quality parameters. Food and Agricultural Organization of the United Nations. Available at <http://www.fao.org/docrep/to55ie/to55ieo3.html>. (Accessed 06/04/2008).
- Farrell-Poe, K. (2000). Water Quality and Monitoring. Connecticut Department of Environmental Protection. Pp. 1-18. <https://cals.arizona.edu/abe/people/kitt-farrell-poe> (Accessed 11/9/2012).
- Feachem, R. G., Bradley, D. J., Garelick, H. and Mara, D. D. (1983). Sanitation and Disease - Health Aspects of Excreta and Wastewater Management. *John Wiley & Sons*, Chicester.
- Fipps, G. (2003). Irrigation water quality standards and salinity management strategies. Texas Agricultural Extension Service, *Texas A&M University System, College Station, TX* (USA). B-1667, 4-03, pp 1–19.
- Frances, S. 2008. Impacts of metals on aquatic ecosystems and human health. Available: <http://www.infomine.com/library/publications/docs/Mining.com/Apr2008c.pdf> Accessed: 20th April. 2016.
- Fraser, P. (1995). Nitrates: epidemiological evidence. IARC Scientific Publication 65: 183-202.
- Genuino, H. C., Luo, Z., Mazrui, N., Seraji, M. I. and Hoag, G. E. (2013). Green synthesized iron nanomaterials for oxidative catalysis of organic environmental pollutants. New and Future Developments in Catalysis, First edition Catalysis for Remediation and Environmental Concerns. *Elsevier*, pp. 41–61.

- GEPA (Ghana Environmental Protection Agency) (2004). Ghana Environmental Protection Agency Annual Report (pp. 1–96). Accra, Ghana: *Ghana Environmental Protection Agency*.
- Ghana Statistical Service (2002). 2000 Population and Housing Census; Summary Report of final results, Accra,
Ghana.<http://www.statsghana.gov.gh/nada/index.php/ddibrowser/3/export?format=pdf&generate=yes>(Accessed 09/05/2014).
- Ghana Statistical Services (2014). 2010 Population and Housing Census. District Analytical Report: Sagnarigu District.
http://www.statsghana.gov.gh/docfiles/2010_District_Report/Northern/Sagnarigu.pdf (Accessed 09/05/2014).
- Ghesquire, P. (1999). Indirect Wastewater reuses for Peri-Urban Irrigation in Kumasi, Ghana. Assessment of surface water quality for irrigation and its implications for human health. Thesis submitted in partial fulfilment of a Diploma in Water and Environment. ENGEES, Strasburg, France/ HR Wallingford, UK.
- Gibbs, P. A., Chambers, B. J., Chaudri, A.M., McGrath, S. P. and Carlton-Smith, C.H. (2006). Initial results from long-term studies at three sites on the effects of heavy metal amended liquid sludges on soil microbial activity. *Soil Use Manag.* 22:180-187
- Gleick, P. H. (2000). The worlds water 2000- 2001: the biennial report on freshwater resources. *Island press*, Washington DC, pp. 315
- Grabow, W. K., Very, A., Uys, M. and de Villiers, J. C. (1997). Evaluation of the application of bacteriophages as indicators of water quality. *South Africa Water Research Commission, Final Report* 540/1/98.
- Gray, F. N. (2002). *Water Technology: An Introduction for Environmental Scientists and Engineers. Butterworth-Heinemann. Oxford* pp. 35-80.
- Guerrant, R. L., Kirchhoff, L. V., Sields, D. S., Nations, M. K., Leslie, J., de Sousa, M. A., Araujo, J. G., Correia, L. L., Sauer, K. T., McClelland, K. E., Trowbridge, F. L. and Hughes, J. M. (1983). Prospective study of diarrhoeal illness in Northeastern Brazil: patterns of disease, nutritional impact, etiologies and risk factors. *J. Inf. Dis.*, 148, 986-997.
- Haiyan, W., & Stuanes, A. O. (2003). Heavy metal pollution in air-water-soil-plant. *Water Air Soil Pollut.*, 147, 79-107.<http://dx.doi.org/10.1023/A:1024522111341>
- Hamilton, A. J., Stagnitti, F., Xiong, X., Kreidl, S. L., Benke, K. K., & Maher, P. (2007). Reviews and Analyses Wastewater Irrigation: The State of Play. *Vadose Zone J.*, 6, 823-840. <http://dx.doi.org/10.2136/vzj2007.0026>
- Health Canada (1998). Protozoa in drinking water. *Guidelines for Canadian Drinking Water Quality*, p. 31.

- Hespanhol, I. and Prost, A.M.E. (1994). WHO guidelines and national standards for reuse and water quality. *Water Research* 28(1): 119-124.
- Hussein, I., Raschid, L., Hanyara, M. A., Marikar, F., and van der Heek, W. (2001). A framework for analyzing Socioeconomic, health and environmental impacts of wastewater use in agriculture in developing countries, working paper 26. Colombo: *International Water Management Institute*, Colombo, Sri Lanka.
- Hussein, H., Farag, S., Kandil, K. and Moawad, H. (2005). Tolerance and uptake of heavy metals by *Pseudomonads*. *Process Biochem.* 40: 955-961.
- ICMSF (1998). Potential application of risk assessment techniques to microbiological issues related to international trade in food and food products, International Commission on Microbiological Specification of Foods, *Journal of Food Protection*; 61(8), 1075-86.
- Idelovitch, E. and Ringskog, K. (1997). Wastewater treatment in Latin America: Old and new options, Washington, DC, World Bank, *Direction in Development Series*.
- Ingraham, J. L. and Ingraham, C. A. (1995). Introduction to Microbiology. *Wadworth Publishing Company*, Belmont, CA.
- ISSER (Institute of Statistical, Social and Economic Research) (2013). University of Ghana, Legon: The State of the Ghanaian Economy in 2000. June 2001. http://isser.edu.gh/images/Publication_files/Policies_and_Options_for_Ghanas_Economic_Development.pdf Accessed 9/10/2013.
- International Water Management Institute (IWMI) Report. (2002). Maximizing the benefits and reducing the risks of wastewater use in agriculture. *Future Harvest*. Accra, Ghana: IWMI.
- Jiménez, B. and Asano, T. (Eds.). 2008. Water reuse: an international survey of current practice, issues and needs. IWA Publishing. London.
- Kalyanaraman, S. B. and Geetha, G. (2005). Correlation analysis and prediction of characteristic parameters and water quality index of ground wat. *Pollut. Res.*, 24(1):1 97-2000
- Kashefi, M., Moshtaghi, M. and Hassani, A.H. (2014). Efficiency evaluation of electro coagulation process for removal of chromium (heavy metal) from municipal and industrial wastewater. *Indian journal of scientific research*, 7, 1258 – 1268.
- Keraita, B., Drechsel, P. and Amoah, P. (2003). Influence of urban wastewater on stream water quality and agriculture in and around Kumasi, Ghana. *Environment and Urbanization* 15(2), 171–178.
- Keraita, B., Danso, G. and Drechsel, P. (2003a). Irrigation methods and practices in urban agriculture in Ghana and Togo. *Urban Agric. Mag.* 10: 6-7.

- Keraita, B., Drechsel, P. and Amoah, P. (2003b). Influence of urban wastewater on stream water quality and agriculture in and around Kumasi, Ghana. *Environ. Urbanization* 15(2): 171-178
- Koger, S. M., Schettler, T., and Weiss, B. (2005). Environmental toxicants and developmental disabilities: A challenge for psychologists. *Am. Psychol.*, 60(3), 243-255. <http://dx.doi.org/10.1037/0003-066X.60.3.243>
- Kotoski, J. E. (1997). Phosphorus Minifact and Analysis Sheet. Black Earth Creek & Limnology: Minifact& Analysis Sheet. *Spring Harbor Environmental Magnet Middle School*. http://osse.ssec.wisc.edu/curriculum/earth/Minifact2_Phosphorus.pdf Accessed on 9/10/2014.
- Kris, M. (2007). Wastewater pollution in China. Available at <http://www.dbc.uci/wsustain/suscoasts/krismin.html>. (Accessed 16/06/2008).
- Lamprey, N. L. (2006). Urban Poverty reduction project launched. *Daily Graphic*; 1.
- Larsdotter, K. (2006). Microalgae for phosphorus removal from wastewater in a Nordic climate. A Doctoral Thesis from the School of Biotechnology, *Royal Institute of Technology, Stockholm, Sweden*, ISBN: 91-7178-288-5.
- Lever, M. (2010). Operator's guide to activated sludge bulking. 35th Annual Qld Water Industry Operations Workshop Community Sports Centre, CQ University, Rockhampton 22 to 24 June, 2010.
- Mahajan, S. V., Savita, K. and Shrivastava, S. V. (2005). A correlation and regression study. *Indian J. Environ. Protec* 25(3): 54-259.
- Mara, D. (1976). *Sewage Treatment in Hot Climates*. John Wiley and Sons.
- Mawdsley, J. L., Bardgett, R.D., Pan, B.F. and Theodorou, M.K. (1995). Pathogens in livestock waste, their potential for movement through soil and environmental pollution appl. *Soil Ecol.* 22, 1-15.
- Mazari-Hiriart, M., Pérez-Ortiz, G., Orta-Ledesma, M. T., Armas-Vargas, F. and Tapia M. A. (2014). Final opportunity to rehabilitate an urban river as a water source for Mexico City. *PLoS One*, 9 (7), p. e102081, 10.1371/ journal.pone.0102081
- Mensah, E., Amoah, P., Abaidoo, R. C. and Drechsel, P. (2001). Environmental concerns of (peri-) urban vegetable production – case studies from Kumasi and Accra. In: Drechsel P, Kunze D (eds.). *Waste Composting for Urban and Peri-urban Agriculture – Closing the Rural–Urban Nutrient Cycle in sub-Saharan Africa*. IWMI/FAO/CABI, Wallingford, UK, pp. 55-68.
- Metcalf, E. (2003). *Wastewater Engineering: Treatment and Reuse*. In: *Wastewater Engineering, Treatment, Disposal and Reuse*. Tchobanoglous G, Burton FL, Stensel HD (eds), *Tata McGraw Hill Publishing Company Limited*, 4th edition. New Delhi, India.

