MODELLING LEVELS OF MICROBIAL AND CHEMICAL CONTAMINANTS IN WASTEWATER USED FOR PERI-URBAN IRRIGATION IN THE TAMALE METROPOLIS, GHANA

BY

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DECLARATION

I hereby declare that, except for references to other peoples work which have been duly acknowledged, this is my own work towards the award of a Doctor of Philosophy (PhD) Degree and that no material previously published by another person nor material which has been accepted for the award of any other degree of the University, except where due acknowledgement has been made in the text.

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ABSTRACT

Wastewater irrigation can pose a variety of potential health risks and also excessive and often imbalanced addition of nutrients to the soil to affect crop production. Thus its use in agriculture without adequate safeguards has been noted to have serious drawbacks for human health and the environment. This study modelled the levels of microbial and chemical contaminants in wastewater used for peri-urban vegetable crop production for both dry and wet seasons and also assessed the efficiency of an on-farm sand filter system on the contaminants in the Zagyuri community of the Tamale Metropolis of the Northern Region of Ghana. Three (3) different set-ups of tanks with lengths (L) 8.5 (T_1), 17 (T_2) and 25.5 (T_3) cm were used as treatments with media sizes ranging from 2 to 45 mm. A total of ten (10) water samples were collected at each sampling time at weekly interval (7 days) using 500 ml bottles for a period of 16 weeks. Standard laboratory analyses procedures were adopted for the microbial and chemical parameters. The microbial results indicated thirteen (13) different types of helminths (H). The Multivariate analysis of Faecal Coliform (FC) data indicated that an increase in the length of the treatment filter column by a unit decreased the FC concentration level in the wastewater. It was observed for both seasons that, the mean concentration levels of FC varied with the season (wet season = 24,444 and dry season = 13,780). T_3 achieved the highest removal efficiency of FC by 80.9 % and the least T_1 with removal efficiency of 68.0 % in the wet season. In the dry season however, T_3 recorded a removal efficiency of 69.7 % compared to the least of T_1 with removal percentage of 62.6 %. The model generated indicated that the parameters L, RH, T, P and pH had an inverse relationship with Total coliform (TC) concentration in the wastewater. Apart from Fe which was insignificant in both seasons, all the other parameters recorded a significant difference in the two seasons. Al, Fe, Mn and Zn on the average recorded higher concentrations in the wet than the dry season whilst Cu recorded a higher concentration value in the dry season than the wet season. Amongst all the heavy metals, Fe recorded a higher concentration in both the dry and wet seasons**.** Concentrations of most of the heavy metals in the study area were lower than the WHO and FAO recommended standards except Mn which had concentration levels exceeding the recommended standard in the wet season only**.** A further study of the bioaccumulation effect of heavy metals in the soils should be undertaken to assist in advising on the impact of continuous use of wastewater on the soils of the area. The current design should be further investigated to serve as a low cost option of treating wastewater on-farm.

DEDICATION

This work is dedicated to my parents, Mr and Mrs Abagale Bole

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ABBREVIATIONS

AATSE	Australian Academy of Technological Sciences and Engineering
APT	Advanced Primary Treatment
BOD	Biological Oxygen Demand
CEPT	Chemical Enhanced Primary Treatment
COD	Chemical Oxygen Demand
CSTR	Completely Stirred Tank Reactor
DALYS	Disability Adjusted Life Years
DEWATS	Decentralised Wastewater Treatment in Developing Countries
DO	Dissolved Oxygen
ECA	Economic Commission of Africa
FAO	Food and Agriculture Organisation
FC	Faecal Coliform
HPC	Heterotrophic Plate Count
HRT	Hydraulic Retention Time
ICMS	International Commission for Microbiological Specification for Food
IWMI	International Water Management Institute
KNUST	Kwame Nkrumah University of Science and Technology
MDG	Millennium Development Goals
MPN	Most Probable Number
NRC	National Research Council of the USA
PACs	Poly Aluminium Chlorides
RMC	Recommended Maximum Concentrations
SAT	Soil Aquifer Treatment
SOC	Soluble Organic Compounds
SS	Suspended Solids
SSA	Sub-Saharan Africa
TC	Total Coliform
TSS	Total Suspended Solids
UDS	University for Development Studies
UN	United Nations
UNHSP	United Nations Human Settlements Programme
UNPD	United Nations Population Division
UPA	Urban Peri-Urban Agriculture
USAB	Upflow Anaerobic Sludge Blanket
USD	United States Dollar
WHO	World Health Organisation

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CHAPTER ONE

INTRODUCTION

1.1 Background

Freshwater is already scarce in many parts of the world and population growth in water-scarce regions is expected to further increase its value. In 1995, 31 countries were classified as water-scarce or water-stressed and it is estimated that 48 and 54 countries will fall into these categories by 2025 and 2050, respectively (Hinrichsen, *et al.*, 1998). These numbers are said not to include people living in arid regions of large countries where there is enough water but is poorly distributed e.g. China, India, and the USA (Hinrichsen, *et al.*, 1998). Agriculture is the single largest user of freshwater in the world, accounting for nearly 70% (> 90% in some countries) of all extractions of freshwater worldwide (Gleick, 2001; FAO, 2002).

As freshwater becomes increasingly scarce due to population growth, urbanisation and climate change, the use of wastewater in agricultural production is expected to increase even more. These factors have been realised to greatly affect the availability of freshwater for commercial, domestic and agricultural purposes. It was estimated that more than 10 % of the world's population consumed foods produced by irrigation with wastewater (Smit and Nasr, 1992). The percentage will be considerably higher among populations in low-income countries within arid and semi-arid climates. Both treated and untreated wastewater are used directly and indirectly (i.e. as faecally contaminated surface water) for irrigation in developed and less developed countries. In places where untreated wastewater or highly contaminated surface water is used for irrigation, health and environmental problems of the same nature and magnitude as those associated with direct wastewater use in agriculture may arise.

Overall, population growth will be the main driving force for a further demand on water resources. There is therefore a growing recognition that the production of wastewater will increase due to the growth of urbanization and that wastewater needs to be better incorporated into the overall management of water resources (WHO, 2006a). Wastewater is approximately 99% water. Where households are connected to piped water supplies, wastewater is generated at a rate of 35 to 200 l/p/d (12 to 70 m^3/p/y), depending on the water supply service level, climate and water availability (Helmer and Hespanho, 1997).

It was indicated by the WHO (2006b) that, wastewater is increasingly being used for agricultural production in both developing and industrialized countries and the principal forces driving this increased use are:

1. Increasing water scarcity and stress, and degradation of freshwater resources resulting from improper disposal of wastewater,
2. Population increase and related increased demand for food and fibre,
3. A growing recognition of the resource value of wastewater and the nutrients it contains and
4. The Millennium Development Goals (MDGs) especially the goals for eradicating extreme poverty and hunger (MDG 1) and ensuring environmental sustainability (MDG 7).

Urban and peri-urban agriculture (UPA) are increasingly attracting attention worldwide and are also contributing significantly to the maintenance of the environment as well as improving the economic and nutritional status of the populace of a particular area. According to the UNPD (1996), about 800 million people were engaged in urban and peri-urban agriculture (UPA) worldwide and contributed about 30 % to the world's food supply. This is increasingly becoming a common expression of most urban areas in developing countries and is seen as an important means of attaining balanced diets and urban food security. In several

African cities, Cofie *et al.* (2003) reported that between 50 and 90% of the vegetable consumed are produced within or close to the city. The proximity of UPA to consumers ensures freshness of the vegetables and likelihood of having higher nutrient contents than those stored and transported for long periods. This is especially said to be important in Sub-Saharan Africa (SSA) where refrigerated food transport and cool storage are scarce. UPA also offers jobs for the poor, often especially women, and is a poverty alleviation strategy (Cofie *et al.,* 2003). In many African countries, 65% of the people involved as UPA farmers or traders are women.

In Ghana, UPA is mainly characterized by backyards and commercial small-scale irrigated vegetable farming and is mainly carried out by men while marketing of the produce is predominantly a women's domain. It also has significant contributions to livelihoods and food security; e.g. around Kumasi, Ghana, more than 12,000 farmers are involved in vegetable farming during the dry seasons (Cornish *et al.,* 2001) and urban farmers grow 90 % of the main vegetables eaten in the city. This is done on virtually every open space close to water sources of almost all major cities and urban centres in the West African sub-region.

The adverse public health and environmental effects of the use of untreated wastewater or polluted water which has high levels of pathogenic organisms cannot be over-emphasized. Reports of disease outbreaks such as typhoid in Santiago, Chile and helminth infections in Egypt and Jerusalem that have been associated with crop contamination from wastewater irrigation have been noted (Blumenthal *et al*., 2000). The use of wastewater can also affect the farm workers since significant *Ascaris* and *Ancylostoma* (hookworm) infections have been reported on sewage used by farmers in India (Blumenthal *et al*., 2000). These reports amongst others are perhaps the main reasons that make UPA in Ghana, like in many other West African countries, not to receive the appropriate public and institutional support despite

its significant contributions to urban food supply, poverty alleviation, women empowerment and improved human nutrition through the provision of balanced diets. Effective wastewater treatment can reduce pathogen levels but in most developing countries it is not an option for the municipal authorities due to the high costs involved (Keraita *et al*., 2002).

Wastewater is an important source of irrigation water and nutrients for crops in arid and semi-arid climates. When wastewater use is well managed, it is known to help in the recycling of plant nutrients and water thus reducing the cost of fertilizers or simply makes them accessible to farmers. Where wastewater treatment services are not provided, the use of wastewater in agriculture actually acts as a low-cost treatment method, taking advantage of the soils filtration capacity, thereby naturally removing contaminants before its direct exposure to the environment. The use of wastewater in irrigation helps to reduce downstream health and environmental impacts that would have been discharged directly into surface water bodies (WHO, 2006b).

The Ghana Statistical Services (2012) indicated that most urban centres in Ghana have no means of treating wastewater and the sewerage network serves only 4.5% of the total human population. Attempts to develop new sanitation facilities have been faced with socio-economic challenges since they disrupt other existing infrastructure hence most new sewerage treatment plants in Ghana are operating below the design capacity.

According to Agodzo *et al*. (2003), the total amount of grey and black wastewater produced annually in urban Ghana has been estimated at 280 million m^3. This wastewater is said to be derived mainly from domestic sources as Ghana's industrial development is concentrated along the coastline where wastewater, treated or untreated, is disposed off into the ocean. In Ghana, collection and disposal of domestic wastewater is done using (Agodzo *et al*., 2003):

- Underground tanks such as septic tanks and aqua-privies, either at industrial facilities or at the community level and then transported by desludging tankers to treatment works or dumping sites,
- Sewerage systems,
- Public toilets, and
- Pit and improved latrines.

The contamination levels of these wastewaters and the environmental impact therefore vary greatly depending on the origin and the disposal method used.

As most of the wastewater is of domestic origin, faecal coliforms are the contaminants of primary concern. According to Awuah *et al.* (2002) in Ghana high levels of faecal coliforms and helminth eggs were isolated in both grey and black water. Toze (2006) reported that due to contamination of food with these pathogens which poses public health risk, wastewater irrigation has been approached with trepidation. Heavy metal levels in water bodies in and around Ghana's urban centres are not elevated (McGregor *et al.,* 2001; Mensah *et al.,* 2001; Cornish *et al.,* 1999). These studies also showed that inter-seasonal variations of water quality especially after the first heavy rains can be high, hence the need for long-term monitoring. Keraita and Drechsel (2007) reported that in Kumasi, faecal coliforms typically reach values of $10^6 – 10^8$/100 ml while total coliform levels often range from $10^8 – 10^{10}$/100 ml. Lower faecal coliform counts of $10^4 – 10^6$/100 ml were measured at some urban farming sites in Accra and Tamale.

1.2 Problem Statement and Justification

It is estimated that within the next 50 years, more than 40% of the world's population will live in countries facing water stress or water scarcity (Hinrichsen *et al.,* 1998). Growing competition between agriculture and urban uses of high-quality freshwater supplies, particularly in arid, semi-arid and densely populated regions, will increase the pressure on this scarce resource. Most population growth is expected to occur in urban and peri-urban areas in developing countries (UNPD, 2002) and this growth increases both the demand for freshwater and the amount of wastes that are discharged into the environment, thus leading to more pollution of clean water sources.

Wastewater use poses environmental risks and it has generally been realised that domestic wastewater for irrigation poses less risk to the environment than the use of industrial wastewater. Industrial discharges containing toxic chemicals are mixed with domestic wastewater in many countries, creating serious environmental problems and, where wastewater is used for crop irrigation, it endangers the health of farmers and products used by consumers (WHO, 2006b).

The effect of the use of wastewater in agriculture can be said to have positive and negative environmental impacts as well as public health issues. It has been commonly agreed that the nutrient value of wastewater is high compared to freshwater sources and this makes its use by especially urban farmers high as it contains the necessary plant nutrients required for their growth. The use of wastewater in agriculture is a form of nutrient and water recycling, and often reduces downstream environmental impacts on soil and water resources (WHO, 2006b). The nutrient value of wastewater in crop production has been widely recognised by farmers.

The water and nutrient resources help people to grow more food without the use of more fertilizers. The reliability of the water supply also means that crops can be grown year-round in warm and water scarce climates. It also represents an important asset in situations where climate change will lead to significant changes in patterns of precipitation (WHO, 2006a). Several research studies (Ensink *et al.*, 2004; Future Harvest, 2001; Faraqui *et al.*, 2004) have reported increases in crop yields, farmers' incomes and a reduction in the use of artificial fertilizers as a result of wastewater for irrigation. WHO (2006b) reported that the use of wastewater for crop irrigation reduces the use of artificial fertilizers and is thus an important form of nutrient recycling. Specifically, at an irrigation rate of 1.5 m/y, a typical requirement in a semi-arid climate, treated municipal wastewater can supply 225 kg of nitrogen and 45 kg of phosphorus per hectare per year. Thus, supplementary fertilization needs can be reduced for some crops, with a consequent increase in farmers' incomes.

WHO (2006b) indicated that the discharge of these contaminated waters into the aquatic systems of the environment would lead to the degradation of water quality and also act as a vehicle for disease transmission to users of polluted waters. According to WHO (2006a), in countries or regions where poor sanitation and hygiene conditions prevail and untreated wastewater and excreta are widely used in agriculture, intestinal worms pose the most frequently encountered health risks. Other excreta-related pathogens may also pose health risks, as indicated by high rates of diarrhoea, other infectious diseases, such as typhoid and cholera, and incidence rates of infections with parasitic protozoa and viruses.

In countries where higher sanitation and hygiene standards prevail, infrastructure for waste treatment is available and treatment processes are well-managed, viral illnesses pose greater health risks than other pathogens. This is partly because viruses are often difficult to remove

through wastewater treatment processes due to their small size, but also because of the resistance of some viruses in the environment and their infectivity at low concentrations. Additionally, people living in conditions where higher sanitation and hygiene standards prevail often have no prior exposure to viral pathogens and therefore have no acquired immunity and are more vulnerable to viral infection and illness. Wastewater irrigation has been realised to contribute to environmental sustainability by using the nutrients and water in wastewaters beneficially for increased crop production, the result of which is a reduction in the amounts of untreated wastewater that will be discharged directly into the environment.

The use of wastewater in agriculture is said to have a direct link with the MDGs of "Goal 1: Eliminate extreme poverty and hunger" and "Goal 7: Ensure environmental sustainability" (WHO, 2006b). The direct impact of the use of this high value resource therefore relates to the ability of communities to grow more food and conserve precious water and plant nutrient resources.

WHO (2006b) indicated that wastewater contains a variety of different pathogens, many of which are capable of survival in the environment (i.e. in the wastewater, on the crops or in the soil) long enough to be transmitted to humans. The report also mentioned that the greatest health risk associated with the use of wastewater without adequate treatment is intestinal helminths.

Keraita and Drechsel (2007) reported of the use of polluted water for vegetable farming to be more widespread in the more populated cities where safe water is scarce and is used for domestic purposes. From a general survey among open-space farmers carried out in 2002, it was found that about 84 % of nearly 800 farmers farming in and close to Accra and almost all 700 farmers in Tamale used polluted water for irrigation.

However, there are health risks to consider both for farmers and consumers. Direct contact with the untreated wastewater exposes farmers to pathogens, viruses and bacteria, as well as

toxic elements. Bacteria and toxic elements can also be transmitted to crops which in turn might harm consumers. Since several trace metals are toxic even at rather low concentrations, their accumulation in agricultural soils may affect the microbial activity as well as plant growth and quality. Keraita and Drechsel (2007) reported of high levels of pollution, specifically microbiological contamination in irrigation water and on crops. In their report, it was indicated that due to the results obtained regarding the level of contamination, the implementation of the WHO irrigation guidelines appears impossible, as improved water treatment appears unviable.

High level contamination of irrigated vegetables above the International Commision for Microbiological Specification for Food (ICMS) by faecal coliforms has been reported severally. Amoah *et al.* (2006) reported contamination levels with helminth eggs of 1.1 and 0.4 wet weight. This presents a high risk to human consumption. Several technologies including the watering can rose covering with net, delayed harvesting and proper treatment of vegetables before consumption, have achieved little with respect to the reduction in contamination levels. Contamination from splash, re-contamination during washing at the farm site and improper treatment before consumption as well as the direct exposure of farmers to the risk of using wastewater are considered very high. Presence of helminth eggs according to the WHO (2006b) in good quality irrigation water for raw vegetables should be less than 10^3/100 ml. One nematode per litre of water has also been recommeded for use in the production of vegetable crops which are usually eaten in their raw state.

Obuobie *et al.* (2006) found that for the Tamale Metropolitan area, Zagyuri community presented a high level of contaminated water used for dry season vegetable production. High levels of faecal and total coliform levels have also been reported from areas where fresh vegetables are cultivated. Helminth eggs have also been noted to be high in the leafy

vegetables produced in the area. Amoah *et al.* (2006) reported faecal coliform range of 4.0 x 10^5 to 7.5 x 10^8 and total coliform of between 1.5 x 10^7 and 10^{10} with helminth eggs of between 1.4 to 2.74/g of fresh vegetables. According to Abdul-Ghaniyu *et al.* (2002), fresh and good water in Tamale is scarce and farmers have no choice other than to use water from stormwater drains polluted with domestic wastewater. Obuobie *et al.* (2006) also reported that Kamina barracks (Zagyuri community) contained the highest level of faecal coliforms where the farmers use a broken down sewage pond for vegetable crop irrigation.

In a study by Zibrilla and Salifu (2004), it was found that 52 % of dry season vegetable farmers in the Tamale Metropolis depended on polluted water whilst Amoah *et al.* (2006) established *truchuriasis* as a common disease with children of vegetable farmers. Exposure to these effects therefore presents a high level of greater risk to the famers as well as the farm family and consumers.

According to the WHO (2004), diarrhoea alone is responsible for 3.2 % of all deaths and 4.2 % of overall disease burden expressed in Disability Adjusted Life Years (DALYs) worldwide. In addition to diarrhoea, WHO estimates that each year, 16 million people contract typhoid and over a billion people suffer from intestinal helminth infections. Also, Kosek *et al.* (2003) reported that children under the age of five (5) in developing countries experienced a median of 3.2 episodes of diarrhoea per year.

It is therefore evident that the use of polluted or contaminated wastewater for vegetable irrigation threatens public health especially among the urban population. Market surveys by IWMI in Kumasi, Accra and Tamale showed that it is very difficult to find any irrigated vegetables (e.g. lettuce, spring onions, cabbage) that are not contaminated with faecal coliforms. Helminth eggs are also commonly found on such vegetables. Coliform

contamination levels of vegetables are often the equivalent of a similar amount of fresh faeces (Keraita *et al.*, 2003). According to Rutkowski *et al.* (2006), for the protection of public health and the environment, the main concerns should however be associated with uncontrolled wastewater irrigation of fresh vegetable crops.

According to WHO (2006b), the different community groups that are at risk from the activities of the use of wastewater, excreta and greywater in agriculture are:

- Farm workers and their families
- Local communities close to the site of activities, and
- Product consumers.

Water quality criteria for irrigation generally take into account, amongst other factors, such characteristics as crop tolerance to salinity, sodium concentration and phytotoxic trace elements. Phytotoxic trace elements such as boron, heavy metals and pesticides may stunt the growth of plants or render the crop unfit for human consumption or other intended uses (Helmer and Hespanho, 1997). Heavy metals and many synthetic chemicals can also be ingested and absorbed by organisms and, if they are not metabolised or excreted, they may bio-accumulate in the tissues of the organisms. Some pollutants can also cause carcinogenic, reproductive and developmental effects. Exposure to different concentrations of pathogens or toxic chemicals through wastewater contact or through consumption of wastewater irrigated products is associated with a certain level of risk (WHO, 2006b).

In general, essential elements are defined as metals that are necessary for a plant to complete its life cycle (Madyiwa, 2006). Heavy metals such as Iron (Fe), Copper (Cu) and Zinc (Zn) are essential for plant growth as they participate in oxidation, electron transfer and various enzyme reactions (Madyiwa, 2006). Non-essential elements are metals with no known role in plant metabolism. Elements like Lead (Pb) and Cadmium (Cd) are not known to have any

metabolic roles in plants and animals and are therefore non-essential (Johannesson, 2002; Elson and Haas, 2003; Madyiwa, 2006).

It was estimated that if only 10 % of the 280 million m^3 of wastewater from urban communities of Ghana could be treated and used for irrigation, the total area that could be irrigated with wastewater alone could be up to 4,600 ha. At an average dry-season farm size of 0.5 ha, this could provide livelihood support for about 9,200 farmers in the peri-urban areas of Ghana (Agodzo *et al.,* 2003).

Drechsel *et al*. (2002) suggested that, on reducing the risk of contamination other approaches which take into account both public health risks and farmers' livelihoods need to be devised and these should focus on low-cost options for risk reduction not only on farms (mini sedimentation ponds, water filters), but also in markets and especially in households. Employing a system that will reduce the levels of pathogens and other contaminants in wastewater before use by farmers for crop irrigation purposes is therefore very important in reducing the risk of contamination of vegetable crops and farmers.

Urban vegetable farming as an income generating source, employment avenue, as well as a food security issue is of immense importance in a developing country like Ghana. Safe vegetable crop production has also become an issue of topical importance especially in the urban areas of Ghana and the world at large. The use of low cost non-treatment options has also been explored but the level of adoption has been realised to be very low for some of them due to the drudgery involved. A further exploration of adoptable low cost non-treatment options of wastewater is necessary in assisting in the production of safe, healthy, disease and risk-free vegetables for urban consumers was considered in the study. The elimination of fear

of vegetable crop contamination among consumers especially depends to a large extent on the improvement in the quality of water used for the production.

This study therefore assessed and modelled the levels and effect of an on-farm sand filter system as a non-treatment option on microbial, nutrient and heavy metal levels contained in wastewater used for peri-urban vegetable production in the Tamale Metropolis of Ghana.

1.3 Objectives of the Study

The main objective of the study was to model the levels of microbial and chemical contaminants in wastewater used for peri-urban vegetable crop production and assess the efficiency of an on-farm sand filter system on the removal of contaminants.

1.3.1 Specific Objectives

Specifically the study was to:

1. Determine the presence and levels of microbial and plant nutrients (macro and micro nutrients) and heavy metals contained in wastewater used for peri-urban vegetable crop production,
2. Assess the levels of BOD and COD contained in the wastewater used for peri-urban vegetable crop production,
3. Assess the efficiency of an on-farm sand filter system on both microbial and plant nutrient levels of wastewater used for peri-urban vegetable crop production, and
4. Model the concentration of desirable nutrient elements and rate of removal of contaminants contained in the wastewater.

1.4 Hypotheses of the Study

The specific objectives were used in the formulation of hypotheses to guide the study and these hypotheses were formulated around the achievement of good experimental results.

The null hypotheses (H_o) were:

a. There are no microbial, plant nutrients and heavy metals contained in the wastewater used for peri-urban vegetable crop production,
b. No appreciable levels of microbial, plant nutrients and heavy metals are contained in wastewater used for peri-urban vegetable crop production,
c. No appreciable levels of BOD and COD are contained in wastewater used for peri-urban agriculture, and
d. On-farm sand filter systems and stabilization ponds are not an option for the treatmemt of wastewater used for fresh vegetable crop production.

The alternate hypotheses (H_1) were;

a. There are microbial, plant nutrients and heavy metals contained in the wastewater used for peri-urban vegetable crop production,
b. High levels of microbial, plant nutrients and heavy metals are contained in wastewater used for peri-urban vegetable crop production, and
c. Appreciable levels of BOD and COD are contained in wasetwater used for peri-urban irrigation, and
d. On-farm sand filter systems and stabilization ponds are the best options for the treatmemt of wastewater used for fresh vegetable crop production in peri-urban areas.

1.5 Limitations of the Study

A longer period of study of the various parameters under assessment is very important but due to limited funds and equipment as well as laboratory reagents, the study could not be extended. Continuous electricity supply is very necessary for laboratory analysis and this was a limiting factor in most cases as samples undergoing analysis had to be repeated due to frequent electricity power cuts. Meteorological data was not available at the site, therefore data from the Tamale synoptic station of the Ghana Meteorological Agency which is close (about 12 km) to the study area provided fairly representative data needed for the study.

1.6 Structure of the Thesis

This thesis is divided into five chapters. Chapter One introduces the study as well as pointing out the reasons for the study. Chapter Two presents the background and reviews extensive literature on global water resources, wastewater use, effects and contaminants contained in them. Chapter Three describes the area of the study as well as providing information on the materials and methods that were used to arrive at the results that answer the objectives. Chapter Four assesses the types and seasonal diversity of helminth eggs in wastewater used by farmers in the study area. Chapter Five models the efficiency of the designed on-farm sand filter system with focus on microbial contaminant removal. Chapter Six examines the chemical quality of wastewater after filtration using the on-farm sand filter system. Chapter Seven looks at the micro nutrient concentration in wastewater used for peri-urban vegetable crop production. Chapter Eight examines the seasonal variation of organic pollution loads in the wastewater. Chapter Nine summarises the results, draws some useful conclusions from the study and also provides recommendations for future studies.

CHAPTER TWO

BACKGROUND AND LITERATURE REVIEW

2.1 Introduction

This chapter examines the state of the world water resources from the global and regional through to the local situation. The aim here was to obtain some facts that will provide the context within which this study could be undertaken more comprehensively.

The chapter also reviews previous works and studies on wastewater and wastewater contaminants as well as the utilisation of wastewater resources in crop production.

2.2 Global Water Resources

Water as a natural resource plays a very vital role in man's daily activities. Even though its distribution is said to be variable to a larger scale, it is available everywhere on earth and its role in the natural ecosystem cannot be downplayed. According to Wikipedia (2012) water resources are sources of water that are useful or potentially useful and the uses of water include agricultural, industrial, household, recreational and environmental activities. Virtually all of these human uses require freshwater. Studies by different authors indicate a range of world water resource base as 42,780 km^3/y (Shiklomanov, 2000); 44,540 km^3/y (Gleick, 2001) and 43,764.3 km^3/year (FAO, 2003). FAO (2003) similarly estimates the total water resources in the world to be in the order of 43,764.3 km^3/y and this resource is distributed throughout the world according to the patchwork of climates and physiographic structures. At the continental level, America has the largest share of the world's total freshwater resources with 45 %, followed by Asia with 28 %, Europe with 15.5 % and Africa with 9 %. In terms of resources per inhabitant or per capita in each continent, America has 24,000 m^3/y, Europe 9,300 m^3/y, Africa 5,000 m^3/y and Asia 3,400.1 m^3/y.

According to Wikipedia (2012) the earth's water resources include freshwater (3 %) and saline (oceans) 97 %. Of the 3 % freshwater, surface water forms 0.3 %, fresh surface water – rivers (2 %) i.e. swamps 11 % and lakes 87 % whilst the remaining 0.9 % constitutes others which includes groundwater (30.1 %) and ice caps and glaciers 68.7 %. The withdrawal of freshwater resources at the global scale is said to be increasing and this has been said to relate directly with population explosion and the rapid industrialisation of continents. This distribution of the earth's water resources is as presented graphically in Figure 2.1.

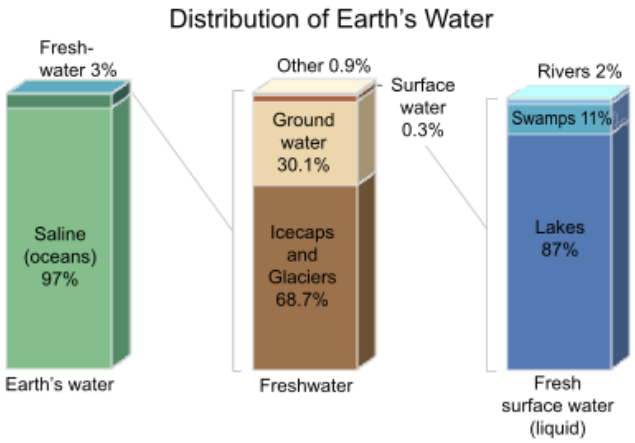


Figure 2.1: Distribution of the Earth's Water Resources. (Source: Wikipedia, 2012).

Shiklomanov (1998) recognised the importance of water especially freshwater as it was indicated that human life itself will be impossible without it as it has no substitution. The utilisation of water from various sources is thus for a wide range of activities. For many hundreds of years, man's impact on water resources was observed to be insignificant and entirely of a local character.

Presently, variability of water supply is observed as being both spatial and temporal in nature. In addition to spatial variability, there is a high variability in time within the month, year or among different years. This variability in distribution is currently being said to vary greatly as a result of the impact of climate change. A study by the FAO (2003) reports that the ten (10)

poorest countries in terms of water resources per inhabitant are Bahrain, Jordan, Kuwait, Libyan Arab Jamahirya, Maldives, Malta, Qatar, Saudi Arabia, United Arab Emirates and Yemen. Water resources are unevenly distributed in relation to human population. Nine (9) countries are said to be the world's giants in terms of internal water resources, accounting for 60 % of the world's natural freshwater whilst the water poor countries are usually the smallest (notably islands) and arid areas.

According to Shiklomanov (1998), comparing previous decades shows that annual water withdrawal during 1951-60 increased fourfold and this occurred because of the dramatic expansion in irrigated areas, the growth in industrial and heat and power engineering water consumption, and the intensive construction of reservoirs in all continents. In the same report by Shiklomanov (1998), it was also observed that all over the world during the last 25-30 years there has been a massive anthropogenic change in the hydrological cycle of rivers and lakes, affecting their water quality, their potential as water resources and the global water budget. Human activities and their impact on the water resources regarding the distribution is also being influenced by climatic factors.

The biggest river in the world, the Amazon according to Shiklomanov (1998), produces 16 % of annual global river runoff. 27 % of the world's water resources are formed by the five largest river systems of the Amazon, the Ganges with the Brahmaputra, the Congo, the Yangtze, and the Orinoco. The rivers are located throughout all the earth's continents with the exception of Australia and the total for all these rivers comprise 52 % of world water resources. Shiklomanov (1998) observed that in many parts of the world, water resources have become so depleted and much contaminated that they are unable to meet the ever increasing demands. The effect of this on economic development and population growth has also been largely expressed. The spatial distribution of freshwater, even though well known to be varied on the global scale, is said to be wide in the arid regions which are known to

have limited water resources, a high degree of use and very fast demographic growth (Shiklomanov, 1998).

2.3 Water Resources Available for Irrigation in Sub-Saharan Africa

In some areas of the world, irrigation of crops is necessary to grow crops and supply the food needs of the population. As global populations grow coupled with the increasing demand for food together with the constant supply of water, the ability to produce food without challenges regarding the application of water is increasing in severity. The availability and quality of water indicates that it is a crucial resource with great implications for African development. Reports from the ECA (2006) indicate that the freshwater situation in Africa is not encouraging and of the estimated 800 million who live on the African continent, more than 300 million live in water-scarce environments.

The importance of water for socio-economic development is well recognized globally, but with increasing population and industrialization and their demands for water for various uses, water scarcity is looming in many countries of the world. Lack of water hampers development through constraining food production, health and industrial development (ECA, 2006).

Continentally, less than four percent (4 %) of Africa's renewable water resources are withdrawn for agriculture, domestic supply, sanitation and industry. There are, therefore, ample water resources available, that, if developed and managed sustainably, will enable Africa reach its water-related goals set within the framework of the MDGs and the Africa Water Vision 2025. Specifically, this called for an increase in the development of the water resources potential by 5 % by 2005, 10 % by 2015, and 25 % by 2025 as recommended in the

African Water Vision 2025 to meet increased demand from agriculture, hydropower, industry, tourism and transportation at the national level (ECA, 2006).

ECA (2006) reported that the vast majority of African countries are not tapping into the potential of irrigated agriculture. Barriers to this include lack of financial and human resources to build infrastructure and acquire technology.

South Asia and Sub-Saharan Africa (SSA) are the regions worst affected by food insecurity and malnutrition, being home to 60 % of the world's food-insecure people and 75 % of its malnourished children (Inocencio *et al.,* 2003). According to the ECA (2006) using the simplified model of society's response to water scarcity as a guide, the key issues in Africa are investing in the development of Africa's potential water resources, reducing drastically the number of people without access to safe water and adequate sanitation, ensuring food security by expanding irrigation areas and protecting the gains of economic development by effectively managing droughts, floods and desertification.