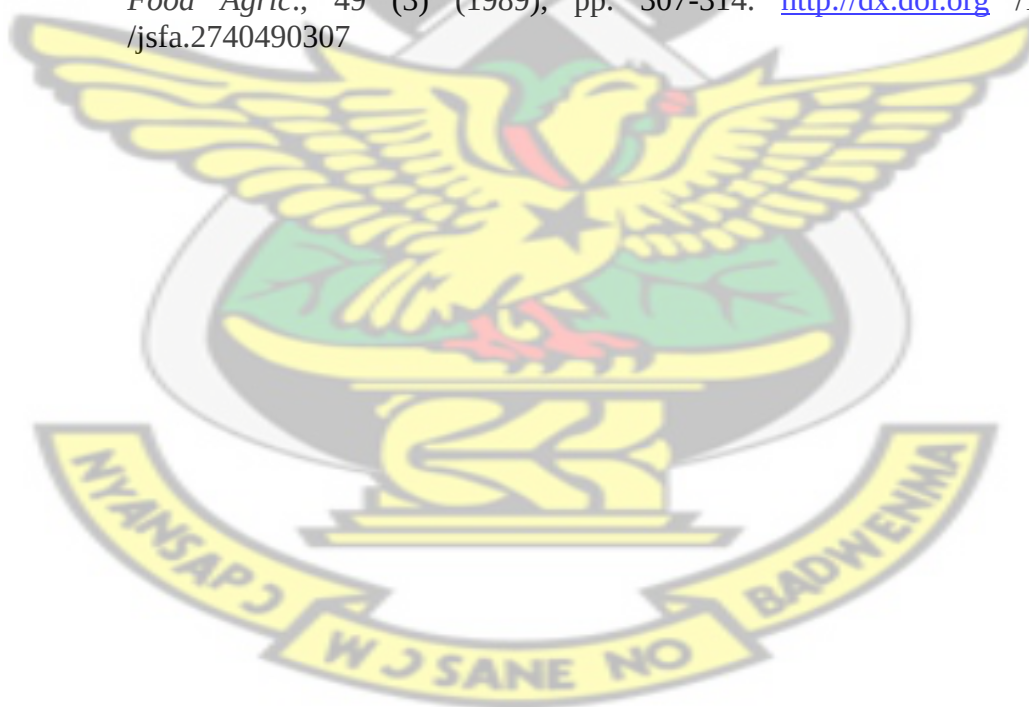
- Momba, M. N. B. and Mfenyana, C. (2005). Inadequate treatment of wastewater: A source of coliform bacteria in receiving surface water bodies in developing countries- Case Study: Eastern Cape Province of South Africa. In: *Water Encyclopedia- Domestic, Municipal and Industrial Water Supply and Waste Disposal*. Lehr JH, Keeley J (eds). *John Wiley & Sons Inc*, pp. 661-667.
- Musa, H. A., Shears, P. Kafi, S. and Elsabag, S. K. (1999). Water quality and public health in northern Sudan: A study of rural and urban peri-urban communities. *Journal of Applied Microbiology*, 87: 676-682.
- Nadzirah, Z., Nor Haslina, H. and Rafida, H. (2015). Removal of important parameter from car wash wastewater: A Review. *Applied mechanics and materials*, 773-774, 1153-1157.
- Nauman, M. and Khalid, S. K. (2010). Heavy Metals Contamination of Soils in Response to Wastewater Irrigation in Rawalpindi Region. *Pak. J. Agri. Sci.*, 47(3), 215-224. <http://www.pakjas.com.pk>
- Nicholson, F. A., Groves, S.J. and Chambers, B.J. (2005). Pathogens survival during livestock manure storage and following land application, *Bioresource Technology* 96, 135-143.
- Nor Haslina, H. and Nadzirah, Z. (2016). Pollutants characterisations of car wash waste water. *EDP Sciences*. [Dol:10.1051/mateconf/2016470508](https://doi.org/10.1051/mateconf/2016470508).
- Obiri-Danso, K., Weobong, C.A.A. and Jones, K. (2005). Aspects of health-related microbiology of the Subin, an urban river in Kumasi, Ghana. *J. Water Health* 3(1): 69-76.
- Obuobie, E., Keraita, B., Danso, G., Amoah, P., Olufunke, O.C., Raschid-Sally, L and Drechsel, P. (2006). Irrigated Urban Vegetable production in Ghana. Characteristics, Benefits and Risks. *IWMI-RUAF-CPWF*, Accra, Ghana: IWMI.
- Ogden, I.D., Fenlon, D.R., Vinten, A.J.A. and Lewis, D. (2001). The fate of *Escherichia coli* 0157 in soil and its potential to contaminate drinking water. *Int. J. Food Microbiol*, 66, 111-117.
- Oknich, J. (2002). The perceived environmental impact of car washing. Ramsey-Washington Metro Watershed District <http://sharepoint.snoqualmie.k12.wa.us/ckms/spiesse/Lists/Announcements/Attachments/43/carwash.pdf>. (Accessed: 31 October 2013).
- Okoh, A. T., Odjadjare, E. E., Igbinsosa, E. O. and Osode, A. N. (2007). Wastewater treatment plants as a source of microbial pathogens in receiving water sheds. *Afr. J. Biotechnol.* 6(25): 2932-2944
- O'Sullivan, A., Smalley, D. and Good, J. (2011). Quantifying the impact of car washing on water quality and assessing simple treatment strategies. Christchurch, New Zealand.

- Oyelude, E. O., Densu, A. E. And Y. E. (2013). Quality of groundwater in Kassena-Nankana district, Ghana and its health implication. *Adv. Appl. Sci. Res.*; 4(4):442-448
- Paillard, D., Dubois, V., Thiebaut, R., Nathier, F., Hogland, E., Caumette, P. and Quentine, C. (2005). Occurrence of *Listeria* spp. In effluents of French urban wastewater treatment plants. *Appl. Environ. Microbiol.* 71(11): 7562-7566.
- Pak, D. and Chang, W. (2000). Factors affecting phosphorus removal in two biofilter system treating wastewater from car-washing facility. *Water Science and Technology*, 41(4-5): 487-492.
- PAHO (2005). Report on the Regional Evaluation of Municipal Solid Waste Management Services in Latin America and the Caribbean. Pan American Health Organization. Available at: http://www.cepis.ops-oms.org/residuos_solidos/evaluacion/i/index.html#Scene_1 (Accessed November 2012).
- Palese, A. M., Pasquale, V., Celano, G., Figliuolo, G., Masi, S. and Xiloyannis, C. (2009). Irrigation of olive groves in Southern Italy with treated municipal wastewater: effects on microbiological quality of soil and fruits. *Agric Ecosyst Environ.*;129(1-3):43-51.
- Patil, P. N., Savant, D. V. and Deshmukh, R. N. (2012). Physico-Chemical parameters for testing of water-A review. *Int. J. Environ Sci.* 3(3): 1194-1207.
- Pautshwa, M. J., van der Walt, A. M., Cilliers, S. S. and Bezuidenhout, C. C. (2009). Investigation of faecal pollution and occurrence of antibiotic resistant bacteria in the Mooi river system as a function of a changed environment. www.ewisa.co.za/literature/files/2008_137.pdf. Accessed 13 August 2009
- Payment, P. and Franco, E. (1993). *Clostridium perfringens* and somatic coliphages as indicators of the efficiency of drinking water treatment for viruses and protozoan cysts. *Appl. Environ. Microbiol.* 59, 2418-2424.
- Pescod, M. D. (1992). Wastewater treatment and use in agriculture. FAO Irrigation and Drainage Paper no. 47, *Food and Agriculture Organization of the United Nations*, Rome, Italy, p. 125.
- Pescod, M. B., and Arar, A. (1985). Treatment and use of sewage effluent for Irrigation. *Proceedings of the FAO regional seminar on the treatment and use of sewage effluent for irrigation held in Nicosia, Cyprus*, (FAO, 1985).
- Pourcher, A., Picard-Bonnaud, F., Ferre, V., Gosinska, A., Stan, V. and Moguedet, G. (2007). Survival of faecal indicators and enteroviruses in soil after land-spreading of municipal sewage sludge, *Appl. Soil Ecol.* 35, 473-479.
- Raschid-Sally, L. and Jayakody, P. (2008). Drivers and characteristics of wastewater agriculture in developing countries: results from a global assessment. *IWMI*, Colombo, Sri Lanka.