Economically, water-scarce countries potentially have enough water resources to meet their future needs, but they may not be in a position to make the additional investments required to actually harness and use these resources. This is the situation confronting most countries in SSA. Country-level situations and scenarios, however, mask significant differences within countries, both temporally and spatially. Some of these SSA countries have regions and river basins that already face serious physical water scarcity. An example is the Ewaso Ng'iro North basin in Kenya (Gichuki, 2002). Large disparities in freshwater withdrawals among the different regions whilst the proportion of water abstracted by the agriculture sectors is highest in less-developed regions relative to other uses. Table 2.1 indicates that per capita abstractions in developed countries are much higher than in developing countries, and lowest

in Africa. These low water withdrawals in SSA are an indicator of under-development and of the opportunity for further development of water resources (Inocencio *et al.*, 2003).

Table 2.1: Annual Freshwater Withdrawals by Region of the World

Region	Average Annual Internal Renewable Water Resources (m^3/Capita) 2000	Annual Freshwater Withdrawals Per Capita (m^3)	Agriculture (%)	Industry (%)	Domestic (%)
Europe	3,981	704	39	45	14
North America	21,583	1,907	25	66	8
South America	34,791	518	71	11	17
Asia	3,668	627	81	9	7
Africa	5,159	307	85	6	9
SSA	-	-	87	4	9
World	7,045	664	70	22	8

Sources: UNDP *et al.*, 2000; World Bank, 2000; FAO, 1995: In: Inocencio *et al.*, 2003.

With rapidly growing urban populations, agriculture will have to compete with increasing urban (municipal and industrial) water needs. Water allocation for agriculture gives way to higher-value urban uses that may adversly affect food production. With food production already lagging behind population growth in Africa, reduced allocations for agriculture may aggravate the problem of food security (Inocencio *et al.*, 2003).

In SSA, most wastewater used for irrigation is not treated. On the other hand, Barry (2002) reports that urban wastewater offers a stable source of supply, especially during droughts when governments give priority to urban water use. To address this probelm, taking into account the needs of both peri-urban farmers and the urban population, Barry (2002) emphasizes the importance of participatory development of peri-urban agriculture and integrating government planning, investment and extension related to wastewater treatment with its subsequent use by informal or private-sector farmers.

The continent's water resources, ample overall, are spread unevenly over a wide range of agro-ecological zones in which access to water can vary starkly and suddenly. Efforts to manage water and to make it available where it is most needed are hampered by long-term under-investment in irrigation and the water sector, by the undeveloped state of institutions for irrigation and water-resource management, and by the prevalence of subsistence farming. Ample groundwater resources in much of the continent also remain largely untapped, except in southern Africa (Svendsen *et al.*, 2008).

Countries of Sub-Saharan Africa have been noted to make less use of their relatively abundant water resources than do other regions of the world. The extent of that use; for irrigation and other purposes, can be considered (and measured) in terms of total water withdrawals, agricultural water withdrawals, the capacity to store surface water, and the extent to which use is made of groundwater (Svendsen *et al.*, 2008).

Total water withdrawals across the region are very low, averaging just 3 % of available supply (Table 2.2). South Africa with its large commercial irrigation sector, urban conglomerations, and well-developed industrial base, and Sudan with its vast Gezira scheme, dwarf other countries in this regard. By contrast, total withdrawals in Asia comprise almost one fifth of available water (19.4 %) (Svendsen *et al.*, 2008).

Table 2.2: Indicators and Baseline Values of Water Resource Use in Africa, Sub-Saharan Africa and the World

	Indicators (Percent)			
Region	Total Water Withdrawals as share of Total Renewable Water Resources	Agricultural Water Withdrawals as share of Total Renewable Water Resources	Dam Capacity as Share of Total Available Surface Water	Groundwater Pumped as a Percentage of Total Renewable Groundwater
Africa	3.8	3.3	14.6	-
SSA	1.5	1.3	11.2	-
Sudano-Sahelian	28.3	27.3	9.8	3.3
Eastern	5.7	4.9	5.5	3.1
Gulf of Guinea	2.2	1.5	61.7	0
Central	0.1	0.1	0.9	0
Southern	9.1	5.8	47.8	21
Indian Ocean Islands	4.4	4.2	0.1	8.7
Asia	19.4	15.8	12	-
World	7.4	5.2	7.6	-

- Indicates No Available Data

Source: FAO Aquastat Database; Global Groundwater Information System**:** *Adopted and Modified* from Svendsen *et al.,* 2008.

Compared with the rest of the world, a very small portion of Africa's territory is equipped for irrigation. And since 2000, the expansion of that area has slowed to a crawl. Just 6 % of the cultivated area in Africa is equipped for irrigation (3.9 % in the 24 sample countries), compared with 33.6 % in Asia and 17.7 % for the world as a whole (Table 2.3) (Svendsen *et al.,* 2008). Lower values reflect facilities that have deteriorated since construction and are no longer usable, areas in which water supply is insufficient to irrigate the entire area, and areas in which deficient management keeps available water from reaching the entire area. The average utilization rate is 69.4 % in the sample countries, comparable to the Asian average, but well below the global average (Svendsen *et al.,* 2008).

Table 2.3: Indicators and Baseline Values of Irrigation Area in Africa, Sub-Saharan Africa, Asia and the World

	Indicators (%)		
Region	Irrigation-equipped areas as share of cultivated area	Area actually irrigated as share of irrigation-equipped area	Water Managed area as share of cultivated area
Africa	5.8	81.6	6.7
SSA	3.5	71.0	4.5
Asia	33.6	66.9	34.3
World	17.7	92.4	17.6

Sources FAO Aquastat Database and Resource Stat Databases: Adopted and Modified from Svendsen, *et al.,* 2008 and McCartney, *et al.,* 2007.

In sub-Saharan Africa, substantial new investments in agriculture are needed to meet targets for poverty alleviation and food security. The FAO of the United Nations (UN) estimates that about 75 % of the growth in crop production required by 2030 will have to come from intensification in the form of yield increases (62 %) and higher cropping intensities (13 %) (FAO, 2002). At least some of this intensification will require development of water resources.

Agricultural and irrigation potential in Africa is huge. It is estimated that currently only 24 % (i.e. 2,820 million hectares) of arable land is under cultivation. Of this, it is estimated that just 0.5 % (i.e. 13 million ha) is under formal irrigation. Furthermore, for sub-Saharan Africa as a whole, annually renewable water resources are abundant though not evenly distributed.

Currently, total human abstractions amount to 73,620 million m^3, which equates to just 2 % of the annual renewable resource of 3,941,000 million m^3 (FAO, 2002).

As Africa's urban population rises, another increasingly common practice is the use of varying combinations of domestic sewage, industrial effluent and storm water, for irrigation

in urban and peri-urban environments. This use of wastewater is associated with environmental and health risks (Scott *et al.,* 2004; Drechsel *et al.,* 2006) such as salinization, eutrophication and pollution of soils and receiving drainage water with heavy metals and other toxic substances. At the same time, wastewater can be an important water and nutrient resource that may bring about improvements in health by improving socio-economic conditions of farmers and their families (Obuobie *et al.,* 2006). In Ghana, irrigated urban and peri-urban vegetable farming using polluted water was found to generate incomes for farmers ranging from US$500-700/y, depending on farm size, crop type and cropping intensity (Danso *et al.,* 2002).

2.4 Concept of Wastewater and Sewage

Wastewater according to Tchobanoglous and Burton (1995) is the combination of the liquid or water-carried wastes removed from residences, institutions, commercial and industrial establishments, together with such groundwater, surface water and storm water as may be present. It is also said that if wastewater is left untreated, and to accumulate, the decomposition of the organic materials it contains can lead to the production of large quantities of malodorous gases. Wastewater is known to contain numerous pathogenic or disease-causing microorganisms that dwell in the human intestinal tract or that may be present in certain industrial waste. Raschid-Sally and Jayakody (2008) looked at urban wastewater to be a combination of one or more of the following which makes it polluted water:

- Domestic effluent consisting of black water (excreta, urine and faecal sludge, i.e. toilet wastewater) and grey water (kitchen and bathing water),
- Water from commercial establishments and institutions, including hospitals,
- Industrial effluents where present and,

- Storm water and urban runoff.

Tchobanoglous and Burton (1995) also indicated that wastewater contains nutrients, which can stimulate the growth of aquatic plants and sometimes even toxic compounds. According to Frans *et al.* (2006), sewage is the wastewater generated by a community, namely: domestic wastewater, from bathrooms, toilets, kitchens, etc., raw or treated industrial wastewater discharged in the sewerage system, and sometimes rain-water and urban runoff (van Haandel and Lettinga, 1994).

Domestic wastewater is said to be the main component of sewage, and it is often taken as being synonymous. Sand and coarse material (paper, bottles, etc.) are not considered part of sewage. They are transported by sewage but handled as solid waste when they arrive at a treatment facility. The sewage flow rate and composition vary considerably from place to place, depending on economic aspects, social behaviour, type and number of industries in the area, climatic conditions, water consumption, type of sewer system, etc. Besides, there are seasonal, monthly, weekly, and hourly variations in both flow rate and composition. The main pollutants in sewage are suspended solids (SS), soluble organic compounds (SOC), faecal pathogenic micro-organisms and nutrients, but sewage is not just made up of human excrement and water. A variety of chemicals like heavy metals, trace elements, detergents, solvents, pesticides and other unusual compounds like pharmaceuticals, antibiotics, and hormones can also be detected in sewage. Direct discharge of raw or poorly treated sewage into the environment is one of the main sources of pollution on a global scale (Gijzen, 2002).

2.5 Wastewater Uses and Problems: Global Perspectives

According to Jiménez *et al.* (2010a), over the years wastewater has become less popular in developed countries with the improvement of treatment technologies and increased awareness of the environmental issues associated with the practice; by contrast, in developing countries,

due to a variety of factors, farmers use it extensively, even drawing advantages to improve their livelihoods. Wastewater and sludge, just as manure, have been used by northern European and Mediterranean civilizations. It was also reused in the 14th and 15th centuries in the Milanese Marcites and in the Valencia Huertas, respectively (Soulié and Tréméa, 1991). In many European and North American cities, wastewater was disposed off in agricultural fields before the introduction of wastewater treatment technologies to prevent pollution of water bodies and the environment. In Paris, for instance, the use of partially treated wastewater was common until the second part of the 1900s (Asano *et al*., 2007). The use of wastewater as a source of crop nutrient supply in countries such as China, Mexico, Peru, Egypt, Lebanon, Morocco, India and Vietnam, over many decades has been reported by AATSE (2004) and Jimenez and Asano (2008). The use of untreated wastewater in crop production has therefore been associated with man for a long time. Characteristics of countries using wastewater for irrigation by Jiménez *et al.* (2010a) are presented in Table 2.4.

Table 2.4: Some Characteristics of Countries Using Wastewater for Irrigation

Use of Wastewater for Irrigation	Total Number of Countries	GDP per capita for 50% of the Countries (in US$)	Sanitation coverage for 50% of the Countries (%)
Untreated	23	880-4800	15-65
Treated and Untreated	20	1170-7800	41-91
Treated	20	4313-19800	87-100

Source: Jiménez *et al.* (2010a).

Jiménez *et al*. (2010a) indicated that there is no comprehensive global inventory of the extent of non-treated wastewater used for irrigation and that even none exist for treated wastewater. An estimation of more than 4-6 million hectares of wastewater or polluted water irrigated fields have been estimated from countries providing data on irrigated areas as reported by

Jiménez and Asano (2008), Keraita *et al.*, (2008) and UNHSP (2008). In the developing world, Raschid-Sally and Jayakody (2008) reported that wastewater without any significant treatment is used for irrigation purposes in four out of five cities. The utilization of wastewater, however, varies from country to country and especially dependent on the geographic location and the freshwater resources that are available. Much higher quantities of this wastewater is reported to be used in developing countries, where 75 % of the world's irrigated land is located (UN, 2003), with a small amount being used in developed countries (Jiménez and Asano, 2008).

FAO (1992) reports on the beneficial use of wastewater that has been practiced in California since the 1890s, when raw sewage was applied on 'sewer farms'. By 1987, more than 0.899 million m^3/d of municipal wastewater (7-8 % of the production) were being used for the applications. Historically, agricultural use has dominated and continues to do so, but over the past decade reclaimed wastewater has been increasingly used for landscape irrigation in urban areas and for groundwater recharge. Most of the reclaimed water (78 %) is used in the Central Valley and South Coastal regions of California. Two hundred reclamation plants throughout California produce the volume of treated effluent indicated and save 0.759 million m^3/d of freshwater (FAO, 1992).

Problems associated with the use of wastewater in crop irrigation are connected with especially the disease pathogens carried by the water which affect health. According to Jiménez *et al.* (2010a), diseases are linked to the nature of the pathogen in the wastewater and thus vary locally following the local public-health pattern. Risks were reported not to be limited to farmers, but also in four groups: agricultural workers and their families; crop handlers; consumers of crops or meat and milk coming from cattle grazing on polluted fields; and those living on or near the areas where wastewater, sludge or excreta is used.

Wastewater according to Abaidoo *et al.* (2009) can be a source of high levels of heavy metals and toxic compounds. Contamination as noted by Jiménez (2006) regarding metals and organic chemicals occurs through absorption from the soil, which depends on location, environmental conditions, bio-availability and type of plant and agricultural practices.

Recommended levels of heavy metals as contained in wastewater that crops and soil can be exposed have been reported severally by Page and Chang (1994) and UNHSP (2008). Even though the use of wastewater for crop fertilization is said to be possible in both developed and developing countries as a result of the low levels (Jiménez and Wang, 2006; UNHSP, 2008), Abaidoo *et al.* (2009) indicated that care has to be taken when dealing with wastewater close to tanneries and mining areas.

2.6 Utilisation of Wastewater in Developing Countries

Lack of reliable and sufficient information and the use of different units and terms in describing the activities and practices related to wastewater in developing countries have been mentioned by Jiménez *et al.*, (2010b). Rashid-Sally and Jayakody (2008) reported from a survey across the developing world that wastewater without any significant treatment is used for irrigation purposes in four out of five cities. UN (2003) noted that 75 % of the worlds irrigated land is located in developing countries and the volume of wastewater used for various purposes varies from country to country. Across major cities in West Africa, 50-90 % of vegetables consumed by urban dwellers are produced within or close to the city (Drechsel *et al.*, 2006) and the source of irrigation water has been said to be mainly polluted.

The use of grey water for gardening and irrigation of non-edible crops in low and middle income countries such as India, Mali, Jordan, Palestine, South Africa, Nepal, Sri Lanka, Costa Rica and Malaysia has been reported by Morel and Diener (2006). Grey water in most

cities of sub-Saharan Africa is channelled into drains where it often gets mixed with storm water, solid waste and excreta from open defecation before it enters natural water bodies. The wastewater contained in these drains is, however, used for irrigation and it is difficult to distinguish between grey water and wastewater use (Cornish and Lawrence, 2001; Drechsel *et al.,* 2006; Qadir *et al.,* 2007).

2.7 Wastewater Generation and Utilization in Ghana

According to Agodzo *et al*. (2003), most of urban Ghana does not have the required infrastructure to manage wastewater and the costs of putting in place the required infrastructure to effectively collect and dispose of all urban waste is prohibitive. It will simply be a matter of time for Ghana to move to such levels of development where urban wastewater can be discharged at logical points and safely. Basically, 85 % of wastewater generated from urban centres worldwide ends up in the environment in its untreated form. In Ghana, only a minor share of the wastewater is treated and less than 5 % of the population has sewerage connections (Obuobie *et al.,* 2006).

Agodzo *et al.* (2003) estimated that, potentially, between 0.76 and 2.1 × 10^6 m^3/d of wastewater can be generated by urban Ghana, between the period 2000 and 2020. If only 10 % of the generated wastewater will be used for agriculture, this could irrigate between 4,600 and 12,700 ha of urban land per year generating employment for between 9,200 and 25,400 farmers. The wastewater flow estimates for urban Ghana and the 10 regional capitals of Ghana are based on the per capita water consumption rates. However, the 10 % is not based on any assumption except to show what is possible.

In 2000, the total urban wastewater generated for the year could reach 278.7 × 10^6 m^3 and that for the 10 regional capitals 178.3 × 10^6 m^3 for the same year. That in the regional capitals alone could generate as much as 64 % of all the wastewater. Projected into 2020 urban Ghana could generate as much as 763.4 × 10^6 m^3 and the regional capitals 405.8 × 10^6 m^3 (53 % of total wastewater) for the same year (Agodzo *et al.,* 2003).

Based on an average per capita daily consumption of 60 l and a wastewater flow of 80% (Cofie and Awuah, 2008), it is estimated that a population of 371,351 (GSS, 2012) will generate approximately 18,000 m^3 of wastewater per day in the Tamale Metropolis.

Water consumption within the period in Ghana increased by 39.71 % but production levels could only increase by 26.85 %. The use of potable water for urban/peri-urban crop production in Ghana is constrained by high tariffs, making it uneconomical and non-viable (Sonou, 2001).

Wastewater utilisation in Ghana has gained some level of prominence especially in the major cities of the country. As a result of the nutrient value of wastewater coupled with increased demand for food in the urban areas, its use in urban agriculture is increasing. The wastewater is normally used in its untreated form and in Ghana, Obuobie *et al.* (2006) reported that only a minor share of the wastewater is treated and less than 5 % of the population has sewerage connections. They also indicated that urban and peri-urban smallholders in search of irrigation water hardly find any unpolluted surface water or end up using water from drains.

Biological oxygen demand (BOD) contained in wastewater in Dakar and Ghana was reported to show high values (Cornish *et al.,* 1999). This indicates the presence of organic matter and high concentrations of nitrogen and phosphorus that constitute essential nutrients for proper plant development (Sonou, 2001).

According to Keraita *et al.* (2002) and Obuobie *et al*. (2006) an estimated 3,300 ha of irrigated area in Ghana use wastewater for crop irrigation and this was said to be equivalent to about 60 % of the actual total area cropped under irrigation in the country. Even though wastewater irrigation in the cities is gaining recognition, the largest cities of Accra, Kumasi, Tamale and Takoradi are leading in this business. The use of raw or untreated wastewater for the production of food crops especially those eaten raw present a high level of risk to health. It has been observed by Drechsel *et al.* (2006) that most of the health issues related to the use and consumption of vegetables irrigated with wastewater are microbiologically linked. The use of wastewater presents a number of benefits to the user and the crops directly as well as challenges or problems.

Due to the increasing demand of freshwater for especially domestic use, wastewater presents itself as an alternative to water as a limited resource. The use of wastewater for crop production serves the purpose of providing employment to the farmers and the traders of the produce. It has been reported by Obuobie *et al.* (2006) that farmers in Accra, Kumasi and Takoradi earn an average monthly income of about US$ 49, 98 and 20 respectively. In the utilisation of the wastewater, a lot of savings are made by farmers as a result of the nutrient value of the resource. The environmental benefit of the reduction in the environmental effect of the disposal of the wastewater is therefore observed to be impacting positively on the maintenance of an environmental balance.

2.8 Composition and Characteristics of Wastewater

The physico-chemical and bacteriological qualities of wastewater are subsequently reviewed.

2.8.1 Physical Characteristics of Wastewater

Temperature

Temperature of wastewater is said to be commonly higher than that of the normal water supply because of the addition of warm water from households and industrial activities (Tchobanoglous and Burton, 1995). It has been pointed out that as the specific heat of water is much greater than that of air, the observed wastewater temperatures during most of the year are lower only during the hottest summer months. Tchobanoglous and Burton (1995) indicated that depending on the geographic location, the mean annual temperature of wastewater varies from about 10 to 21^{o}C. This value also greatly depends on the time of the year or the month in which measurements were taken and the effluent temperatures can either be higher or lower than the corresponding influent values.

Tchobanoglous and Burton (1995) further noticed that the temperature of water is a very important parameter because of its effect on chemical reactions and reaction rates, aquatic life and the suitability of the water for beneficial uses.

Oxygen has been indicated by Tchobanoglous and Burton (1995) to be less soluble in warm water than in cold water. The increase in the rate of biochemical reactions that accompanies an increase in temperature, combined with the decrease in the quantity of oxygen present in surface waters, can often cause serious depletions in dissolved oxygen concentrations in the summer months. When significantly large quantities of heated water are discharged to natural receiving waters, these effects are magnified. Tchobanoglous and Burton (1995) mentioned that optimum temperatures for bacterial activity are in the range of 25 to 35 ^{o}C. Aerobic digestion and nitrification stop when temperature rises to 50 ^{o}C. When temperature drops to about 15 ^{o}C, methane – producing bacteria become quite inactive, and at about 5 ^{o}C, the

autotrophic-nitrifying bacteria practically cease functioning. At 2 ^{o}C, even the chemo-heterotrophic bacteria acting on carbonaceous material become essentially dormant.

Total Solids (TS)

Tchobanoglous and Burton (1995) defined total solid content of wastewater as all the matter that remains as residue upon evaporation at 103-105 ^{o}C. Matter that has a significant vapour pressure at this temperature is lost during evaporation and is not defined as solid. Settleable solids are those solids that will settle to the bottom of a cone-shaped container (Imhoff cone) in a 60-minute period. Dissolved solids consist of both organic and inorganic molecules and ions that are present in true solution in water.

pH

The hydrogen-ion concentration is an important quality parameter for both natural waters and wastewaters. The concentration range suitable for the existence of most biological life is quite narrow and critical. Wastewater with an adverse concentration of hydrogen-ion is difficult to treat by biological means, and if the concentration is not altered before discharge, the wastewater effluent may alter the concentration in natural waters (Tchobanoglous and Burton, 1995). Alkalinity in wastewater results from the presence of hydroxides, carbonates, and bicarbonates of elements such as calcium, magnesium, sodium, potassium or ammonia. The alkalinity in wastewater helps to resist changes in pH caused by the addition of acids. Wastewater is normally alkaline, receiving its alkalinity from the water supply, the groundwater and the materials added during domestic use.

2.8.2 Macro Nutrients in Wastewater

Nitrogen and phosphorus have been indicated to be essential to the growth of protista and plants and as such are known as nutrients or bio-stimulants. Trace quantities of other

elements, such as iron, are also needed for biological growth, but nitrogen and phosphorus are, in most cases, the major nutrients of importance (Tchobanoglous and Burton, 1995). Wastewater has been noted to contain a variety of plant nutrients necessary for crop growth.

It is estimated that 1000 m^3 of municipal wastewater used to irrigate one hectare can contribute 16-62 kg total nitrogen, 4-24 kg phosphorous, 2–69 kg potassium, 18–208 kg calcium, 9–110 kg magnesium, and 27–182 kg sodium (Qadir *et al.,* 2007).

The nutrient concentration of wastewater even though has a very important role to play in relation to plant growth may have deleterious effect when in excess of the recommended levels. This includes plant toxicity and even the promotion of excessive vegetative growth amongst others.

Jiménez *et al.* (2010b) indicated that few studies have reported on the level of economic gains made from nutrients contained in wastewater under actual field conditions. In Guanajuato, Mexico, Keraita *et al*. (2008) report that the estimated saving arising from using wastewater to supply the required nitrogen and phosphorous for crops was US $135/ha. The annual income of farmers from India, Ghana, Senegal, Kenya and Mexico varied from US$ 420 to US$ 2800 /ha/y.

Nitrogen Compounds

Nitrogen is a necessary macro-nutrient for plants that can be found in wastewater as nitrate, ammonia, organic nitrogen and nitrite (WHO, 2006b). The sum of all these forms is known as total nitrogen. Most plants absorb nitrate only, but normally the other forms are transformed into nitrates in the soil (NRC, 1996). Nevertheless, only 50 % of the ammonia and 30 % of organic nitrogen are assimilated by plants, and the rest is lost during transformation through several mechanisms, such as volatization (Girovich, 1996). The main problem with nitrogen is that nitrates are very soluble in water, which is why, when irrigating crops, most of it is

washed out. Often, this cannot be controlled, because many crops require large quantities of water to grow properly (Pescod, 1992). The quantity of nitrogen washed out depends mainly on the irrigation rate, the soil characteristics and the nitrogen content of the wastewater. Nitrogen needs to be added for each agricultural cycle, and nitrogen removed from the soil's nitrogen content (0.05–2 %) and the crop demand, which oscillates between 50 and 350 kg of nitrogen per hectare, depending on the stage of the cropping cycle (Girovich, 1996). Nitrates are stable in groundwater and can build up to concentrations that might contribute to methaemoglobinaemia in bottle-fed infants if this water is used to prepare infant formulas (WHO, 2004).

Excessive concentrations of nitrogen in wastewater can lead to over fertilization and cause excessive vegetative growth, delayed or uneven crop maturity and reduced quality (Jiménez, 2006; Qadir *et al.*, 2007). Nitrogen levels in sewage has been reported to range from 20 to > 100 mg/l, depending on in-house water use and diet of the local people and on the treatment of the sewage effluent prior to Soil-Aquifer Treatment (SAT) (Pescod, 1992). According to Pescod (1992) secondary effluent of much of the nitrogen will often be in the ammonium form but some processes are designed to achieve nitrification and the effluent will then contain primarily nitrate-nitrogen. Raw sewage has been reported to have considerable organic nitrogen.

Phosphorus

Pescod (1992) indicated that sewage effluent can contain 5 to 50 mg/l phosphorous, depending on diet and water use of the local population. During pre-treatment of the sewage, and in passage through the soil of the SAT system, organic phosphorus is biologically converted to phosphate.

In calcareous soils and at alkaline pH, phosphate precipitates with calcium to form calcium phosphate. In acid soils, phosphate reacts with iron and aluminium oxides in the soil to form

insoluble compounds. Pescod (1992) added that sometimes, phosphate is initially immobilized by adsorption to the soil and then slowly reverts to insoluble forms, allowing more adsorption of mobile phosphate, etc. In clean sands with about neutral pH, phosphate can be relatively mobile.

Phosphorus according to WHO (2006b) is noted to be often scarce in soils in a form that is bio-available to plants and almost always needs to be added with fertilizers. Phosphorus is relatively stable in soils and may contribute in them, especially at or near the soil surface. Wastewater normally contains low amounts of phosphorus, so its use for irrigation is beneficial and does not negatively impact the environment (Girovich, 1996). This is the case even when wastewater effluents with high concentrations of pathogens (e.g. effluents from dairy factories) are applied over long periods of time (Degens *et al.,* 2000). However, because phosphorus builds up at the soil surface, it can affect surface waters through soil erosion and runoff.

The mining of phosphate causes environmental damage because it is often removed close to the surface in large open mines, leaving behind scared lands. Approximately 25 % of the mined phosphorus ends up in aquatic environments or buried in landfills or other sinks (Tiessen, 1995). This causes eutrophication of water bodies, leading to more environmental damage. Moreover, to reduce eutrophication from phosphorus in wastewater discharged into surface waters, wastewater treatment plants require expensive, complex processes to remove it. Thus, the use of wastewater in agriculture recycles phosphorus, minimizes environmental impacts and reduces the costs of wastewater treatment to meet environmental regulations (EcoSanRes, 2005). As a result of the global phosphorous crises, excreta and wastewater can be critical sources of phosphorous (Rosemarin, 2004).

Potassium

This is a macro-nutrient that is present in high concentrations in soils (3% of the lithosphere) but is not bio-available, since it is bound to other compounds. Therefore, potassium needs to be added to soils through fertilizers. Approximately 185 kg/ha of potassium is required. Wastewater contains low potassium concentrations, insufficient to cover the theoretical demand. The use of wastewater in agriculture does not normally cause negative environmental impacts associated with potassium (Mikkelsen and Camberato, 1995).

2.8.3 Biochemical Oxygen Demand (BOD)

Biochemical Oxygen Demand (BOD) is the amount of dissolved oxygen needed by aerobic biological organisms in a body of water to breakdown organic material present in a given water sample at certain temperature over a specific time period.

Numerous studies carried out worldwide show that wastewater contains high organic matter and fertilizing potential that can enrich and recondition agricultural soils to increase crop production (Birley and Kock, 1999). This was confirmed by analyses carried out on some wastewater bodies in Dakar and Ghana that showed high values of BOD (Cornish *et al.*, 1999). This indicated the presence of organic matter and high concentrations of nitrogen and phosphorus that constitute essential nutrients for proper plant development (Sonou, 2001). The benefits of the application of wastewater are constrained by the presence of pathogens, heavy metals and other pollutants that can be a health hazard to the consumers of agricultural produce.

2.8.4 Heavy Metals in Wastewater Used for Irrigation

Excessive concentrations of some trace elements may also cause plant toxicity and sometime become a health risk for crop farmers (Jiménez *et al*., 2010a). There are also contributions

from anthropogenic sources, including mining, incineration, production of plastics, nuclear radiation, fossil fuel burning from vehicles and power generating plants (Maisto *et al.,* 2003; Nicola *et al.,* 2003). Some of these heavy metals are picked up by the roots of plants growing in soils and are stored in different parts of the plants in different concentrations based on the type of plant (Chang *et al.,* 1997; Kulli *et al.,* 1999). Some metals and metalloids are essentially required for adequate plant growth, but are toxic at elevated concentrations (Table 2.5); e.g. copper (Cu), zinc (Zn), iron (Fe) Aluminium (Al) and Manganese (Mn) (Qadir and Scott, 2010).

Table 2.5: Recommended Maximum Concentrations (RMC) of Selected Metals and Metalloids in Irrigation Water

Element	RMC mg l^{-1}	Remarks
Aluminium	5.00	Can cause non-productivity in acid soils (pH < 5.5), but more alkaline soils at pH > 7.0 will precipitate the ion and eliminate any toxicity.
Arsenic	0.10	Toxicity to plants varies widely, ranging from 12 mg/l for Sudan grass to less than 0.05 mg/l for rice.
Beryllium	0.10	Toxicity to plants varies widely, ranging from 5 mg/l for kale to 0.5 mg/l for bush beans.
Cadmium	0.01	Toxic at concentrations as low as 0.1 mg/l in nutrient solution for beans, beets and turnips. Conservative limits recommended.
Chromium	0.10	Not generally recognized as an essential plant growth element. Conservative limits recommended.
Cobalt	0.05	Toxic to tomato plants at 0.1 mg/l in nutrient solution. It tends to be inactivated by neutral and alkaline soils.
Copper	0.20	Toxic to a number of plants at 0.1 to 1.0 mg/l in nutrient solution.
Iron	5.00	Non-toxic to plants in aerated soils, but can contribute to soil acidification and loss of availability of phosphorus and molybdenum.
Lithium	2.50	Tolerated by most crops up to 5 mg/l. Mobile in soil. Toxic to citrus at low concentrations with recommended limit of < 0.075 mg/l.
Manganese	0.20	Toxic to a number of crops at few-tenths to a few mg/l in acidic soils.
Molybdenum	0.01	Non-toxic to plants at normal concentrations in soil and water. Can be toxic to livestock if forage is grown in soils with high concentrations of available molybdenum.
Nickel	0.20	Toxic to a number of plants at 0.5 to 1.0 mg/l; reduced toxicity at neutral or alkaline pH.
Lead	5.00	Can inhibit plant cell growth at very high concentrations.
Selenium	0.02	Toxic to plants at low concentrations and toxic to livestock if forage is grown in soils with relatively high levels of selenium.
Zinc	2.00	Toxic to many plants at widely varying concentrations; reduced toxicity at pH≥ 6.0 and in fine textured or organic soils.

The maximum concentration is based on a water application rate which is consistent with good irrigation practices (10,000 m^3 ha^{-1} yr^{-1}). If the water application rate greatly exceeds this, the maximum concentrations should be adjusted downward accordingly. No adjustment should be made for application rates less than 10,000 m^3 ha^{-1} y^{-1}. The values given are for water used on a long-term basis at one site. *Source:* Ayers and Westcot (1985); Pescod (1992)

Copper

Copper (Cu) is an essential element for plant growth and plays a significant role in many physiological processes, including photosynthesis, respiration, carbohydrate distribution, nitrogen fixation, protein metabolism, antioxidant activity, cell wall metabolism and hormone perception. In general, copper concentrations in cells need to be maintained at low levels. However, plants usually find an ample supply of copper in soils, and copper at high concentrations can be a stress factor triggering physiological responses (Yruela, 2005). At the cellular level, copper is a structural and catalytic component of many proteins and enzymes involved in a variety of metabolic pathways (Pilon *et al*., 2006).

Zinc

Zinc is essential for the normal healthy growth and reproduction of plants, animals and humans and when the supply of plant-available zinc is inadequate, crop yields are reduced and the quality of crop products is frequently impaired. In plants, zinc plays a key role as a structural constituent or regulatory co-factor of a wide range of different enzymes and proteins in many important biochemical pathways and these are mainly concerned with (Alloway, 2008):

1. Carbohydrate metabolism, both in photosynthesis and in the conversion of sugars to starch,
2. Protein metabolism,
3. Auxin (growth regulator) metabolism,
4. Pollen formation,
5. The maintenance of the integrity of biological membranes and
6. The resistance to infection by certain pathogens.

Zinc reaching soil by effect of human activities is more mobile than native zinc (Kabata Pendias and Pendias, 2001) and can easily enter the soil solution, thereby increasing its own bioavailability – but also, at high enough levels, causing phytotoxicity problems (Pérez-Novo *et al.,* 2011).