- Rose, D. G. (1999). Community based technologies for domestic wastewater treatment and reuse: options for urban agriculture. Report 27, CFP Report series.
- Runion, R. (2008). Factors to consider in wastewater-2. Ezine Articles (April 14). Available at <http://ezinearticles.com/?factors-ToConsider-Wastewater--2&id=1108477>. Accessed 09/05/2013.
- Sarkinnoma, A. Yarkasuwa, I. C. and Modu, K. A. (2013). Analysis of Physicochemical Parameters of Sewage Water used for Irrigation in Bauchi Metropolis – Nigeria. *Journal of Environment and Earth Science*; 3:10, 37-40.
- Scott, C.A., Faruqui, N.I. and Raschid-Sally, L. (2004). Wastewater use in irrigated agriculture: Management challenges in developing countries. In: Scott, C.A., N.I. Faruqui, and L. Raschid Sally (eds.) *Wastewater Use in Irrigated Agriculture: Confronting the Livelihoods and Environmental Realities*. UK. CABI Publishing.
- Sharma, R. K., Agrawal, M. and Marshall, F. (2007) 'Heavy metal contamination of soil and vegetables in suburban areas of Varanasi, India'. *Ecotoxicology and Environmental Safety*, vol 66, pp258–66
- Shende, G. B. (1985). Status of wastewater treatment and agricultural reuse with special reference to Indian experience and research and development needs. In: Pescod, M. S., Arar, A., eds. *Treatment and use of sewage effluent for irrigation*. London, Butterworths, pp. 185–209.
- Smith, D. J. and Shilley, H. (2009). Residential car wash water monitoring study. City of Federal Way. Washington: Public Works, Surface Water Management.
- Sou, M., Yacouba, H. and Mermoud, A. (2011). Fertilising value and health risks assessment related to wastewater reuse in irrigation, case study in a Soudano-Sahelian city. Ouagadougou. *Journées Scientifiques du*. 21E 6: 4-8.
- Speijers, G. J. A. (1996). Nitrate in Toxicological evaluation of certain food additive and contaminations in food. *WHO Food Additives Series 35*, Geneva, pp. 325-360.
- Sperling, M. (2007). Waste stabilisation ponds. Biological wastewater treatment series. Volume 3. IWA Publishing.
- Stagnitti, F., Sherwood, J., Allinson, G., Evans, L., Allison, M., Li, L., & Philips, I. (1998). An Investigation of localized soil heterogeneities on solute transport using a multi segment percolation system. *New Zealand J. Agric. Res.*, 41, 603-612. <http://dx.doi.org/10.1080/00288233.1998.9513344>
- Stagnitti, F. (1999). A model of the effects of non-uniform soil-water distribution on the sub-surface migration of bacteria: Implications for land disposal of sewage. *Math Computer Mod.*, 29, 41-52. [http://dx.doi.org/10.1016/S0895-7177\(99\)00038-2](http://dx.doi.org/10.1016/S0895-7177(99)00038-2)

- Stahl, Y., Wink, R.H., Ingram, G.C. and Simon, R. (2009) A signaling module controlling the stem cell niche in Arabidopsis root meristem. *Curr. Biol.* 19, 909–914.
- Sunitha, V., Sudharshan, V., Rajeshwara and Reddy, B. (2005). Hydro-geochemistry of ground water. Gooty area, Anantapur district, Andhra Pradesh, India *Poll. Res.*, 24 (1): 217-224
- Todorovi, Z., Pol, P., Dgordjevi, D. and Autoni, J. S. (2001). Lead Distribution in Water and its Association with Sediments Constituents of the Baije Lake. *J. Serb.Chem. Soc.* 66(1), pp697-708.
- Toze, S. (1997): Microbial pathogens in wastewater. Literature review for urban water systems. Multi-divisional research program, CSIRO, Land and Water. *Technical Report*, 1/97. UNEP/GRID-Arendal, 2000.
- UN (2013). World Economic and social survey 2013: Sustainable Development challenges: Department of economic and social office.
- Veenhuizen, R. van, Cofie, O., Martin, A., Jianming, C., Merzthal, G. and Verhagen, J. (2007) 'Multiple sources of water for multifunctional urban agriculture. *2nd SWITCH Scientific Meeting*', SWITCH, Delft, The Netherlands.
- Veenstra, I. S and Polprasert. C. (2000). Sustainable wastewater treatment 1: Natural treatment systems. (Lecture notes), IHE Delft, The Netherlands.
- Wajahat, N., Sajida, P. and Syed A. (2006). Shah Evaluation of Irrigation Water for Heavy Metals of Akbarpura Area. *Journal of Agricultural and Biological Science*. 1(1). www.arpnjournals.com
- Ward-Paige, C. A., Risk, M. J. and Sherwood, O. A. (2005a). Reconstruction of nitrogen sources on coral reefs: $\delta^{15}\text{N}$ and $\delta^{13}\text{C}$ in gorgonians from Florida Reef Tract. *Mar. Ecol. Prog. Ser.* 296: 155-163.
- Ward-Paige, C. A., Risk, M. J., Sherwood, O. A. and Jaap, W. C. (2005b). Clionid sponge surveys on the Florida Reef Tract suggest land-based nutrient inputs. *Mar. Pollut. Bull.* 51: 570-570.
- Water Environment Federation (1996). Operation of Municipal Wastewater Treatment Plant: Manual of Practice, 5th edn vol. 2. *Alexandria*.
- Weiss, B. (2000). Vulnerability of children and the developing brain to neurotoxic hazards. *Env. Health Perspect.*, 108(3), 375-381. <http://dx.doi.org/10.1289/ehp.00108s3375>
- Wescott, D. W. (1997). Quality control of wastewater for irrigated crop production. (*Water Reports – 10*). Food and Agriculture Organization of the United Nations, Rome.
- WHO (1989). Health guidelines for the use of wastewater in agriculture and aquaculture: Report of a WHO Scientific Group. *WHO Technical Report Series 778*. World Health Organization, Geneva. 74 p.

- WHO (1997). Pesticide residues in food: 1997 evaluations. *WHO Expert Group on Pesticide Residues*, Geneva, 6-15 December 1997.
- WHO (2010). Guidelines for the safe use of wastewater, excreta and greywater. Volume 2: Wastewater use in agriculture.
- WHO (2006). Guidelines of the Safe Use of Wastewater, Excreta and Greywater: Wastewater Use in Agriculture, Vol. 2. *World Health Organization*, Geneva, Switzerland.
- WHO (2007). Levels of Protection. Geneva: World Health Organization – Available at http://www.who.int/water_sanitation_health/gdwqrevision/levelsofprotection/en/index.html.
- WHO, UNICEF and WSSCC (2000). Global Water Supply and Sanitation Assessment R 2000, United States.
- WORLD BANK (2013). Introduction to wastewater treatment processes. Infrastructure and menu of technical options. <http://water.worldbank.org/shw-resource-guide/infrastructure/menu-technical-options/wastewater-treatment>
- Zurera-Cosano, G., Moreno-Rojas, R., Salmeron-Egea, J. and Lora, R. P. (1989). Heavy metal uptake from greenhouse border soils for edible vegetables *J. Sci. Food Agric.*, 49 (3) (1989), pp. 307-314. <http://dx.doi.org/10.1002/jsfa.2740490307>



APPENDICES

APPENDIX I

Results from analysis of Microbial parameters of wastewater used for irrigation of vegetables eaten raw during dry season irrigation along the Tamale old water works

Appendix II: Sampling of Wastewater for Microbial analysis (TWWS) in the month of December 2013

Parameter	WWU	GMS1	NMS2	TKDS
Total Coliform	219000	4000	194000	16000
Faecal Coliform	27000	0	23000	1000
<i>E.coli</i>	12000	0	8000	0
<i>Staphylococci</i>	194000	17000	0	1000
<i>Enterococci</i>	0	0	12000	997
<i>Clostridium</i>	0	0	0	0
<i>Pseudomonas</i>	142000	19000	291000	12000
Total Heterotrophic Bacteria	1458000	1120000	388000	972000

Appendix III: Sampling of Wastewater for Microbial analysis (cfu/100) in the month of January 2013

Parameter	WWU	GMS1	NMS2	TKDS
Total Coliform	383000	44000	387000	378000
Faecal Coliform	0	13000	79000	84000
<i>E.coli</i>	0	0	0	2000
<i>Staphylococci</i>	57000	6000	0	13000
<i>Enterococci</i>	0	0	16000	1000
<i>Clostridium</i>	0	0	0	0
<i>Pseudomonas</i>	213000	79000	277000	116000
Total Heterotrophic Bacteria	72	151	105	1458

Appendix IV: Sampling of Wastewater for Microbial analysis (TWWS) in the month of February 2013

Parameter	WWU	GMS1	NMS2	TKDS
Total Coliform	105000	11000	391000	194000
Faecal Coliform	8000	0	103000	46000
<i>E.coli</i>	6000	0	68000	3000
<i>Staphylococci</i>	155000	2000	16000	28000
<i>Enterococci</i>	1000	1000	96000	18000
<i>Clostridium</i>	0	0	0	0
<i>Pseudomonas</i>	245000	11000	217000	49000
Total Heterotrophic Bacteria	176	432	243	432