Aluminium

Aluminium (Al) is the most abundant metal in the earth's crust, comprising about 7 % of its mass. Since many plant species are sensitive to micromolar concentrations of aluminium, the potential for soils to be aluminium toxic is considerable. Fortunately, most of the aluminium is bound by ligands or occurs in other non phytotoxic forms such as aluminosilicates and precipitates. However, solubilization of this aluminium is enhanced by low pH and Aluminium toxicity is a major factor limiting plant production on acid soils. Soil acidification can develop naturally when basic cations are leached from soils, but it can be accelerated by some farming practices and by acid rain (Kennedy, 1986). According to Delhaize and Ryan (1995), the most easily recognized symptom of A1 toxicity is the inhibition of root growth, and this has become a widely accepted measure of A1 stress in plants. If the soil becomes acidic, aluminium is solubilized into toxic forms like $[Al\ (H_2O)_6]^{3+,}$ generally referred to as $Al^{3+,}$ which is now present in 40 % of the arable lands in the world. Excess Al^{3+} in soil enters roots, resulting in reduced plant vigour and yield (Delhaize and Ryan, 1995; Matsumoto, 2000; Ciamporová, 2002).

Manganese

Manganese (Mn) is the eleventh abundant element forming the earth's crust. In terms of abundance, manganese-containing compounds are after iron (Fe) in the earth's crust. Total amount of manganese in the soil is between 20 to 3000 ppm and 600 ppm on average.

Divalent manganese is absorbed by clay minerals and organic material, and in terms of nutrition of plants, divalent manganese ions (Mn^{2+}) is most important (Malakouti and Tehrani, 1999). In the soil, manganese occurs as exchangeable manganese, manganese oxide, organic manganese and component of ferro-manganese silicate minerals. The manganese ion (Mn^{2+}) is similar in size to magnesium (Mg^{2+}) and ferrous iron (Fe^{2+}) and can substitute for these elements in silicate minerals and iron oxides. Manganese reactions in soils are quite complex. The amount of available manganese is influenced by soil pH, organic matter, moisture, and soil aeration (Schulte and Kelling, 1999).

Manganese and iron (Fe) has an interaction in plants, iron uptake by plants affects with high amounts of manganese in the soil; the same (Fe imposed deficiency by Mn) can exacerbate the problems caused by manganese toxicity in plants. Moreover, if the amount of iron in the soil is too much, then it can cause manganese deposits and manganese uptake to be reduced for the plant (Michael and Beckg, 2001; Malakouti and Tehrani, 1999).

Iron

Iron is one of 16 essential elements for plant growth and reproduction and one of the most abundant elements on the planet. The most abundant form of Fe in soils is ferric oxide (Fe_2O_3) or hematite, which is extremely insoluble and imparts a red colour to the soil. The oxide form is commonly hydrated. In aerobic soils, the oxide, hydroxide and phosphate forms control the concentration of Fe in solution and its availability to plants (Hochmuth, 2011).

Although required by plants in small amounts, Fe is involved in many important compounds and physiological processes in plants. Iron is involved in the manufacturing process of chlorophyl, and it is required for certain enzyme functions (Hochmuth, 2011).

2.9 Soil and Heavy Metal Bioaccumulation

Sewage effluent has been reported to contain a wide spectrum of other chemicals at low concentrations and these include heavy metals that, fluorine and boron (Pescod, 1992). Unless these elements were already present in large concentrations in the drinking water or added to the sewage water in significant amounts by industrial discharges, their concentrations in sewage are usually below the maximum limits for irrigation water (FAO, 1985).

Metals are significantly retained in most soils but a high pH favours immobilization (Pescod, 1992). Bioaccumulation takes place when substances are taken in the food and water. These substances accumulate because they cannot be taken in faster than they are used up by organisms. Bioaccumulation is not hazardous when the substance accumulator is not harmful, but when compounds and heavy metals are harmful to human health accumulate like mercury, then bioaccumulation become dangerous (Brookes and Grath, 1984).

When cadmium, zinc, lead, mercury, arsenic, copper, chromium, nickel and manganese accumulate in the soil over long periods, they reduce food quality and quantity. A high heavy metals load in the soil reduces the functioning of soil biota resulting in reduced microbial activity (Kandeler *et al*., 1996). The rate of uptake of nutrient ions by plant roots depends largely on their concentration in the soil solution at the root surface and on replenishment in solution. The same applies to ions that are not essential nutrients. Desorption also depends on the activity of microorganisms, which change the pH at micro sites and form soluble organic complexes, on proton release by roots, the effect being greatest in the rhizosphere (Wild, 1996). If these plants are harvested for human use, exposure to harmful levels of metals can happen. Normally, this is a concern only if plants are collected from areas with high concentrations of metals in the soil. Metals uptake by plants is dependent on soil acidity (pH).

The higher the acidity, the more soluble and mobile the metals become, and the more likely they are to be taken up and accumulated in plants. In general, humans are more likely to be exposed to metal contamination from soil that sticks to plants than from bioaccumulation. This is because it is very difficult to wash all soil particles off plant materials before preparing and ingesting them. Root crops (like potatoes and carrots), leafy vegetables (like spinach and lettuce) and parts of plants that grow near the soil are a higher risk for exposure to metal contamination (Martin and Griswold, 2009). Heavy metals are easily accumulated in the edible parts of leafy vegetables as compared to grain or fruit crops (Mapanda, *et al.,* 2005). Vegetables take up heavy metals and accumulate them in their edible (Bahemuka and Mubofu, 1991) and inedible parts in quantities high enough to cause clinical problems both to animals and human beings consuming these metal-rich plants (Alam *et al.,* 2003).

2.10 Biological Constituents of Wastewater

Most pathogens associated with wastewater have been observed by several authors to survive for long period of time in soils and crop surfaces and consequently transmitted to humans or animals. Helminth eggs, viruses, protozoa, bacteria and fungi are observed to be the common pathogens associated with wastewater.

2.10.1 Helminth Eggs

According to WHO (2006b) pathogens most resistant in the environment are helminth eggs, which in some cases can survive for several years in the soil. The common helminth eggs identified from analyzed selected vegetables in Ghanaian markets by Oboubie *et al*. (2006) indicated that *Ascaris lumbricoides, Ancylostoma, Trichostrongylus, Schistosoma haematobium* and *Trichuris trichiura* were common. Also identified during the study were

Strongyloides stercoralis and *nuaplius* larvae. The presence of helminth eggs and survival depend largely on the viability of the eggs.

The WHO (2006b), indicated that irrigation with wastewater at a quality of ≤ 1 egg per litre results in no detectable contamination. In Brazil, a study conducted by Ayres *et al*. (1992) when lettuce was spray-irrigated with effluent from waste stabilization ponds, the levels of crop contamination decreased with increased pond retention time, from anaerobic pond through to maturation pond.

Stott *et al.* (1994) in a study in a green house with seeded effluent (*Ascaridia galli*) indicated that irrigation with wastewater containing 10 eggs per litre resulted in low levels of nematode contamination on lettuce (maximum of 1.5 eggs per plant) and improving wastewater quality further to ≤ 1 egg per litre resulted in very slight contamination of some plants (0.3 egg per plant). No transmission of *Ascaridia galli* infection was found from wastewater-irrigated crops using animal studies, although the infective dose was very low at < 5 embryonated eggs.

There is some evidence in adult men that consumption of vegetables irrigated with untreated wastewater (< 100 eggs per litre) had a greater effect than irrigation with treated wastewater (< 1 egg per litre), but this did not reach statistical significance. A descriptive (ecological) study provides suggestive evidence that treatment using sedimentation and biological oxidation reduces the risks of *Ascaris* among consumers of uncooked vegetables to below the levels seen where no wastewater irrigation takes place (WHO, 2006b).

In a study by Ackerson and Awuah (2012) in Kumasi, Ghana, helminth eggs identified in water samples exceeded the WHO (2006b) recommended level of ≤ 1 egg l^{-1} for unrestricted irrigation. The high population according to the authors was probably due to high poultry manure run-off from the field and also poor sanitation and hygiene on the farm sites.

Helminth Ova Characteristics

An important characteristic of helminth ova is that they have a shell that consists of 3-4 basic layers with a specific chemical composition: a lipoid inner layer, a chitinous middle layer and outer protein layer. All these layers render the eggs very resistant to several environmental conditions. Helminth ova of concern in the sanitary field have a size between 20 to 80 μm and a density of 1.06 - 1.15 (Ayres *et al*., 1992) and are very sticky. All these properties determine helminth ova's behaviour during treatment. First, it is very difficult to inactivate them unless the temperature is above 40 ^{o}C or moisture is reduced to below 5 % (TS > 95 %), according to Feachem *et al*. (1983). But details about the contact time under these conditions and other related environmental factors are generally not known. Only contact time at temperatures of around 40 ^{o}C has been established for one genus of helminth, *Ascaris.* These inactivation conditions cannot be achieved in wastewater treatment but are common in sludge treatment. Thus, helminth ova are removed from wastewater and inactivated in sludge.

Helminth Ova Removal from Wastewater

Helminth ova are particles forming a fraction of the suspended solids. Actually, the helminth ova content is related to the suspended solids (TSS) and in particular to the 20-80 μm particle content. Both correlations are useful for tracking process performance when indirectly evaluating helminth ova in wastewater. However, it seems that this correlation is not universal and needs to be established for each type of wastewater and treatment process. Nevertheless, it is worth it because 70 USD are needed to determine helminth ova content using the optical microscope procedure, while the TSS or the particle evaluation procedures have a cost of 7-12 USD or 3 USD per sample, respectively (Chavez *et al.*, 2004).

2.10.2 Viruses

Several types of viruses have been observed to be present in wastewater or crops irrigated with virus contaminated wastewater. Some of these viruses include: *rotavirus, reovirus, poliovirus, parvovirus, norovirus, hepatitis E virus, hepatitis A virus, enteroviruses, echovirus, coxsackievirus A, coxsackievirus B, coronavirus, calicivirus, astrovirus, adenovirus, echovirus, etc.* These viruses result in several diseases such as respiratory disease, eye infections, gastroenteritis, herpangina, aseptic meningitis, respiratory illness, fever, paralysis, heart and kidney diseases, rash infection hepatitis, etc (Edwards, 1992; NRC, 1998). The survival of these viruses according to Strauss (1985) and Jimenéz (2003) are dependent on environmental factors such as humidity, soil content, temperature, pH, sunlight (uv radiation), foliage/plant type and competition with native fauna and flora. According to WHO (2006b) most of the studies conducted with viruses have been based on wastewater or water seeded with viruses. The survival times of 1–13 days was observed by Ward and Irving (1987), when the irrigation water contained between 5.1×10^2 and 2.6×10^5 type 1 poliovirus VU per litre.

2.10.3 Protozoa

Crop contamination reports by protozoa present in wastewater used for irrigation is said to be limited. Armon *et al.* (2002) found that Zucchini spray-irrigated with poor-quality wastewater (>100 oocysts per litre) accumulated higher levels of *Cryptosporidium* oocysts (80-10000 oocysts per 0.5 kg) on the surface than other types of crops. In Peru a study by Ortega *et al.* (1997) *Cryptosporidium* and *Cyclospora* oocysts were identified on produce sold in markets. Contamination in this case was suggested to have resulted from the use of sewage-contaminated surface water for irrigation rather than the direct use of wastewater for irrigation.

2.10.4 Thermotolerant Bacteria

Bacteria commonly present in wastewater are thermotolerant bacteria and of which are basically faecal and total coliforms. Contamination of vegetable crops by these bacteria has been noted to vary greatly from the entry point concerned. According to Obuobie *et al.* (2006) lower levels of both total and faecal coliform populations were recorded for vegetable samples from Kumasi compared to those from Accra and Tamale. The reason for the difference is linked closely with the source of water as shallow wells are used in the Kumasi area whilst in Accra and Tamale water for irrigation is mainly from drains. The mean coliform count of 1 x 10^3/100 ml is recommended by WHO (2006a) for unrestricted irrigation of crops likely to be eaten raw.

Total Coliform Bacteria

General Description

The term "total coliforms" refers to a large group of gram-negative, rod-shaped bacteria that share several characteristics. The group includes thermotolerant coliforms and bacteria of faecal origin, as well as some bacteria that may be isolated from environmental sources. Thus, the presence of total coliforms may or may not indicate faecal contamination. In extreme cases, a high count for the total coliform group may be associated with a low, or even zero, count for thermotolerant coliforms. Such a result would not necessarily indicate the presence of faecal contamination. It might be caused by entry of soil or organic matter into the water or by conditions suitable for the growth of other types of coliform. In the laboratory, total coliforms are grown in or on a medium containing lactose, at a temperature of 35 or 37 °C. They are provisionally identified by the production of acid and gas from the fermentation of lactose (UNEP/WHO, 1996).

Indicator Value

Total coliforms include organisms that can survive and grow in water. Hence, they are not useful as an index of faecal pathogens, but they can be used as an indicator of treatment effectiveness and to assess the cleanliness and integrity of distribution systems and the potential presence of biofilms. However, there are better indicators for these purposes. As a disinfection indicator, the test for total coliforms is far slower and less reliable than direct measurement of disinfectant residual. In addition, total coliforms are far more sensitive to disinfection than are enteric viruses and protozoa. Heterotrophic Plate Count (HPC) measurements detect a wider range of microorganisms and are generally considered a better indicator of distribution system integrity and cleanliness (WHO, 2008). Total coliform bacteria (excluding *E. coli*) occur in both sewage and natural waters. Some of these bacteria are excreted in the faeces of humans and animals, but many coliforms are heterotrophic and able to multiply in water and soil environments. Total coliforms can also survive and grow in water distribution systems, particularly in the presence of biofilms (WHO, 2008).

Faecal Coliforms

General Description

The term "faecal coliform" has been used in water microbiology to denote coliform organisms which grow at 44 or 44.5 ^{o}C and ferment lactose to produce acid and gas. In practice, some organisms with these characteristics may not be of faecal origin and the term "thermotolerant coliform" is, therefore, more correct and is becoming more commonly used. Nevertheless, the presence of thermotolerant coliforms nearly always indicates faecal contamination. Usually, more than 95 % of thermotolerant coliforms isolated from water are the gut organism *Escherichia coli*, the presence of which is definitive proof of faecal contamination. As a result, it is often unnecessary to undertake further testing to confirm the

specific presence of *E. coli*. In the laboratory, thermotolerant coliforms are grown on media containing lactose, at a temperature of 44 or 44.5 °C.

Indicators of Faecal Contamination

For the microbiological analysis of water samples in relation to human health, it is necessary to determine principally the pathogenic organisms. Detection of all possible pathogens would be a costly and very time consuming process. Methods have, therefore, been developed which detect organisms which are indicative of the presence of faecal pollution, such as the normal intestinal bacteria. If evidence for faecal material is found in a water sample it can be assumed that faecal pathogens may be present and if no evidence is found it is likely, although not totally certain, that the water is safe for human use. Examination of water samples for the presence of faecal bacteria is a sensitive technique indicating recent faecal contamination. The organisms most commonly used as indicators of faecal pollution are the coliform bacteria, particularly *Escherichia coli* and other faecal coliforms. A count of total viable bacteria in a freshwater sample can distinguish between freshwater species and those from human and animal faeces by their different optimal growth temperatures. Water bacteria show optimal growth at 15 to 25 °C (i.e. incubation at 22 °C) and faecal bacteria at 37 °C. Careful sample handling and processing methods are necessary to ensure that there is no contamination from other sources and helps to prevent excess growth of any bacteria present in a water sample. Absence of faecal bacteria in any single sample does not guarantee the absence of faecal contamination (UNEP/WHO, 1996).

2.11 Risk of Wastewater Utilisation and Tools for Risk Assessment of Wastewater

Wastewater use in agriculture has substantial benefits, but can also pose substantial risks to public health - especially when untreated wastewater is used for crop irrigation. Farmers often have no alternative but to use untreated wastewater because there is no wastewater treatment and freshwater is either unavailable or too expensive (World Bank, 2010). So despite all its benefits in terms of food supply, nutrition, employment and poverty alleviation, urban vegetable production poses human health and environmental risks which makes it struggle for official recognition, not to mention support, especially in Sub-Saharan Africa with its complex urban sanitation problems (Drechsel *et al*., 2006; Obuobie *et al*., 2006).

Assessment of risks mainly relies on data from microbiological analysis, epidemiological studies and/or quantitative microbial risk assessment (QMRA), the latter being a prospective assessment rather than extrapolation from evaluations. Traditionally, microbial analysis and epidemiological studies have been extensively used in evaluating risks in wastewater-irrigated agriculture, especially among affected farmers. A number of epidemiological studies in this area have shown higher prevalence of infections in the exposed population compared to unexposed populations. The studies have also clearly associated levels of pathogens in irrigation water to infection levels (Blumenthal and Peasey, 2002). Nevertheless, from the perspective of possible risk to society or planned agricultural wastewater irrigation, the epidemiological approach has limitations in that it is relatively expensive and it does not meet the need of the public, governments and other stakeholders to obtain health-risk estimates before the commissioning of projects. QMRA is increasingly used for this purpose, giving a prospective risk assessment for the wastewater irrigation situation at hand (Hamilton *et al*., 2007).