APPENDIX V: Results from analysis of physicochemical parameters of wastewater used for irrigation of vegetables eaten raw during dry season irrigation along the Tamale old water works

Appendix VI: Sampling of Wastewater for Physicochemical Analysis (TWWS) in the month of December 2013

Parameter	WWU	GMS1	NMS2	TKDS
Temperature (°C)	23.7	23.1	21.4	22.1
pH	7.1	6.7	7.53	7.39
Colour (Hazen)	2.8	9.5	54.4	28.7
Turbidity (NTU)	7	16	108	57
Conductivity (µS/cm)	112.9	436	1,348.00	1,097
Total Dissolved solids, (TDS) (mg/L)	564.5	218	676	549.1
Total Suspended Solid, (TSS) (mg/L)	9	7	20	57
Total Alkalinity (CaCO₃) (mg/L)	109	69	436	159
Total Hardness (CaCO₃) (mg/L)	43	26	178	73
Calcium Hardness (CaCO₃) (mg/L)	36	24	70	64
Magnesium Hardness (MgCO₃) (mg/L)	7	2	108	11
Carbonate Alkalinity (CO₃²⁻) (mg/L)	102	20	48	68
Bicarbonate Alkalinity (HCO₃²⁻) (mg/L)	7	20	388	91
Calcium (mg/L)	14.4	9.6	28	2.673
Magnesium (mg/L)	1.701	0.486	26.244	0.486
Chloride (mg/L)	123	35	330	358
Fluoride (mg/L)	0.02	0	0.36	0.28
Sulphate (mg/L)	81.7	46.7	36.7	15
Sulphide (mg/L)	0.034	0.018	0.172	0.034
Phosphate (mg/L)	0.77	0.52	5.06	1.66
Ammonia – Nitrogen (mg/L)	0.96	0.53	34.4	14.2
Nitrate – Nitrogen (mg/L)	2.5	2.25	0	0.25
Nitrite – Nitrogen (mg/L)	0.016	0.015	0.001	0.001
Aluminium (mg/L)	0.024	0.033	0.047	0.038
Iron (Total) (mg/L)	0.53	0.86	1.29	1.55
Manganese (mg/L)	0.659	0.207	0.36	0.232
Copper (mg/L)	1.51	0.03	0.08	0
Zinc (mg/L)	0	0	0.03	0
Cyanide (mg/L)	0.013	0.006	0.004	0.009
Chromium(Total) (mg/L)	0.04	0.02	0.01	0.06
Potassium (mg/L)	6.8	6.1	79.4	79

**Appendix VII: Sampling of Wastewater for Physicochemical analysis (TWWS)
in the month of January 2013**

Parameter	WWU	GMS1	NMS2	TKDS
Temperature (°C)	19.4	19.2	19	19
pH	6.5	6.3	7.2	7.3
Colour (Hazen)	7.4	4	5.5	26
Turbidity (NTU)	6.13	7.86	12.2	9.07
Conductivity (µS/cm)	195.5	1,587.00	1,410.00	1,579.00
Total Dissolved solids, (TDS) (mg/L)	97.8	798	711	799
Total Suspended Solid, (TSS) (mg/L)	10	7	96	20
Total Alkalinity (CaCO₃) (mg/L)	53	47	455	539
Total Hardness (CaCO₃) (mg/L)	41	28	150	98
Calcium Hardness (CaCO₃) (mg/L)	30	27	82	76
Magnesium Hardness (MgCO₃) (mg/L)	9	1	68	22
Carbonate Alkalinity (CO₃²⁻) (mg/L)	18	16	170	86
Bicarbonate Alkalinity (HCO₃²⁻) (mg/L)	35	31	285	451
Calcium (mg/L)	12	10.8	32.8	30.4
Magnesium (mg/L)	2.187	6.561	16.524	18.486
Chloride (mg/L)	25	31	316	350
Fluoride (mg/L)	0.07	0	0.18	0.32
Sulphate (mg/L)	45	25.6	33.3	10
Sulphide (mg/L)	0.011	0.058	0.668	0.094
Phosphate (mg/L)	0.69	0.52	9.3	0.87
Ammonia – Nitrogen (mg/L)	0.39	0.84	47.8	40.7
Nitrate – Nitrogen (mg/L)	2	2.75	3.75	2
Nitrite – Nitrogen (mg/L)	0.002	0.01	0.014	0.005
Aluminium (mg/L)	0.023	0.004	0.095	0
Iron (Total) (mg/L)	0.56	0.39	1.65	1.52
Manganese (mg/L)	0	0	0.128	0.023
Copper (mg/L)	0.06	0.08	0.21	0.1
Zinc (mg/L)	0.1	0.13	0	0.06
Cyanide (mg/L)	0.015	0.004	0.014	0.009
Chromium (Total) (mg/L)	0.03	0	0	0.02
Potassium (mg/L)	5.7	5.1	81.5	76

Appendix VIII: Sampling of Wastewater for Physicochemical analysis (TWWS) in the month of February 2013

Parameter	WWU	GMS1	NMS2	TKDS
Temperature (°C)	14.9	13.9	14.3	14.2
pH	6.9	6.9	7.3	7.4
Colour (Hazen)	5.3	9.3	67	37
Turbidity (NTU)	5.52	11.4	35.9	33.9
Conductivity (µS/cm)	464	462	1,920.00	1,936.00
Total Dissolved solids, (TDS) (mg/L)	232	231	960	968
Total Suspended Solid, (TSS) (mg/L)	8	9	60	62
Total Alkalinity (CaCO₃) (mg/L)	40	24	654	611
Total Hardness (CaCO₃) (mg/L)	25	22	278	100
Calcium Hardness (CaCO₃) (mg/L)	21	20	120	75
Magnesium Hardness (MgCO₃) (mg/L)	4	2	158	25
Carbonate Alkalinity (CO₃²⁻) (mg/L)	14	18	96	118
Bicarbonate Alkalinity (HCO₃²⁻) (mg/L)	26	6	558	493
Calcium (mg/L)	8.4	8	48	30
Magnesium (mg/L)	0.972	0.486	38.394	6.075
Chloride (mg/L)	22	21	449	437
Fluoride (mg/L)	0	0	0	0
Sulphate (mg/L)	45	47.7	20	36.7
Sulphide (mg/L)	0.159	0.082	0.792	0.316
Phosphate (mg/L)	1.15	0.61	7.4	1.88
Ammonia – Nitrogen (mg/L)	9.72	3.61	89.72	99.44
Nitrate – Nitrogen (mg/L)	2.25	0.75	10.5	4
Nitrite – Nitrogen (mg/L)	0.022	0.003	0.016	0.009
Aluminium (mg/L)	0.005	0.019	0.043	0.063
Iron (Total) (mg/L)	0.46	0.4	1.97	1.53
Manganese (mg/L)	0	0	0.407	0.63
Copper (mg/L)	0.02	0.05	0.1	0.16
Zinc (mg/L)	0.03	0	0	0
Cyanide (mg/L)	0.349	0.122	0.029	0.011
Chromium(Total) (mg/L)	0.06	0.01	0.01	0
Potassium (mg/L)	4.9	4.9	104.5	61

APPENDIX IX: Results from analysis of Microbial parameters of wastewater used for irrigation of vegetables eaten raw during rainy season irrigation along the Tamale old water works

Appendix IX: Sampling of Wastewater for Microbial analysis (TWWS) in the month of March 2013

Parameter	WWU	GMS1	NMS2	TKDS
Total Coliform	2100000	293000	30600000	38900000
Faecal Coliform	0	0	12400000	2100000
<i>E.coli</i>	0	0	8600000	600000
<i>Staphylococci</i>	0	1800000	2300000	1700000
<i>Enterococci</i>	0	0	6300000	500000
<i>Clostridium</i>	0	0	0	0
<i>Pseudomonas</i>	28100000	4000000	38700000	100000
Total Heterotrophic Bacteria	58	386	139	97

Appendix X: Sampling of Wastewater for Microbial analysis (TWWS) in the month of April 2013

Parameter	WWU	GMS1	NMS2	TKDS
Total Coliform (CFU/100ml)	3900000	38300000	48700000	28800000
Faecal Coliform (CFU/100ml)	1200000	1600000	4400000	2800000
<i>E.coli</i> (CFU/100ml)	100000	200000	3200000	500000
<i>Staphylococci</i> (CFU/100ml)	2100000	2600000	2300000	3100000
<i>Enterococci</i> (CFU/100ml)	300000	400000	1100000	700000
<i>Clostridium</i> (CFU/1ml)	0	0	0	0
<i>Pseudomonas</i> (CFU/100ml)	1000000	500000	1600000	1300000
Total Heterotrophic Bacteria (CFU/1ml)	718	429	966	566

Appendix XI: Sampling of Wastewater for Microbial analysis (TWWS) in the month of May 2013