2.12 Microbial Risks to Public Health

In low and middle-income countries, the greatest risks are primarily to public health from the microbial pathogens (disease-causing organisms) contained in domestic wastewater, including bacteria, viruses, protozoa and helminths. Epidemiological studies carried out over the past four decades have linked the uncontrolled use of untreated or partially treated wastewater for edible crop irrigation to the transmission of endemic and epidemic diseases to farmers and crop consumers. Actual risks of using untreated wastewater for irrigation include the increased prevalence of helminthic diseases (such as *Ascariasis* and *Ancylostoma*) in field workers and consumers of uncooked vegetables and bacterial and viral diseases (such as diarrhoea, typhoid and cholera) in those consuming salad crops and raw vegetables (World Bank, 2010).

2.13 Chemical Risks to Public Health

Chemical risks are greater for middle and high-income countries where industrial wastewaters may be discharged to public sewers and contaminate municipal wastewaters. Chemical risks to human health may be caused by heavy metals (such as cadmium, lead, and mercury) and by many organic compounds (such as pesticides). There is also increasing concern in high-income countries about an emerging class of "anthropogenic" chemical compounds, which include pharmaceuticals, hormones and endocrine disruptors, antibiotics, and personal care products – although their long-term health effects are less clearly understood (World Bank, 2010).

2.14 Risks to Plant Health

The principal risk to plants is reduced crop yields if the physico-chemical quality of wastewater used for irrigation is unsuitable e.g. by being too saline or having excessive

concentrations of boron, heavy metals or other industrial toxicants, nitrogen and/or sodium. Risks to plant health are reduced if there is little industrial effluent in the wastewater, but in all cases five parameters should be monitored during the irrigation season: electrical conductivity, the sodium adsorption ratio, boron, total nitrogen and pH (World Bank, 2010).

2.15 Risks to Soil

The main and most common problem that wastewater use can cause in soils is salinization. The problems occur even with freshwater if appropriate soil washing does not occur and land drainage is adequate. The use of wastewater can accelerate the process of soil salinization due to its higher salt content. Salinization causes soil structure to collapse, losing pores and interconnections that allow water air passage and consequently (WHO, 2006b):

i. Lateral drainage is increased,
ii. Soils erode more easily,
iii. Oxygenation is limited,
iv. Root development is inhibited and
v. Plant growth is diminished or stopped.

In the long term, wastewater use will always increase salinity of the soil and groundwater, as it contains more salts than freshwater. And therefore, it is necessary to combine the use of wastewater with practices to control salinization (WHO, 2006b). The key to controlling many of the chemical risks to humans, plants and the environment is to put in place effective industrial wastewater pre-treatment and control programmes. Of course, effective programmes are not the norm in developing countries, so special attention has to be paid to chemical risks in such circumstances (World Bank, 2010).

2.16 Filtration and Filtering Systems

Filtration of water is basically the passing of water through beds of fine granular materials like sand and this has the potential of removing impurities such as suspended particles, pathogenic bacteria, colour, odour, etc. Rangwala (2007) noticed that the following effects occur during the process of filtration:

1. The suspended and colloidal impurities which are present in water in a finely divided state are removed to a great extent,
2. The chemical characteristics of water are altered, and
3. The number of bacteria present in water is also considerably reduced.

According to Rangwala (2007), the theory of filtration is based on four actions that is mechanical straining, biological metabolism, sedimentation and electrolytic changes.

i. Mechanical straining: In this the suspended particles which are unable to pass through the voids of sand grains are arrested and removed by the action of mechanical straining.

ii. Sedimentation: With this, the voids between sand grains of the filter act more or less like small sedimentation tanks. The particles of impurities, arrested in these voids, adhere to the particles of sand grains mainly because:

   a. Of the presence of a gelatinous film or coating developed on sand grains by previously caught bacteria and colloidal matter and,
   b. Due to the physical attraction between the two particles of matter.

   The suspended materials are therefore removed by the filter through the action of sedimentation.

iii. Biological metabolism: With this when the action of bacteria is caught in the voids of sand grains, a zoological jelly or film is formed around the sand grains.

The film contains large colonies of living bacteria. The bacteria feed on the organic impurities contained in water. They convert such impurities into harmless compounds by the complex biochemical reactions.

iv. Electrolytic changes: The work of the filter is also explained by the ionic theory. It states that when two substances with opposite electric charges are brought into contact with each other, the electric charges are neutralised and new chemicals formed.

Some of the sand grains of filter are charged with electricity of some polarity. Therefore when particles of suspended and dissolved matter containing electricity of opposite polarity come into contact with such sand grains, they neutralise each other and it ultimately results in the alteration of chemical characteristics of water. After some time interval, the electrical power of sand grains gets exhausted and this necessitates the cleaning of the filter to restore this characteristic.

2.17 Characteristics of Filter Media

The characteristics of the sand to be used in the filtration process is very important in the achievement of good results. According to Rangwala (2007), the sand should be free from clay, loam, vegetable matter, organic impurities, etc. It should also be uniform in nature and size. It is usually classified on the basis of effective size and uniformity coefficient. The effective size of sand indicates the size of sieve in mm through which 10 % of the sample of sand by weight will pass whilst uniformity coefficient of sand is the ratio of sieve size in mm through which 60 % of the sample of sand by weight will pass to the effective size of sand.

2.18 Filter Systems

Rangwala (2007) classified filters into two categories: slow sand and rapid sand filters but considers pressure filter as also a major category of filter.

- **Slow Sand Filters:** in the case of the slow sand filtration, the water is allowed to pass slowly through the layer of sand placed above the base material and thus the purification process aims at simultaneously improving the biological, chemical and physical characteristics of the water. The slow sand filter basically consists of the following parts; enclosure tanks, underdrainage system, base material, filter media of sand and appurtenances (Rangwala, 2007).
    a. Enclosure tank: it is a watertight tank constructed of stone or brick masonry with the sides and floor being coated with water proof material. The bed slope is about 1 in 100 to 1 in 200 towards the central drain. The depth of tank is about 2.50 m to 3.50 m with varying surface area of 30 m^2 to 2000 m^2.
    b. Underdrainage system: it consists of a central drain and lateral drains. The lateral drains are placed at a distance of about 2.50 to 3.50 m and they are stopped at a distance of about 500 to 800 mm from the walls of the tank. The drains may be of pipes which are laid with open joints or they may consist of patented drain devices.
    c. Base Material: this is gravel and it is placed on the top of underdrainage system. Its depth varies from 300-750 mm. It is usually graded and laid in layers of 150 mm. The topmost layer should be bigger size gravel e.g. 3-6 mm as topmost layer, 6-20 mm and 20-40 mm as intermediate layers and lowest layer of 40-65 mm.
    d. Filter media of sand: a layer of sand is placed above the gravel layer. The depth of sand layer varies from 600-900 mm. The effective size of sand varies from 0.20-0.30 mm and the uniformity coefficient of sand is about 2-3. The finer the sand,

the better will be the efficiency of the filter with respect to bacteria removal. The output in terms of quantity of water from the filter will, however, be lowered.

e. Appurtenances: the various appurtenances are to be installed for the efficient working of slow sand filters. The vertical air pipe passing through the layer of sand may be provided. Devices for measuring loss of head, maintaining rate of flow and controlling depth of water above sand layer are suitably installed.

Generally, according to Rangwala (2007), the rate of filtration for a normal slow sand filter varies from 100-200 l/h/m^2 of filter area. Slow sand filters have also been recognised to be highly efficient in the removal of bacterial load from water. They are expected to remove about 98-99 % of bacterial load from raw water and this percentage may be as high as 99.50-99.90 when pre-treatment is given.

- **Rapid Sand Filters:** except constructional differences, the rapid and slow sand filters have the same parts. Unlike the slow sand filter, the effective size of sand for the rapid sand filter varies from 0.35-0.60 mm and the uniformity coefficient of sand is between 1.20-1.70. The spaces of the voids between sand particles are therefore increased leading to increased rate of filtration. The rapid sand filter has been recognised to be less effective in the removal of bacterial load. It is expected that they remove about 80-90 % of bacterial impurity in water. Its rate of infiltration is, however, very high producing about 3000-6000 l/h/m^2 of filter area.

Table 2.6 presents the differences between slow and rapid sand filters as used in the filtration of water and wastewater.

Table 2.6: Differences between Slow and Rapid Sand Filters

Item	Slow Sand Filters	Rapid Sand Filters
Base Material of Gravel	Varies from 3-65 mm in size and 300-750 mm in depth	Varies from 3-40 mm in size and 600-900 mm in depth
Compactness	Requires large area for installation	Requires small area for installation
Construction	Simple	Complicated
Cost of operation	Low	High
Efficiency	Very efficient in the removal of bacteria but less efficient in the removal of colour and turbidity	Less efficient in the removal of bacteria but more efficient in the removal of colour and turbidity
Filter Media Size	Effective size varies from 0.20-0.30 mm and uniformity coefficient is about 2-3.	Effective size varies from 0.35-0.60 mm and uniformity coefficient is about 1.2-1.7
Rate of Filtration	100-200 l/h/m^2 of filter media	3000-6000 l/h/m^2 of filter area

Adopted and Modified from Rangwala (2007)

2.19 Filtration of Sewage

According to Rangwala (2007), the filters which are commonly employed in the secondary treatment of sewage are of four types:

1. Contact beds
2. Intermittent sand filters
3. Trickling filters and
4. Miscellaneous filters.

Contact bed: also known as contact filter, is a water tight tank. It is filled with filtering media which may be of gravel, ballast or broken stone with sizes varying from 15-40 mm.

The sewage effluent is kept in contact with the filtering media for some period usually about two (2) hours. As the sewage effluent passes through the filtering media, an organic film is produced around the particles of filtering media. A large number of aerobic bacteria present in this film carry out the oxidation of organic matter. In the second contact period the filter obtains oxygen from the atmosphere and the organic matter caught in the voids of filtering media gets oxidised. The effluent from a contact bed is said to be usually turbid and with a high bacterial load. It is said to have the following efficiencies; bacterial removal of 50 - 75 %, organic matter removal of 60 - 80 % and suspended matter removal of 80 - 90 %.

Intermittent Sand Filters: also called the land filtration process, the sewage effluent is applied on the specially prepared bed of sand filter at regular intervals. As the effluent passes through the filtering media of sand, the purification of sewage effluent is effected by two actions of the filter; mechanical straining and bacterial action taking place in the voids of the sand particles. In this system, the sewage is purified by the aerobic bacteria and it is necessary to apply sewage on the filter at regular intervals. The filter material consists of sand free of clay, loam, soft limestone and other impurities. The effective size of sand should be between 0.20-0.50 mm and the uniformity coefficient of sand should not exceed 5. The thickness of sand layer is kept at about 750-900 mm and to facilitate drainage of the effluent, a layer of about 150-300 mm depth of gravel is provided at the bottom of sand layer. Raking at regular intervals to break-up the materials caught in the top part of the filter is needed. Renewal of the sand of the filter is also very important. The rate of filtration of an intermittent sand filter depends on the depth and size of the filtering material, nature of the influent and quality of the effluent.

Trickling Filters: also called percolating filters or sprinkling filters, the sewage sprinkle or trickles over a bed of coarse, rough, hard material and it is then collected through the under drainage system. The oxidation of the organic matter is carried out under aerobic conditions. A bio-film is formed around the particles of filtering media and for the existence of this film, the oxygen is supplied by the intermittent working of the filter and by the provision of suitable ventilation facilities in the body of the filter. This bio-film consists of bacteria, fungi, algae, lichens, protozoa, etc. The filter media consist of crushed rock or clinker or specially manufactured material. They should be cubical in shape and the filtering media should be free from flat or elongated pieces and should not contain dirt or undesirable materials. Size of filter material generally ranges from 30-80 mm. The effective depth of trickling filters is generally between 1.8-2.4 m.

2.20 Guidelines for Wastewater Irrigation in Developing Countries

While some countries, especially more developed ones, have national guidelines addressing wastewater use in agriculture, the best known international guidelines are those produced by the WHO of the UN. This helps protect public health and facilitate the rational use of wastewater and excreta in agriculture and aquaculture: WHO developed the document *Reuse of Effluents: Methods of Wastewater Treatment and Public Health Safeguards* in the early 1970s. This first normative document from the WHO in the field of wastewater use was developed in the absence of good epidemiological studies and borrowed essentially a low-risk approach from the USA (Carr, 2005). In 1976, it was complemented by the FAO's Irrigation and Drainage Paper 29 which addressed the water-quality challenges of salinity and specific ion toxicity (FAO, 1976). The WHO publication relied on water thresholds, i.e. critical pathogen levels in the irrigation water (100 coliforms per 100 ml) which should not be exceeded and gave best practice recommendations on how to treat the water to achieve this

quality standard (Havelaar *et al.,* 2001). In the two decades following the publication of these documents, the use of wastewater in agriculture expanded in many arid and semi-arid countries. This trend and the health and safety questions concerning this practice became the driving forces for conducting a number of epidemiological studies (Shuval *et al.,* 1986). As epidemiological evidence was compiled, it became clear that the initial WHO publication needed to be revised and the following additional issues needed to be considered (Carr, 2005):

- Overly strict water-quality standards were impossible to achieve in many situations and were therefore often ignored, rendering the guidelines useless, and
- The guidelines needed to include risk-management approaches that would complement available treatment processes or could be used in the absence of wastewater treatment to reduce health risks.

Based on these considerations a second edition of the WHO Guidelines was published in 1989. The FAO's Irrigation and Drainage Paper 47 followed in 1992, building on the 1989 guidelines while also addressing issues specific to irrigation such as managing salinity (FAO, 1992). Both guidelines have been very influential and many countries have adopted them, in some cases with adaptations. In view of pathogenic threats, both reports emphasized the need for appropriate wastewater treatment before use and for water-quality criteria that are easy to monitor (Mara and Cairncross, 1989). In 1997, the FAO's *'Water Report no. 10'* challenged the application potential of the WHO water-quality standards, as adequate treatment facilities sufficient to help meet these standards could well be a decade or more away (FAO, 1997). A major change was the shift from critical levels of microbial contamination of irrigation water to health-based targets (WHO, 2006b).

2.21 Conventional Options of Wastewater Treatment and their Limitations in Developing Countries

Little wastewater in the developing world was reported to undergo treatment of any kind and even in affluent countries the cost of treatment is a key criterion determining the likely success or failure of a reuse scheme (Robinson, 2003). Wastewater treatment in designed plants or pond systems has long been considered the ultimate solution for reducing risks in wastewater-irrigated agriculture. Wastewater treatment as a risk-mitigation measure has therefore been widely studied and documented in both developed and developing countries (Tchobanoglous and Burton, 1995). The efficacy or effectiveness of conventional treatment systems is being questioned especially in removing pathogens, some organic chemical compounds, such as pesticides and their residues, pharmaceutically active compounds and endocrine disrupting substances.

Indeed, most conventional systems have two treatment systems: primary treatment where suspended solids and organic matter are removed; and secondary treatment for removing biodegradable organics. Tertiary level treatment may also be available, but the aim of tertiary treatment is removal of nutrients and toxic compounds (Tchobanoglous and Burton, 1995). So conventional treatment systems are designed mainly to address environmental concerns and not human health risks. This was further shown by a review of more than 20 studies conducted for WHO, for the third edition of its guidelines. The review showed wide variations in the effectiveness of log unit removals of various pathogens by different conventional treatment processes (WHO, 2006b). The processes involved in several conventional treatment systems, except stabilization ponds, are difficult and costly to operate in developing-country contexts as they have high energy requirements, need skilled labour and also have high installation, operation and maintenance costs (Carr and Strauss, 2001).

This perhaps explains the high number of dysfunctional treatment plants and low general levels of wastewater treatment in developing countries of less than 1 % in sub-Saharan Africa, about 35 % in Asia and 14 % in South America (WHO and UNICEF, 2000). A survey in Ghana, for example, reported that only 10 % of the reported 70 treatment plants and faecal sludge stabilization ponds are still operating as planned, most of them belonging to larger hotels (IWMI, 2009). Therefore new mechanisms are needed to be created for conventional wastewater treatment before it can be observed as a rational health risk alleviation alternative in developing countries.

2.22 Wastewater Treatment Processes

Wastewater if not properly treated would pose drastic effects on the health of humans. Researchers, government and stakeholders in the field have invested more effort in its treatment. Some wastewater treatment processes adopted over the years include:

2.22.1 Waste Stabilization Ponds

Waste stabilization ponds are very efficient at removing all kinds of pathogens. They remove up to 6 logs of bacteria, up to 5 logs of viruses and practically all the protozoan and helminth ova (Feachem *et al.,* 1983). These performances are higher than those observed in conventional processes (1-2 logs of bacteria, and 70-99 % of protozoa and helminth ova) using specific disinfection steps. Several factors contribute to this removal (sedimentation, temperature, sunlight, pH, microorganisms predation, adsorption and absorption), but concerning a helminth ovum, sedimentation is the most effective. To efficiently remove helminth ova, a minimum of 5-20 days depending on the initial content is required, with at least twice as much to reduce thermotolerant coliforms to less than 1000 MPN/100 ml. To control *Cryptosporidia,* almost 38 days are needed (Mara, 2003). Care must be taken, because removal efficiencies are not attained in practice due to hydraulic problems, such as

flow short circuiting (Huntington and Crook, 1993). In developing countries with warm climates, the use of stabilization ponds to recycle wastewater for agriculture is recommended when land is available at a reasonable price. However, care must be taken in arid zones with high evaporation rates because ponds may represent a net loss of water. Water losses through evaporation can account for 20-25% of the water inflow (Duqqah, 2002). Water evaporation also increases salinity content in the effluent making difficult its use for agricultural irrigation. There is little data concerning helminth ova survival at the bottom of the ponds. Nelson *et al.* (2004), in a study performed in several waste stabilization ponds in Mexico, found 14 viable HO/g TS in sludge stored for at least 9 years.

2.22.2 Reservoirs

Similar to stabilization ponds, reservoirs and dams remove helminth ova from wastewater if retention time is greater than 20 d (Juanicó and Milstein, 2004). This way, reservoirs are useful for both removing helminth ova and supplying variable water flows to irrigate crops from wastewater that is constantly produced.

2.22.3 Wetlands

In wetlands, helminth ova are removed by filtration through the soil and adhesion to roots. Besides removing pathogens, wetlands are also efficient at removing nitrogen, phosphorus and heavy metals. Several wetlands have been installed in different countries, but few data concerning pathogen removal is available due to the high cost involved in monitoring the system. Wetlands remove 90-98 % of thermotolerant coliforms, 67–84 % of coliphages and 60-100 % of protozoa. To remove 100 % of helminth ova, it is necessary to couple wetlands with a horizontal flow gravel bed where removal takes place within the first 25 m (Stott *et al.,* 1999 and Rivera *et al.,* 1995). Practical data show that pathogen removal is very variable depending on the climate, the type of wetland and the type of plant used.

2.22.4 Coagulation-Flocculation

Jiménez and Alma (2002) recommend coagulation-flocculation to produce water fit for agricultural reuse. When this process uses low coagulant doses combined with a high molecular weight and high density charge flocculants it is called Chemical Enhanced Primary Treatment (CEPT). If it is coupled with a high rate settler instead of a conventional one, it is called Advanced Primary Treatment (APT). APT and CEPT are both efficient at removing helminth ova while allowing organic matter, nitrogen and phosphorus to remain in water in the dissolved fraction or as very small particles. This produces an effluent of an adequate quality for agriculture, with low TSS and helminth ova content, but that still requires disinfection to inactivate bacteria. This can be done with chlorine, ultra-violet light or a combination of both.

The operating principle is very simple: it consists of accelerating the helminth ova's settling velocity (normally of around 0.39-1.53 m/h) and using chemicals (Mara, 2003). An effluent with less than 20–40 mg TS/l may have helminth ova content of 3-10 HO/l and with less than 20 mg TS/l a content of ≤ 1 HO/l (Chavez *et al.*, 2004). Different coagulants may be used, Fe or Al being the most common. When combined with proper polymers (regularly anionic ones), coagulant doses may be considerably reduced (40-50 mg/l of $FeCl_3$ or 50-70 mg/l of Al_2SO_4). If poly aluminium chlorides (PACS) are used as main coagulants, doses are reduced to only some mg/l. The CEPT version has a total hydraulic retention time of 4-6 h, while for APT it is only 0.5-1 h. Consequently, this latter process costs 1/3 of what a conventional activated sludge system, including operation and sludge treatment and disposal within 20 km. APT removes one log of faecal coliforms, one log of *Salmonella spp.*, 50-80 % protozoan cysts (*Giardia and Entamoeba coli, E. histolytica*) and 90-99 % of helminth ova. From a content of up to 120 HO/L, APT may constantly produce an effluent with 0.5-3 HO/l (Jiménez *et al*., 2001; Chavez *et al*., 2004).

2.22.5 Rapid Filtration (> 2 m/h)

This is a useful treatment for removing protozoa and helminth ova from effluents, either physico-chemical or biological ones. Rapid filtration removes 90 % of faecal coliforms, pathogenic bacteria (*Salmonella* and *Pseudomonas aeruginosa*), enteric viruses, 50-80 % of protozoan cysts (*Giardia, Entamoeba coli, E. histolytica*), and 90-99 % of helminth ova (Jiménez *et al.*, 2001). These removals may be increased by 2-4 log if coagulants are added (USEPA, 1992). Rapid filtration is performed in sand filters (helminth ova sticks easily to silica, a reason why silica glass material should not be used for sampling or during helminth ova analysis). Specific filtration media size is from 0.8-1.2 mm, with a minimal filter bed of 1 m for filtration rates varying from 7-10 m^3/m^2h. Under these conditions, the effluent constantly has a helminth ova content of < 0.1HO/l with filtration cycles of 20-35 h (Jimenez, 2007b).

2.22.6 Upflow Anaerobic Sludge Blanket

Upflow Anaerobic Sludge Blanket (UASB) reactors remove helminth ova through filtration in the sludge bed and sedimentation. von Sperling *et al*. (2002) in a 5.5 h UASB produced an effluent with 1.3-45 HO/l from wastewater containing 64-320 HO/l. The mean removal efficiency obtained was 96 %, so they recommended coupling UASB reactors with stabilization ponds in order to completely and constantly remove them from wastewater. Paulino *et al*. (2001), in an anaerobic fluidized bed also observed a variable removal efficiency of 60-93 %.

2.23 Methods and Benefits of Wastewater Irrigation

Wastewater, apart from its numerous problems has been known to have several agronomic and economic benefits. FAO (1997) stated that there are agronomic and economic benefits of wastewater use in agriculture. Irrigation with wastewater can result in the release of the available water supply or better quality supplies of alternative uses. In addition to this economic benefit that conserves natural resources, the plant nutrient values of many wastewaters are important. FAO (1997) estimated that typical wastewater effluent from domestic sources could supply all nitrogen (N) and most of the phosphorous (P) and potassium (K) required for agricultural crop production. In addition, micro-nutrients and organic matter also provide additional benefits.

2.24 Modelling Removal of Coliforms and Helminth Eggs

One of the main advantages of waste stabilization ponds is their capacity to remove pathogenic organisms. Protozoan cysts and helminth eggs are removed mainly by sedimentation and ponds are generally able to produce effluents with concentrations close to or equal to zero (von Sperling *et al.,* 2004). Pathogenic bacteria and viruses are removed by a combination of various factors that lead to an unsuitable environment for them, including high pH, high DO, ultraviolet radiation, predation, starvation and others (Curtis *et al.,* 1992; Mara, 2003). Effluent concentrations depend on the number of ponds in series, pond geometry, detention time and a number of other external and internal factors (Oragui *et al.,* 1995).

The decay of coliforms (thermotolerant coliforms or more specifically *Escherichia coli*) in ponds is, from a practical point of view, accepted as being able to represent satisfactorily well the removal of pathogenic bacteria and under many circumstances, viruses (von Sperling *et*

al., 2003). Modelling the decay of coliforms in ponds is therefore important as a means of predicting the suitability of the effluent for reuse (agriculture or aquaculture) or discharge into water courses. Application of mathematical models for treatment systems such as ponds is aimed at enabling the development of the most suitable design criteria for the conditions under analysis. Coliform die-off in designed treatment systems is usually modelled assuming first-order kinetics i.e. die-off rate directly proportional to the concentration.

According to von Sperling (2005) there are basically three (3) models to represent the reactor hydraulics and these are plug flow, complete mix (also CSTR—completely stirred tank reactor) and dispersed flow. The dispersed-flow model was indicated to be more flexible since it may be set to adjust to different pond geometries. Plug-flow models are indicated for more elongated ponds, while the complete-mixed model is more suited to square or mildly rectangular ponds. von Sperling (2002) stresses the adequacy of the dispersed flow model, but presents a methodology and equations for converting coefficients derived for this model into coefficients for the complete-mix and plug-flow models. For the same removal efficiency, von Sperling (2005) showed that the coliform die-off coefficient (d^{-1}) K_b value for complete mix will always be higher and the K_b value for plug flow will always be lower than the K_b for dispersed flow.

The equation for estimating the effluent coliform concentration according to the complete-mix model is widely used, and is frequently reported as Marais model (Marais, 1974):

$$N = \frac{N_o}{1 + K_b t'} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad 2.1$$

Where:

N_o = influent coliform concentration (MPN/100 mL)

N = effluent coliform concentration (MPN/100 mL)

K_b = coliform die-off coefficient (d^{-1})

t = hydraulic detention time (d)

The equations representing the effluent coliform concentration in the dispersed-flow model are expressed by the classical Wehner and Wilhelm (1956) model:

$$N = N_o \frac{4ae^{1/2d}}{(1+a)^2 e^{a/2d} - (1-a)^2 e^{-a/2d}} \quad \ldots\ldots 2.2$$

$$a = \sqrt{1 + 4K_b td} \quad \ldots\ldots 2.3$$

Where:

d is the dispersion number (dimensionless)

Values of K_b are usually reported at the standard temperature of 20 ^oC. The value of K_b may be corrected for other temperatures using the Arrhenius equation:

$$K_{b(20^oC)} = K_{b(T)} \theta^{(20-T)} \quad \ldots\ldots 2.4$$

Where:

$K_{b(20^oC)}$ = K_b is the coefficient at the liquid temperature of 20^{o}C (d^{-1})

$K_{b(T)}$ = K_b the coefficient at a liquid temperature T (d^{-1})

θ = the temperature coefficient

In the complete-mix model, the only coefficient is K_b, whereas in the dispersed-flow model, there are two coefficients (K_b and d). Therefore, in order to allow the application of both

models for design purposes, it is essential to have satisfactory values of these model coefficients.

2.25 Conclusions

Freshwater scarcity has been realised to be a contributory factor to the dependence on wastewater in vegetable crop production in the world and especially the sub-Saharan Africa region. Widespread use of wastewater especially in sub-Saharan Africa and Ghana in particular with little or no treatment has been realised to be very common. Several proposals have been made to reduce the level of contamination of the wastewater used commonly for irrigation of crops especially in urban and peri-urban areas. The review noted that treatment of wastewater in sub-Saharan Africa and Ghana seems difficult due to limited funds and lack of commitment on the part of government. Due to the widespread utilisation of the wastewater resource especially for crop production, an affordable and user friendly system for the resource poor farmer has not been largely explored. The study therefore aimed at filling the gap of providing an efficient, low cost and less labour intensive alternative to the treatment of wastewater in urban and peri-urban areas for dry season crop production which provides jobs for a lot of people.

CHAPTER THREE

MATERIALS AND METHODS

3.1 Study Area

The Tamale Metropolitan area is located at the centre of the Northern Region of Ghana. Tamale has been described as the fastest growing city in West Africa and it is the largest urban centre in the north of Ghana. It occupies 750 km^2 which is 13 % of the total area of the Northern Region. The population of Tamale Metropolis is reported as 371,351 with 185,995 (50.09 %) being males and 185, 356 (49.91 %) being females (GSS, 2012). The Metropolis experiences one rainy season starting from April/May to September/October with a peak period in July/August. The dry season is usually from November to March. The mean annual rainfall is 1100 mm within 95 days of intense rainfall. The mean day temperatures range from 33 to 39 ^oC while mean night temperature range from 20 to 22 ^oC. The mean annual day sunshine is approximately 7.5 hours.

In the Metropolis there are several sites where wastewater vegetable farming takes place and the crops cultivated include cabbage, lettuce, *Amaranthus, Chochorus* and others. This study was done in the Zagyuri community of the Tamale Metropolis where community farmers numbering about 150 farmers and their families of averaging 5 members per household depend on the use of wastewater from a broken down sewer of the Kamina Military Barracks for vegetable crop production. Figure 3.1 shows a map of Ghana and the Tamale Metropolitan Area. The study area according to Obuobie *et al.* (2006) is 8 km from the city centre and covers according to different sources in total about 7-12 ha. The experimental field was located on latitude 09^{o}47’388’’ N, longitude 00^{o}84’ 776’’ W and at an altitude of 167 m above sea level.

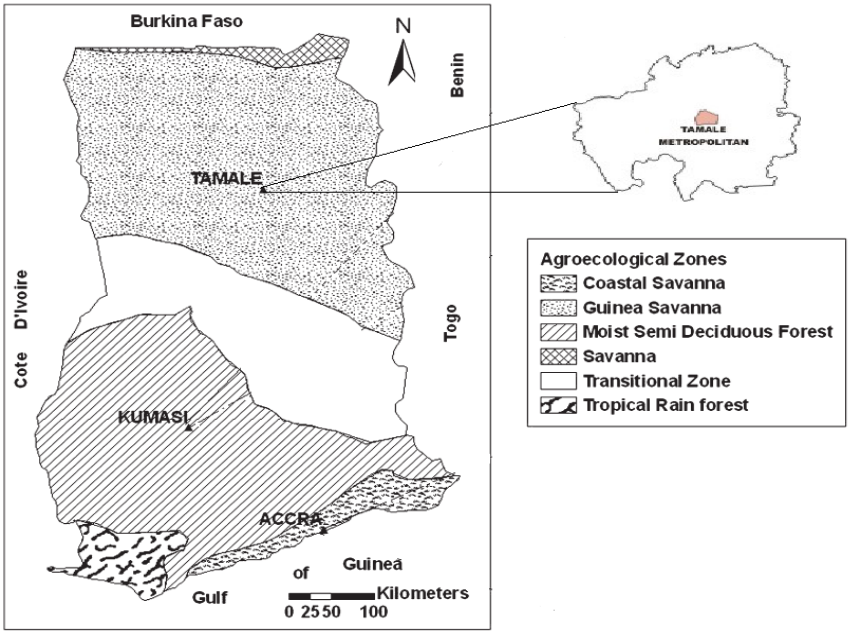


Figure 3.1: Map of Ghana Showing the Tamale Metropolitan Area *(Adopted and Modified from Amoah, 2008).*

3.2 Filter Unit and Experimental Design

3.2.1 Filter Unit Design

The study designed and used eighteen cylindrical containers each with a diameter of 6.5 cm of varying lengths. Each horizontal sand filter unit was designed and fabricated to contain the following:

- A mosquito netting at inflow and outflow ends to sieve out debris to prevent clogging.
- The cylindrical shaped container set-up was made of one container only (8.5 cm length), two containers only (17 cm length) and three containers only (25.5 cm length) and serially connected to stabilization ponds.

Stabilization ponds were built at 2 m x 7 m with a staircase design at 1 m interval for 2 m at intake point of the tank unit with the remaining 4.5 m being the depth of the stabilization pond.

Cement and concrete blocks were used for the construction of a staircase connecting the filter units to the stabilization ponds and the water source.

3.2.2 Experimental Design

The experiment had three (3) treatments:

Treatment one (T_1) where the length of the filtering container was 8.5 cm,

Treatment two (T_2) where the length of the filtering container was 17 cm,

Treatment three (T_3) where the length of the filtering container was 25.5 cm, and

The Control (Main Source - MS) where the wastewater was without any filtration.

Each treatment had three (3) replications.

Each filtering unit was filled with six (6) different sizes of the filter media as presented in Table 3.1. Stabilization ponds of dimensions 2 m x 7 m were created to harvest the filtered wastewater from the various treatment set-ups. Wastewater from the Kamina Barracks sewage system was directed to the constructed treatment system. Wastewater samples were taken from each of the ponds and the main source to the laboratory for microbial and chemical quality analysis.

Table 3.1: Filter Media Sizes

Layer	Filter Media Size (mm)
Topmost	2.00
First	4.75
Second	8.00
Third	19.0
Fourth	37.5
Lowest	45.0

3.3 Materials and Data Collection

Wastewater samples were collected once a day at weekly intervals (7 days) for a period of two (2) months and two (2) seasons for two years (2011 and 2012) that is August and September for the wet season and January and February for the dry season. During the sampling and laboratory analysis periods, sterile sampling containers, hand gloves, water and standard chemical reagents were used. An ice box was used for the storage and transportation of collected wastewater samples from the field to the laboratory for analysis.

3.3.1 Data Collection

Filtered wastewater sampling was done at weekly (7 days) intervals for a period of sixteen (16) weeks that is eight (8) weeks for the rainy season and eight (8) weeks for the dry season in each sampling year. Data collection was done in the years 2011 and 2012. A total number of ten (10) filtered wastewater samples were collected at each sampling time resulting in 160 wastewater samples per year and 320 samples for the whole study.