Parameter	WWU	GMS1	NMS2	TKDS
Total Coliform (CFU/100ml)	58000000	48500000	77600000	39500000
Faecal Coliform (CFU/100ml)	19600000	100000	37900000	0
<i>E.coli</i> (CFU/100ml)	800000	0	19100000	0
<i>Staphylococci</i> (CFU/100ml)	0	0	600000	0
<i>Enterococci</i> (CFU/100ml)	100000	100000	900000	0
<i>Clostridium</i> (CFU/1ml)	0	0	0	0
<i>Pseudomonas</i> (CFU/100ml)	0	0	2600000	0
Total Heterotrophic Bacteria(CFU/1ml)	668	408	788	625

APPENDIX XII: Results from analysis of physicochemical parameters of wastewater used for irrigation of vegetables eaten raw during Rainy season irrigation along the Tamale old water works

Appendix XIII: Sampling of Wastewater for Physicochemical analysis (TWWS) in the month of March 2013

Parameter	WWU	GMS1	NMS2	TKDS
Temperature (°C)	26.7	26.7	27.3	26.6
pH	6.3	6.4	7.3	7.9
Colour (Hazen)	10.5	8.3	94	51.9
Turbidity (NTU)	6.86	6.49	45.5	43.4
Conductivity (µS/cm)	152.1	1,305.00	1,522.00	1,766.00
Total Dissolved solids, (TDS) (mg/L)	76	652.5	761	883
Total Suspended Solid, (TSS) (mg/L)	27	47	237	164
Total Alkalinity (CaCO ₃) (mg/L)	64	41	582	621
Total Hardness (CaCO ₃) (mg/L)	22	21	408	78
Calcium Hardness (CaCO ₃) (mg/L)	20	19	65	70
Magnesium Hardness (MgCO ₃) (mg/L)	2	2	343	8
Carbonate Alkalinity (CO ₃ ²⁻) (mg/L)	18	22	112	100
Bicarbonate Alkalinity (HCO ₃ ²⁻) (mg/L)	46	30	470	521
Calcium (mg/L)	8	7.6	26	28
Magnesium (mg/L)	0.486	0.486	83.349	1.944
Chloride (mg/L)	16	15	324	443
Fluoride (mg/L)	0	0	0	0
Sulphate (mg/L)	41.7	38.3	11.7	33.3
Sulphide (mg/L)	0.027	0	3.72	0.365
Phosphate (mg/L)	9.11	12.1	41.1	23.56
Ammonia – Nitrogen (mg/L)	0.18	19.33	12.5	16.67
Nitrate – Nitrogen (mg/L)	3.75	2	19.25	7.5
Nitrite – Nitrogen (mg/L)	0.01	0.003	0.041	0.028
Aluminium (mg/L)	0.057	0	0.014	0.63
Iron (Total) (mg/L)	0.38	0.52	2.37	0.97
Manganese (mg/L)	0.007	0.006	0.49	0.474
Copper (mg/L)	0.15	0.22	0.02	0.46
Zinc (mg/L)	0.04	0.13	0	0
Cyanide (mg/L)	0.006	0.302	0.021	0.004
Chromium(Total) (mg/L)	0.06	0	0	0.01
Potassium (mg/L)	7.3	5.9	37.1	48.3

Appendix XIV: Sampling of Wastewater for Physicochemical analysis (TWWS) in the month of April 2013

Parameter	WWU	GMS1	NMS2	TKDS
Temperature (°C)	31.9	30.5	32.3	32.7
pH	7.1	6.9	7.1	7.2
Colour (Hazen)	131	47.1	52.2	84.8
Turbidity (NTU)	228	91	101	162
Conductivity (µS/cm)	231	465	1,018.00	753
Total Dissolved solids, (TDS) (mg/L)	115.5	232	509	376
Total Suspended Solid, (TSS) (mg/L)	48	19	99	113
Total Alkalinity (CaCO₃) (mg/L)	161	104	500	183
Total Hardness (CaCO₃) (mg/L)	37	20	313	100
Calcium Hardness (CaCO₃) (mg/L)	28	15	52	35
Magnesium Hardness (MgCO₃) (mg/L)	9	5	261	65
Carbonate Alkalinity (CO₃²⁻) (mg/L)	34	32	32	40
Bicarbonate Alkalinity (HCO₃²⁻) (mg/L)	127	72	468	148
Calcium (mg/L)	11.2	6	20.8	14
Magnesium (mg/L)	2.187	1.215	63.423	15.795
Chloride (mg/L)	120	50	234	147
Fluoride (mg/L)	0	0	0	0
Sulphate (mg/L)	68.3	36.66	5	63.33
Sulphide (mg/L)	0.26	0.107	0.182	0.321
Phosphate (mg/L)	18.43	7.74	29.28	8.24
Ammonia – Nitrogen (mg/L)	30.38	7.72	19.5	5.27
Nitrate – Nitrogen (mg/L)	1.5	1.75	0	18.5
Nitrite – Nitrogen (mg/L)	0.007	0.003	0	0.043
Aluminium (mg/L)	0.014	0.086	0.107	0
Iron (Total) (mg/L)	3.4	2.02	2.13	4.39
Manganese (mg/L)	0.104	0.056	0.603	0.577
Copper (mg/L)	0.17	0.05	0	0.51
Zinc (mg/L)	0.13	0	0.04	0.09
Cyanide (mg/L)	0.34	0.201	0.033	0.008
Chromium(Total) (mg/L)	0	0	0	0
Potassium (mg/L)	26.7	13.1	34	24.9

Appendix XV: Sampling of Wastewater for Physicochemical analysis (TWWS) in the month of May 2013

Parameter	WWU	GMS1	NMS2	TKDS
Temperature (°C)	18.6	17.5	15.7	17.7
pH	7	6.7	7.5	7.3
Colour (Hazen)	49.5	8.6	51.8	15
Turbidity (NTU)	96	22	99	31
Conductivity (µS/cm)	623	455	1,485.00	1,097.00
Total Dissolved solids, (TDS) (mg/L)	296.5	212	727	533
Total Suspended Solid, (TSS) (mg/L)	16	4	17	8
Total Alkalinity (CaCO ₃) (mg/L)	196	85	461	322
Total Hardness (CaCO ₃) (mg/L)	30	19	53	68
Calcium Hardness (CaCO ₃) (mg/L)	24	17	42	52
Magnesium Hardness (MgCO ₃) (mg/L)	6	2	11	16
Carbonate Alkalinity (CO ₃ ²⁻) (mg/L)	20	30	56	36
Bicarbonate Alkalinity (HCO ₃ ²⁻) (mg/L)	176	55	405	286
Calcium (mg/L)	9.6	6.8	16.8	20.8
Magnesium (mg/L)	1.458	0.486	2.673	3.888
Chloride (mg/L)	315	29	423	315
Fluoride (mg/L)	0	0	0	0
Sulphate (mg/L)	18.33	38.33	26.67	11.66
Sulphide (mg/L)	0.033	0.052	0.06	0.084
Phosphate (mg/L)	0.89	1.28	4.08	1.42
Ammonia – Nitrogen (mg/L)	30.38	0.67	17.94	8
Nitrate – Nitrogen (mg/L)	0	0	3.25	1.75
Nitrite – Nitrogen (mg/L)	0.007	0.003	0.012	0.529
Aluminium (mg/L)	0.104	0.036	0.08	0.078
Iron (Total) (mg/L)	2.08	0.53	1.25	0.16
Manganese (mg/L)	0.054	0.033	0.014	0
Copper (mg/L)	0.16	0	0	0.05
Zinc (mg/L)	0	0	0	0.01
Cyanide (mg/L)	0	0.06	0.004	0.001
Chromium(Total) (mg/L)	0.05	0.01	0	0
Potassium (mg/L)	20	30	75	5

APPENDIX XVI: Ghana and WHO guidelines on Microbial parameters for drinking and irrigation water used for irrigation of vegetables eaten raw

Parameter	Ghana Irrigation guidelines	WHO Irrigation guidelines
Total Coliform (CFU/100ml)	0	0
Faecal Coliform (CFU/100ml)	0	0
<i>E.coli</i> (CFU/100ml)	0	0
<i>Staphylococci</i> (CFU/100ml)	0	0
<i>Enterococci</i> (CFU/100ml)	0	0
<i>Clostridium</i> (CFU/1ml)	0	0
<i>Pseudomonas</i> (CFU/100ml)	0	0
Total Heterotrophic Bacteria (CFU/1ml)	500	500

APPENDIX XVII: Ghana guidelines on physicochemical parameters for drinking and irrigation water used for irrigation of vegetables eaten raw

Parameter	Unit	Ghana Guidelines for drinking	Ghana Guidelines for irrigation water
Temperature	°C	NO SV	NO SV
pH	-	6.50 – 8.50	6.5 – 8.4
Colour	HU	5.00	NO SV
Turbidity	NTU	5.00	1000.00
Conductivity	µS/cm	1,400.00	≤300.00
Total Dissolved Solids	mg/L	1000.00	≤200.00
Total Suspended Solids	mg/L	1000.00	NO SV
Alkalinity	mg/L	NO SV	850.00
Total Hardness	mg/L	500.00	850.00
Calcium Hardness	mg/L	NO SV	NO SV
Bicarbonate (as mg/L HCO ₃)	mg/L	NO SV	NO SV
Carbonate (as mg/L CO ₃ ⁻)	mg/L	NO SV	NO SV
Calcium	mg/L	NO SV	50.00
Magnesium	mg/L	NO SV	40.00
Nitrate (NO ₃ -N)	mg/L	50.00	NO SV
Nitrite (NO ₂ -N)	mg/L	3.00	≤30.00
Ammonia (NH ₃ -N)	mg/L	1.50	NO SV
Chloride	mg/L	250.00	≤50.00
Fluoride	mg/L	1.50	NO SV
Sulphate	mg/L	250.00	10.00
Aluminium	mg/L	0.2	NO SV
Cyanides	mg/L	0.100	NO SV
Total Chromium	mg/L	0.05	NO SV
Potassium	mg/L	30.00	40.0
Sodium	Mg/L	200.00	90.0
Zinc	Mg/L	3.00	NO SV
Total Iron	mg/L	0.30	50.0
Manganese	mg/L	0.10	NO SV
Silica	Mg/L	NO SV	100.00
Phosphate	mg/L	NO SV	10.0
Copper	Mg/L	NOSV	2mg/L
Total Coliform Bacteria	cfu/100ml	0	0
Faecal Coliform (MPN/100ml)	Count/100ml	0	0
<i>E. coli</i>	Count/100ml	0	0

NOTE: NO SV means, No Standard Value set

APPENDIX XVIII: Mean of Microbial and Physicochemical parameters for dry and rainy season irrigation

APPENDIX XIX: Means of Microbial Parameters for Dry season wastewater irrigation

Parameter	GMS 1	NMS 2	TKDS	WWU	MM	LSD	CV %
Total Coliform (CFU/100ml)	19667.00b	324000.00a	196000.00ab	235667.00ab	193833	*	65.98
Faecal Coliform (CFU/100ml)	4333.00b	68333.00a	43667.00ab	11667.00ab	32000	*	94.53
<i>E.coli</i> (CFU/100ml)	0.00a	25333.00a	1667.00a	6000.00a	8250	NS	228.35
<i>Staphylococci</i> (CFU/100ml)	8333.00b	5333.00b	14000.00b	135333.00a	40750	*	89.42
<i>Enterococci</i> (CFU/100ml)	333.00a	413330.00a	6666.00a	333.00a	12166.4	NS	198.9
<i>Pseudomonas</i> (CFU/100ml)	36333.00b	261667.00a	59000.00b	200000.00a	139250	**	33.07
Total Heterotrophic Bacteria (CFU/1ml)	373528.00a	129449.00a	324630.00a	486083.00a	328422	NS	185.88

GMS1; NMS2;TKDS;WWU;MM; Mean of means, LSD; least significance difference, CV %; Coefficient of variation, *; Significant difference at 0.05, **; Highly significant difference at 0.05, NS; No significant difference at 0.05, Columns with the same alphabet are not different.

**APPENDIX XX: Means of Physicochemical Parameters for Dry season
wastewater irrigation**

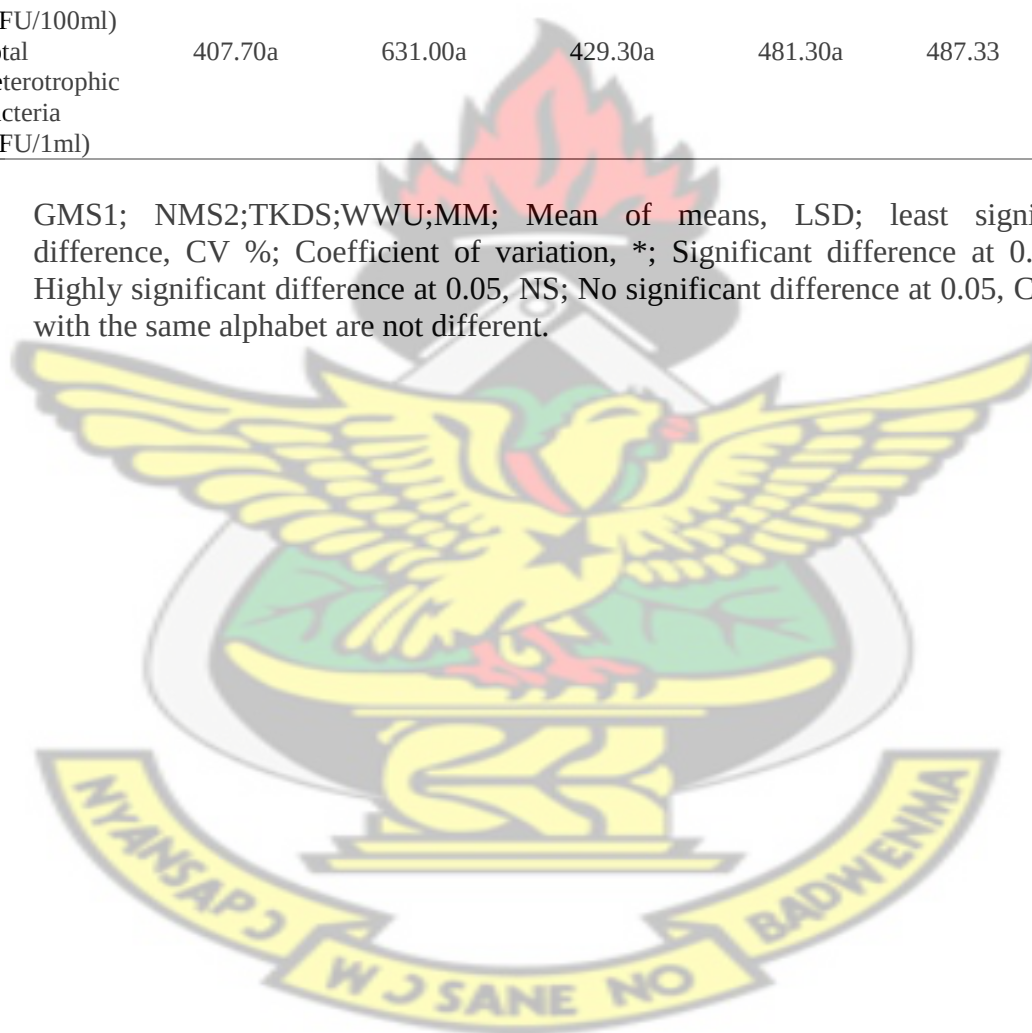
Parameter	GMS 1	NMS 2	TKDS	WWU	MM	LSD	CV %
Temperature (°C)	18.73a	18.23a	18.43a	19.33a	18.68	NS	22.32
Ph	6.63b	7.34a	7.36a	6.83b	7.04	*	3.32
Colour (Hazen)	7.60b	42.30a	30.57ab	5.17b	21.4	*	77.58
Turbidity (NTU)	11.75a	52.03a	33.32a	6.22a	25.83	NS	107.45
Conductivity (μS/cm)	828.30ab	1559.30a	1537.30ab	257.50b	1045.62	**	41.17
Total Dissolved solids, (TDS) (mg/L)	415.70a	782.30a	772.00a	298.10a	567.03	NS	42.82
Total Suspended Solid, (TSS) (mg/L)	7.67b	58.67a	46.33a	9.00b	30.42	*	73.04
Total Alkalinity (CaCO ₃) (mg/L)	46.70b	515.00a	436.30a	67.30b	266.3	**	51.55
Total Hardness (CaCO ₃) (mg/L)	25.33b	202.00a	90.33b	36.33b	88.5	**	39.39
Calcium Hardness (CaCO ₃) (mg/L)	23.67b	90.67a	71.67a	29.00b	53.75	**	26.23
Magnesium Hardness (MgCO ₃) (mg/L)	1.67b	111.33a	19.33b	6.67b	34.75	**	65.85
Carbonate Alkalinity (CO ₃ ²⁻) (mg/L)	18.00b	104.67a	90.67ab	44.67ab	64.5	*	64.36
Bicarbonate Alkalinity (HCO ₃ ²⁻) (mg/L)	19.00b	410.30a	345.00a	22.70b	119.25	**	65.53
Calcium (mg/L)	9.47b	36.27a	21.02ab	11.60ab	19.59	*	49.28
Magnesium (mg/L)	2.51b	27.05a	8.35b	1.62b	9.88	**	74.63
Chloride (mg/L)	29.00b	365.00a	381.67a	56.67b	208.08	**	25.21
Fluoride (mg/L)	0.00a	0.18a	0.20a	0.03a	0.1	NS	123.5
Sulphate (mg/L)	40.00ab	30.00ab	20.57b	57.23a	36.95	*	40.23
Sulphide mg/L	0.05b	0.54a	0.15b	0.07b	0.2	*	91.12
Phosphate (mg/L)	0.55b	7.25a	1.47b	0.87b	2.54	**	43.45
Ammonia – Nitrogen (mg/L)	1.66b	57.31a	51.45ab	3.69b	28.53	*	92.19
Nitrate – Nitrogen (mg/L)	1.92a	4.75a	2.08a	2.25a	2.75	NS	104.41
Nitrite – Nitrogen (mg/L)	0.01a	0.01a	0.01a	0.01a	0.01	NS	78.77
Aluminium (mg/L)	0.02a	0.06a	0.03a	0.02a	0.03	NS	70.91
Iron (Total) (mg/L)	0.55b	1.64a	1.53a	0.52b	1.06	**	20.61
Manganese (mg/L)	0.07a	0.29a	0.29a	0.22a	0.22	NS	119.22
Copper (mg/L)	0.05a	0.13a	0.09a	0.53a	0.2	NS	214
Zinc (mg/L)	0.04a	0.01a	0.02a	0.04a	0.03	NS	169.42
Cyanide (mg/L)	0.04a	0.02a	0.01a	0.13a	0.05	NS	210.52
Chromium (Total) (mg/L)	0.01ab	0.01b	0.03ab	0.04a	0.02	*	83.21
Potassium (mg/L)	5.37c	88.47a	72.00b	5.80c	42.91	**	19.78

GMS1; NMS2;TKDS;WWU;MM; Mean of means, LSD; least significance difference, CV %; Coefficient of variation, *; Significant difference at 0.05, **; Highly significant difference at 0.05, NS; No significant difference at 0.05, Columns with the same alphabet are not different.

APPENDIX XXI: Means of Microbial Parameters for Rainy season wastewater irrigation

Parameter	GMS 1	NMS 2	TKDS	WWU	MM	LSD	CV %
Total Coliform (CFU/100ml)	29031000.00a	52300000.00a	35733333.00a	21333333.00a	3.50E+07	NS	68.59
Faecal Coliform (CFU/100ml)	566667.00a	18233333.00a	1633333.00a	6933333.00a	6841667	NS	151.49
<i>E.coli</i> (CFU/100ml)	66667.00b	10300000.00a	366667.00b	300000.00b	2758333	*	146.9
<i>Staphylococci</i> (CFU/100ml)	1466667.00a	1733333.00a	1600000.00a	700000.00a	1375000	0.76	93.54
<i>Enterococci</i> (CFU/100ml)	166667.00a	2766667.00a	400000.00a	133333.00a	866667	0.19	178.47
<i>Pseudomonas</i> (CFU/100ml)	1500000.00a	14300000.00a	466667.00a	9700000.00a	6491667	0.55	204.68
Total Heterotrophic Bacteria (CFU/1ml)	407.70a	631.00a	429.30a	481.30a	487.33	0.83	65.59

GMS1; NMS2;TKDS;WWU;MM; Mean of means, LSD; least significance difference, CV %; Coefficient of variation, *; Significant difference at 0.05, **; Highly significant difference at 0.05, NS; No significant difference at 0.05, Columns with the same alphabet are not different.



**APPENDIX XXII: Means of Physicochemical Parameters for Rainy season
wastewater irrigation**

Parameter	GMS 1	NMS 2	TKDS	WWU	MM	LSD	CV %
Temperature (°C)	24.90a	25.10a	25.67a	25.73a	25.35	NS	29.19
pH	6.67b	7.30ab	7.47a	6.80a	7.06	*	4.68
Colour (Hazen)	21.33a	66.00a	50.57a	63.67a	50.39	NS	77.41
Turbidity (NTU)	39.83a	81.83a	78.80a	110.29a	77.69	NS	92.43
Conductivity (µS/cm)	741.70ab	1341.70a	1205.30ab	335.40b	906	*	44.35
Total Dissolved solids, (TDS) (mg/L)	365.50ab	665.70a	597.30a	162.70b	447.79	*	44.91
Total Suspended Solid, (TSS) (mg/L)	23.33a	117.67a	95.00a	30.33a	66.58	NS	104.67
Total Alkalinity (CaCO ₃) (mg/L)	76.67b	514.33a	375.33a	140.33b	276.67	*	44.13
Total Hardness (CaCO ₃) (mg/L)	20.00b	258.00a	82.00b	29.67b	97.42	*	94.78
Calcium Hardness (CaCO ₃) (mg/L)	17.00b	53.00a	52.33a	24.00b	36.58	*	29.29
Magnesium Hardness (MgCO ₃) (mg/L)	3.00b	205.00a	29.67b	5.67b	60.83	*	144.42
Carbonate Alkalinity (CO ₃ ²⁻) (mg/L)	28.00a	66.67a	58.67a	24.00a	44.33	NS	62.54
Bicarbonate Alkalinity (HCO ₃ ²⁻) (mg/L)	52.33b	447.67a	318.33a	116.33b	233.67	*	43.69
Calcium (mg/L)	6.80b	21.20a	20.93a	9.60b	14.63	*	29.29
Magnesium (mg/L)	0.73b	49.82a	7.21b	1.38b	14.78	*	144.42
Chloride (mg/L)	31.33b	327.00a	301.67a	150.33ab	202.58	0.05	57.52
Fluoride (mg/L)	0.00a	0.00a	0.00a	0.00a	0	0	0
Sulphate (mg/L)	37.76a	14.46a	36.10a	42.78a	32.77	0.33	57.54
Sulphide (mg/L)	0.05a	1.32a	0.26a	0.11a	0.43	NS	240.55
Phosphate (mg/L)	7.04a	24.82a	11.07a	9.48a	13.1	NS	92.91
Ammonia – Nitrogen (mg/L)	9.24a	16.65a	9.98a	20.31a	14.05	NS	74.82
Nitrate – Nitrogen (mg/L)	1.25a	7.50a	9.25a	1.75a	4.94	NS	137.13
Nitrite – Nitrogen (mg/L)	0.00a	0.02a	0.02a	0.01a	0.06	NS	249.98
Aluminium (mg/L)	0.04a	0.07a	0.24a	0.06a	0.1	NS	175.28
Iron (Total) (mg/L)	1.02a	1.92a	1.84a	1.95a	1.68	NS	86.22
Manganese (mg/L)	0.03a	0.37a	0.35a	0.06a	0.2	NS	109.69
Copper (mg/L)	0.09ab	0.01b	0.34a	0.16ab	0.15	*	93.15
Zinc (mg/L)	0.04333a	0.01333a	0.03333a	0.05667a	0.037	NS	155.68
Cyanide (mg/L)	0.18767a	0.01933a	0.00433a	0.11533a	0.08	NS	140.77
Chromium (Total)(mg/L)	0.00333b	0.00000b	0.00333b	0.03667a	0.01	*	153.08
Potassium (mg/L)	16.33a	48.70a	26.07a	18.00a	27.28	NS	64.58

GMS1; NMS2;TKDS;WWU;MM; Mean of means, LSD; least significance difference, CV %; Coefficient of variation, *; Significant difference at 0.05, **; Highly significant difference at 0.05, NS; No significant difference at 0.05, Columns with the same alphabet are not different.

Appendix XXIII: Results of the statistical analysis of means of Microbial Parameters for dry and rainy season wastewater irrigation
Appendix XXIV: Oneway

Descriptive

Dry season wastewater Microbial Statistical Analysis

	N	Mean	Std. Deviation	Std. Error	95% Confidence Interval for Mean		Minimum	Maximum
					Lower Bound	Upper Bound		
WWU	7	153583.3	175683.5	66402.1	-8896.8	316063.4	333.0	486083.0
GMS1	7	63218.1	137442.5	51948.4	-63895.0	190331.3	0.0	373528.0
NMS2	7	175349.3	158720.1	59990.6	28557.7	322140.9	5333.0	413330.0
TKDS	7	92232.9	122395.1	46261.0	-20963.7	205429.4	1667.0	324630.0
Total	28	121095.9	148678.0	28097.5	63444.6	178747.2	0.0	486083.0

Appendix XXV: Test of Homogeneity of Variances

Test of Homogeneity of Variances

Dry season wastewater Microbial Statistical Analysis

Levene Statistic	df1	df2	Sig.
0.6	3.0	24.0	0.6

Appendix XXVI ANOVA

ANOVA

Dry season wastewater Microbial Statistical Analysis

	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	57272390748.1	3.0	19090796916.0	0.9	0.50
Within Groups	539566429744.6	24.0	22481934572.7		
Total	596838820492.7	27.0			

Appendix XXVII: Post Hoc Tests

Multiple Comparisons

Dependent Variable: Dry season wastewater Microbial Statistical Analysis

(I) Site (J) Site	Mean Difference		Sig.	95% Confidence Interval	
	(I-J)	Std. Error		Lower Bound	Upper Bound
WWU GMS1	90365.1	80146.2	0.27	-75048.4	255778.7
NMS2	-21766.0	80146.2	0.79	-187179.6	143647.6
TKDS	61350.4	80146.2	0.45	-104063.2	226764.0
GMS1 WWU	-90365.1	80146.2	0.27	-255778.7	75048.4
NMS2	-112131.1	80146.2	0.18	-277544.7	53282.4
TKDS	-29014.7	80146.2	0.72	-194428.3	136398.9
NMS2 WWU	21766.0	80146.2	0.79	-143647.6	187179.6
GMS1	112131.1	80146.2	0.18	-53282.4	277544.7
TKDS	83116.4	80146.2	0.31	-82297.2	248530.0
TKDS WWU	-61350.4	80146.2	0.45	-226764.0	104063.2
GMS1	29014.7	80146.2	0.72	-136398.9	194428.3
NMS2	-83116.4	80146.2	0.31	-248530.0	82297.2

Appendix XXVIII: Descriptive

Descriptive

Rainy season wastewater Microbial Statistical Analysis

Rainy season wastewater microbial Statistical Analysis								
					95% Confidence Interval			
					for Mean			
	N	Mean	Std. Deviation	Std. Error	Lower Bound	Upper Bound	Minimu m	Maximu m
WWU	7	5585782.9	7952601.1	3005800.7	-1769146.4	12940712.2	481.3	2.13E+7
GMS 1	7	4685439.4	10753914.1	4064597.5	-5260272.4	14631151.1	407.7	2.90E+7
NMS 2	7	14233423.4	18123883.5	6850184.1	-2528373.2	30995220.1	631.0	5.23E+7
TKDS	7	5742918.5	13239733.8	5004149.0	-6501793.0	17987629.9	429.3	3.57E+7
Total	28	7561891.1	12932755.3	2444061.0	2547092.1	12576690.0	407.7	5.23E+7

Appendix XXIX: Test of Homogeneity of Variances

Test of Homogeneity of Variances

Rainy season wastewater Microbial Statistical Analysis

Levene Statistic	df1	df2	Sig.
0.6	3.0	24.0	0.7

Appendix XXX: ANOVA

ANOVA

Rainy season wastewater Microbial Statistical Analysis

	Sum of Squares	Df	Mean Square	F	Sig.
Between Groups	419978881821731.6	3.0	139992960607243.9	0.2	0.5
Within Groups	4095937422257459.0	24.0	170664059260727.4		
Total	4515916304079190.0	27.0			

Appendix XXXI: Post Hoc Tests

Multiple Comparisons

Dependent Variable: Rainy Season Wastewater Microbial Statistical Analysis

(I) Site	(J) Site	Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval	
					Lower Bound	Upper Bound
WWU	GMS1	900343.5	6982919.2	0.90	-13511693.3	15312380.3
	NMS2	-8647640.5	6982919.2	0.23	-23059677.3	5764396.3
	TKDS	-157135.6	6982919.2	0.98	-14569172.4	14254901.2
GMS1	WWU	-900343.5	6982919.2	0.90	-15312380.3	13511693.3
	NMS2	-9547984.0	6982919.2	0.18	-23960020.8	4864052.7
	TKDS	-1057479.1	6982919.2	0.88	-15469515.7	13354557.7
NMS2	WWU	8647640.5	6982919.2	0.23	-5764396.3	23059677.3
	GMS1	9547984.0	6982919.2	0.18	-4864052.7	23960020.8
	TKDS	8490505.0	6982919.2	0.24	-5921531.8	22902541.7
TKDS	WWU	157135.6	6982919.2	0.98	-14254901.2	14569172.4
	GMS1	1057479.1	6982919.2	0.88	-13354557.7	15469515.9
	NMS2	-8490505.0	6982919.2	0.24	-22902541.7	5921531.8

Appendix XXXII: Paired Samples Statistics

Paired Samples Statistics					
		Mean	N	Std. Deviation	Std. Error Mean
Dry & Rainy season wastewater Microbial Statistical Analysis		121095.9	28.0	148678.0	28097.5
		7561891.1	28.0	12932755.3	2444061.0

Appendix XXXIII: Paired Samples Correlations

Paired Samples Correlations				
		N	Correlation	Sig.
Dry & Rainy season wastewater Microbial Statistical Analysis		28.0	0.2	0.2

Appendix XXXIV: Paired Samples Test

Paired Samples Test						Sig. (2-tailed)		
Paired Differences						t	df	
						95% Confidence Interval of the Difference		
		Mean	Std. Deviation	Std. Error Mean		Lower	Upper	
Dry & Rainy season wastewater Microbial Statistical Analysis		-7440795	12897418	2437383		-12441892	-2439699	-3 27 0.005

Appendix XXXV: Results of the Statistical Analysis of Means of Dry and Rainy season wastewater Physicochemical Parameters

Appendix XXXVI: Oneway

Descriptive

Dry Season wastewater Physicochemical Statistical Analysis

	N	Mean	Std. Deviation	Std. Error	95% Confidence Interval for Mean		Minimum	Maximum
					Lower Bound	Upper Bound		
WWU	31	31	69	12	5	55	0.0	298.1
GMS1	31	49.1	162.4	29.2	-10.5	108.7	0.0	828.3
NMS2	31	147.5	317.8	57.1	30.9	264.1	0.0	1559.3
TKDS	31	131.0	311.9	56.0	16.6	245.4	0.0	1537.3
Total	124	89.6	241.9	21.7	46.6	132.6	0.0	1559.3

Appendix XXXVII: Test of Homogeneity of Variances

Test of Homogeneity of Variances

Dry Season wastewater Physicochemical Statistical Analysis

Levene Statistic	df1	df2	Sig.
4.8	3.0	120.0	0.0

Appendix XXXVIII: ANOVA

ANOVA

Dry Season wastewater Physicochemical Statistical Analysis

	Sum of Squares	Df	Mean Square	F	Sig.
Between Groups	315598.1	3.0	105199.4	1.8	0.2
Within Groups	6882356.0	120.0	57353.0		
Total	7197954.07	123			

Appendix XXXIX: Post Hoc Tests

Multiple Comparisons

Dependent Variable: Dry Season wastewater Physicochemical Statistical Analysis

LSD

					95% Confidence Interval	
Mean Difference						
(I) site	(J) site	(I-J)	Std. Error	Sig.	Lower Bound	Upper Bound
WWU	GMS1	-18.5	60.8	0.76	-138.9	102.0
	NMS2	-116.9	60.8	0.06	-237.3	3.6
	TKDS	-100.3	60.8	0.10	-220.7	20.1
GMS1	WWU	18.5	60.8	0.76	-102.0	138.9
	NMS2	-98.4	60.8	0.11	-218.9	22.0
	TKDS	-81.9	60.8	0.18	-202.3	38.6
NMS2	WWU	116.9	60.8	0.06	-3.6	237.3
	GMS1	98.4	60.8	0.11	-22.0	218.9
	TKDS	16.6	60.8	0.79	-103.9	137.0
TKDS	WWU	100.3	60.8	0.10	-20.1	220.7
	GMS1	81.9	60.8	0.18	-38.6	202.3
	NMS2	-16.6	60.8	0.79	-137.0	103.9

Appendix XL: One way

Descriptive

Rainy Season wastewater Physicochemical Statistical Analysis

					95% Confidence Interval for			
			Std.		Mean			
	N	Mean	Deviation	Std. Error	Lower Bound	Upper Bound	Minimum	Maximum
WWU	31.0	42.9	73.1	13.1	16.1	69.8	0.0	335.4
GMS1	31.0	49.4	144.2	25.9	-3.5	102.3	0.0	741.7
NMS2	31.0	140.8	279.8	50.3	38.1	243.4	0.0	1341.7
TKDS	31.0	109.7	245.3	44.1	19.8	199.7	0.0	1205.3
Total	124	86	205	18	49	122	0.0	1342

Appendix XLI: Test of Homogeneity of Variances

Rainy Season wastewater Physicochemical Statistical Analysis

Levene Statistic	df1	df2	Sig.
4.6	3.0	120.0	0.0

Appendix XLII: ANOVA

Rainy Season wastewater Physicochemical Statistical Analysis

	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	209396.0	3.0	69798.7	1.7	0.2
Within Groups	4937768.1	120.0	41148.1		
Total	5147164.1	123.0			

Appendix XLIII: Post Hoc Tests

Multiple Comparisons

Dependent Variable: Rainy Season wastewater Physicochemical Statistical Analysis

LSD

		Mean	95% Confidence Interval			
(I) site	(J) site	Difference (I-J)	Std. Error	Sig.	Lower Bound	Upper Bound
WWU	GMS1	-6.5	51.5	0.90	-108.5	95.5
	NMS2	-97.8	51.5	0.06	-199.9	4.2
	TKDS	-66.8	51.5	0.20	-168.8	35.2
GMS1	WWU	6.5	51.5	0.90	-95.5	108.5
	NMS2	-91.3	51.5	0.08	-193.4	10.7
	TKDS	-60.3	51.5	0.24	-162.3	41.7
NMS2	WWU	97.8	51.5	0.06	-4.2	199.9
	GMS1	91.3	51.5	0.08	-10.7	193.4
	TKDS	31.0	51.5	0.55	-71.0	133.1
TKDS	WWU	66.8	51.5	0.20	-35.2	168.8
	GMS1	60.3	51.5	0.24	-41.7	162.3
	NMS2	-31.0	51.5	0.55	-133.1	71.0

Appendix XLIV: T-Test

Paired Samples Statistics				
	Mean	N	Std. Deviation	Std. Error Mean
Dry & Rainy Season wastewater Physicochemical Statistical Analysis	89.6	124.0	241.9	21.7
	85.7	124.0	204.6	18.4

Appendix XLV: Paired Samples Correlations

Paired Samples Correlations			
	N	Correlation	Sig.
Dry & Rainy Season wastewater Physicochemical Statistical Analysis	124.0	1.0	0.0

Appendix XLVI: Paired Samples Test

Paired Samples Test								
Paired Differences								
	Mean	Std. Deviation	Std. Error Mean	95% Confidence Interval of the Difference		t	df	Sig. (2-tailed)
				Lower	Upper			
Physiochemical Statistical Analysis for Dry & Rainy season Irrigation	3.8	51.4	4.6	-5.3	13.0	0.8	123.0	0.408