3.3.2 Laboratory Materials

- 500 ml measuring cylinder
- YSI 556 Multi Probe System (MPS) was used for the pH determination
- Leica Microscope Eyepieces Hc Plan 10X/20 Glasses M 507802 for helminth egg detection
- Centrifuge “Centro-8-Bl” With Angle Rotor for 7-15 ml tubes and 75 x 13 mm Vac
- 25 ml and 10 ml cells
- 1.5-litre plastic container
- 160 µm screen
- Centrifuge with 450 ml, 50 ml, 15 ml centrifugal flask

- Spatula
- Micro pipette
- Solid medium (McConkey agar)
- Petri dishes
- Incubator
- Colony counter
- 50 ml graduated cylinder
- 2 l litre Conical flask
- 50 ml centrifugal flask
- DR 2800 Spectrophotometer and
- Timer

3.4 Methods

The following methods were used for the determination of the physical characteristics of the filter media as well as the various microbial and chemical parameters:

3.4.1 Bulk Density, Particle Density and Porosity of Filter Media

The filter media was obtained from igneous rock material. The bulk densities of the various filter media were determined using a measuring cylinder and a weighing scale. The relationship between the weight and volume was used to determine the bulk density using relation (3.1):

$$\rho_b = \frac{m_{fm}}{v_{fm}} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots 3.1$$

Where:

ρ_b is the average bulk density in gcm^{-3}

v_{fm} is the volume of the filter media in cm^{-3}

m_{fm} is the mass of the dried filter media in g.

Average particle density of the filter media was determined using liquid immersion method as described by Rühlmanna *et al.* (2006). Particle density was determined using the relation (3.2):

$$\rho_p = \frac{m_{fm}}{v_{fp}} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots 3.2$$

Where:

ρ_p is the average particle density in gcm^{-3}

v_{fp} is the volume of the filter media excluding pore space in cm^{-3}

m_{fm} is the mass of the dried filter material in g

Porosity of the filter media was determined by relating the average particle and bulk densities of the various media used (relation 3.3).

$$\eta = \left(\frac{\rho_b}{\rho_p}\right) \times 100\ \% \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots 3.3$$

where:

η is the porosity of the filter media in %.

3.4.2 Determination of Total and Faecal Coliform

The heterotrophic plate count method was used in the biological examination for the determination of the total and faecal coliform. The procedure used was:

1. 1 ml of the sample was taken into 100 ml test tube using a micro pipette.
2. The 1 ml samples in the test tube were then diluted to 100 ml and shaken thoroughly to obtain homogeneity.
3. 1 ml of the diluted sample was then poured into arranged Petri dishes.

4. Solid McConkey agar medium was melted in boiling water and allowed to cool to 42 ^{o}C.
5. 10 ml of the melted McConkey agar medium was then poured onto the diluted sample.
6. The Petri dish was shaken for uniform mixing and inverted into the incubator.
7. Inspection was done in 24 hours.
8. The coliform counter was then used for the counting in Coliform Forming Unit (CFU) per 100 ml.

NB:

- The final result was multiplied by the dilution factor 100 to determine the actual number of the total and faecal coliform.
- The total coliform was determined by a pink colour whilst faecal coliform by a cream colour (Plate 3.1).

Plate 3.1: Bacteria (Total and Faecal) Coliform Growth observed on McConkey Agar

3.4.3 Determination of Helminths Eggs

Helminth eggs were enumerated using the concentration method as described by Schwartzbrod (1998). This is a modified USEPA method, but the same principle of floatation and sedimentation as in the method of Ayres and Mara (1996) was followed.

Reagents

1. $ZnSO_4(7H_2O)$ at 573 g/L (d = 1.3)
2. Acid /alcohol buffer solution: H_2SO_4 at 0.1N at 35 % ethanol; that is 350 ml ethanol and 5.16 ml of H_2SO_4.
3. Ethyl ether.

Procedure

1. The wastewater sample was allowed to settle for 3 hours and the supernatant sucked and the sediment placed in a 50 ml centrifugal flask.
2. The 2-litre containers were then rinsed 3 times.
3. Centrifuging was done at 1,450 rpm for 3 minutes and the supernatant poured away whilst re-suspension of the deposit was done with $ZnSO_4$ of 1.3 densities by three (3) times of the volume of the sediments.
4. Homogenization with a spatula was done and centrifuging at 1,450 rpm was undertaken again for 3 minutes.
5. The $ZnSO_4$ supernatant was then poured into a 2- litre flask and diluted with 1 litre of water and allowed 3 hours to settle.
6. Sucking of the supernatant and re-suspension of the deposit by shaking and emptying it into 2 tubes of 50 ml and finally rinsing 3 times with deionised water.
7. The rinsing liquid was then placed in 50 ml tubes and centrifuged at 1,600 rpm for 3 minutes.
8. Regrouping of the deposit was done into 2 tubes and a tube of 50 ml was then centrifuged at 1,600 rpm for 3 minutes.
9. The deposit was then re-suspended in 5 ml acetic acid solution and 10 ml ethyl ether added.

10. Shaking and opening were done occasionally to let out the gas.
11. Centrifuging was again undertaken at 1,900 rpm for 3 minutes and the supernatant sucked to leave less than 1 ml of liquid using a micro pipette.
12. The 1 ml in the micro pipette was then poured onto a microscope slide and the helminth eggs counted.

The number of eggs per litre was calculated from the relation (3.4):

$$N = \frac{AX}{PV} \quad \ldots\ldots 3.4$$

Where:

N = number of eggs per litre of sample

A = number of eggs counted on slide or mean counts from two or three slides.

X = volume of the final product (ml)

P = volume of the slide (0.3 ml)

V = original sample volume (litres)

Plate 3.2: Helminth Eggs Identification using a Light Microscope in the Laboratory

3.4.4 Ammonia Determination by Nessler Method

1. 5 ml of each wastewater sample was diluted with distilled water up to the 25 ml and 1 ml of Roscheil salt added to each sample.
2. 1 ml of Nessler reagent was then added to the solution and allowed 1 minute reaction time before the spectrophotometer reading.
3. Distilled water was used to zero the DR 2800 Spectrophotometer and the actual reading done with the prepared sample.

3.4.5 Nitrate Determination Using Spectrophotometric Method

1. 1 tablet of nitrate 1 and nitrate 2 were crushed into 10 ml of each of the wastewater sample consecutively.
2. The mixture was then allowed 6 minutes reaction time before the spectrophotometer reading.
3. One original sample was used to zero the DR 2800 Spectrophotometer before actual reading.

3.4.6 Nitrite Determination Using Colorimetric Method

1. 50 ml of each wastewater sample was measured into a clean Erlenmeyer flask and 2 ml of Gricess – Ilosvay's solution number 1 and 2 added simultaneously.
2. The samples were then swirled gently and the mixture allowed 15 minutes reaction time.
3. The sample was then transferred into a Nesseler's tube and zeroing of the DR 2800 Spectrophotometer was done with the sample before reading the nitrite level.

3.4.7 Phosphorus Determination Using Spectrophotometric Method

1. The programme no 490 was entered on the DR 2800 Spectrophotometer.
2. The sample cells were filled to 25 ml and 1 phosvate 3 powder pillow added.
3. Two (2) minutes reaction time was alloed.
4. Another 25 ml cell was filled with the sample as the blank to zero the DR 2800 Spectrophotometer.
5. The recorded value was then divided by 3 to obtain the amount of Phosphorus in milligram per litter (mg/l).

3.4.8 Determination of Zinc Using Zincon Method

Reagents: ZincoVer 5 Reagent powder pillows.

Procedure

1. A 50 ml graduated mixing cylinder was filled with the wastewater sample and one Zincover 5 reagent powder pillow stopper added. The samples were then inverted several times to completely dissolve powder pillows.
2. 25 ml of the wastewater sample was then measured into a blank cell and 1.0 ml of cyclohexanone added to the remaining 25 ml solution in the cylinder.
3. The cylinder was then stopped and shaken for 30 seconds and allowed a reaction time of 3 minutes.
4. The solution from the cylinder was then poured into the sample cell.
5. After the 3 minutes the blank was then placed onto the spectrophotometer for zeroing and reading of the zinc concentration on each was then done.

3.4.9 Determination of Aluminium Using Aluminon Method

Reagents: Ascorbic Acid powder pillow and AluVer 3 Aluminium Reagent Powder Pillow.

Procedure

1. 50 ml graduated mixing cylinder was filled with the wastewater sample and the content of one Ascorbic Acid powder pillow added.
2. Immediately one AluVer 3 Aluminium reagent powder pillow was added to the mixture.
3. A 25 ml of the mixture was then poured into a 25 ml cell and the contents of one bleaching 3 reagent powder pillows added to the remaining 25 ml in the graduated mixing cylinder and vigorously shaken for 30 seconds.
4. The remaining 25 ml of the mixture was then poured into the mixing cylinder of another 25 ml cell to serve as a blank.
5. The two mixtures were then left for a period of 15 minutes for complete reaction time and a blank was then placed into the cell holder of the spectrophotometer for zeroing and reading of the Aluminium concentration.

3.4.10 Determination of Manganese Using Pan Method

Reagents: Ascorbic Acid powder pillow and Alkaline Cyanide Reagent

Procedure

1. 25 ml of distilled water was poured into a cell as a blank and 25 ml of wastewater sample was also poured into another cell.
2. 1 Ascorbic Acid powder pillow was then added to each cell and swirled to mix.
3. 1 ml of Alkaline Cyanide Reagent solution was also added to the mixture in each cell and swirled to mix.

4. 1.0 of 0.01% PAN indicator solution was added to the mixture and swirled to mix and an orange colour developed in the sample indicating manganese is presence. The sample was then left for a 2 minute reaction period.
5. Zeroing was done by placing the blank on the spectrophotometer and followed by the samples after the reaction time for reading the levels of manganese.

3.4.11 Determination of Copper Using Bicinchoninate Method

Reagents: CuVer 1 Copper Reagent

Procedure

1. A cell was filled with 25 ml of the wastewater sample and one CuVer 1 Copper Reagent Powder pillow was added to each sample and swirled to mix.
2. A period of 2 minutes reaction time was allowed.
3. Another cell was then filled with 25 ml of the wastewater sample and used as a blank.
4. Zeroing was then done by placing the blank into the cell holder.
5. After zeroing the spectrophotometer, the 25 ml mixture in each cell was placed into the cell holder of the spectrophotometer and the copper reading was taken.

3.4.12 Determination of Iron Using Ferrover Method

Reagents: Ferrover Iron Reagent

Procedure:

1. A 25 ml cell was filled with the wastewater sample and one Ferrover Iron Reagent Powder Pillow added to each sample in the 25 ml cell and swirled to mix.
2. The mixture was allowed a 5 minutes reaction time.
3. Zeroing was then done by placing the blank into the cell holder.

4. After zeroing the spectrophotometer, the 25 ml mixture in each cell was placed into the cell holder of the spectrophotometer and the iron reading was taken.

3.5 Modelling the Decay of Thermotolerant Coliform and Helminth Eggs

A multivariate linear regression model was developed for each season for the three (3) biological contaminants (faecal coliform, total coliform and helminth eggs) taking into consideration the environmental factors which have high level of influence on the occurrence and concentrations. The environmental factors considered were temperature, rainfall, solar radiation (duration), relative humidity, pH and the design length of the filter system.

The model was developed following the generalized linear model (3.5) as:

$$Y_i = \beta_1 + \beta_{11}X_{11} + \beta_{12}X_{12} + \ldots\ldots\ldots\ldots \beta_{ij}X_{ij} + \varepsilon_i \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots 3.5$$

$$\beta_{ij} \geq 1 \; ; i = 1, \ldots\ldots\ldots\ldots\ldots m$$

$$\beta_{ij} \geq 1; j = 1, \ldots\ldots\ldots\ldots\ldots n$$

Where:

$$Y_i = Natural \log of \; daily \; microbial \; contaminant \; concentration \left(\frac{MPN}{100ml}\right) on \; day \; j$$

$$\beta_{ij} = slope \; cooeficient \; explanatory \; variable \; X_i : X_{ij} \; is \; the \; i^{th} \; explanantory \; variable \; on \; day \; j$$

$$\varepsilon_i = model \; error \; or \; residual \; on \; day \; j$$

The dependent variables were considered as faecal coliform, total coliform and helminth eggs whilst the independent variables were the design parameter of the system, pH and the environmental factors.

3.6 Determination of Helminth Egg Species Diversity Indices

3.6.1 Shannon-Wiener Index

Used widely in ecological studies and also known as Shannon's diversity Index, the Shannon-Weaver Index and the Shannon entropy, the Shannon-Wiener Index was used in the determination of the diversity of the types of helminth eggs contained in the wastewater. It quantifies the uncertainty (entropy or degree of surprise) associated with this prediction. It is most often calculated using relation 3.6:

$$H' = -(\ln P_1^{P1} + \ln P_2^{P2} + \ln P_3^{P3} + \ldots + \ln P_R^{PR}) \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots 3.6$$

Where:

H'is the helminth eggs diversity

p_i is the proportion of individuals belonging to the i^{th} species in the dataset.

3.6.2 Simpson Index

The Simpson Index measures the degree of concentration when individuals are classified into types. The measure equals the probability that two entities taken at random from the dataset of interest represent the same type. The Simpsons Index is presented as (3.7):

$$l = \frac{\sum_{i=1}^{R} n_i(n_i - 1)}{N(N-1)} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots 3.7$$

Where:

n_i = Number of individuals of i^{th} species, and N = Total number of individuals of all species. The value of this Index ranges from 0 – 1 with 1 showing high diversity and 0 no diversity.

3.6.3 Berger-Parker Index

The Berger-Parker Index equals the maximum p_i value in the dataset, i.e. the proportional abundance of the most abundant type. This corresponds to the weighted generalized mean of the p_i values when *q* approaches infinity, and hence equals the inverse of true diversity of order infinity ($1/^{\infty}D$).

3.7 Data Analysis

The above relations were used in the calculation of the concentration of the helminth eggs using the Most Probable Number (MPN) and indices. GENSTAT was used for the analysis of variance and correlation of total coliforms, faecal coliforms and helminth eggs. Multivariate analysis was run using SPSS version 16.00 for the biological parameters of the study.

CHAPTER FOUR

TYPES AND SEASONAL DIVERSITY OF HELMINTH EGGS IN WASTEWATER

4.1 Introduction

It is estimated that at least 20 million ha are irrigated with wastewater, and about 200 million farmers are involved (Raschid-Sally and Jayakody, 2008). Sewage is one of the major wastewater streams which have an effect on the environment. Its use for agricultural purposes also has to a large extent various health and environmental implications. Various microbial contaminants have been realised to exist in this type of water and grey water which forms part of sewage has been reported by Katukiza *et al.* (2013) and Birks and Hills (2007) to contain waterborne viruses, bacteria, parasitic protozoa and helminths.

It is common in urban and peri-urban areas of Ghana to see resource poor farmers using contaminated or polluted wastewater for especially dry season vegetable production. Based on an average per capita daily consumption of 60 l and a wastewater flow of 80 % (Cofie and Awuah, 2008), it is estimated that a population of 371,351 (GSS, 2012) will generate approximately 18,000 m^3 of wastewater per day in the Tamale Metropolis.

Resource poor farmers use wastewater mainly because crop yields are higher as the wastewater contains not only water for crop growth, but also important plant nutrients necessary for crop growth and performance. However, there is the risk that wastewater irrigation may facilitate the transmission of excreta-related diseases.

According to UN (2003), globally there are 5 million people suffering *helminthiases*, mainly in developing countries. *Helminthiases* are particularly common in regions where poverty and poor sanitary conditions are dominant, reaching incident rates of up to 90 % (Bratton and Nesse, 1993).

Ascariasis also prevails among poor people and is widespread in warm climates, being one of the most common infections in developing countries. According to Bratton and Nesse (1993), *ascariasis*, is endemic in Africa, Latin America, South America, and the Far East, with an incidence of up to 90 % in specific sectors of the population. The most important factors responsible for the high prevalence of *ascariasis* in the world are closely related to poverty.

Several treatment options of wastewater have been developed and tested but the results of these options mainly as well as the level of drudgery influence the level of adoption by farmers. In the year 2000, WHO reported that wastewater treatment in sub-Saharan Africa is not up to 1 % (WHO, 2000). Following from that, Keraita *et al.* (2010) mentioned that the level of treatment often undertaken in these countries was noted to be minimal or partial and often resulting in poor quality effluent. According to Rashid-Sally and Jayakody (2008), wastewater without any significant treatment is used for irrigation purposes in and around four out of five cities in the developing world.

Keraita *et al.* (2010) proposed farm-based measures such as the use of alternative sites for agricultural production, alternative water sources, different types of pond systems, low-cost filtration, improved ways of water fetching and application, and the choice of alternative crops to reduce the contamination risk of urban vegetables produced using wastewater in Ghana.

4.2 Wastewater Sampling and Analysis

Filtered and unfiltered wastewater sampling was done at weekly (7 days) intervals for a period of sixteen (16) weeks that is eight (8) weeks for the rainy season and eight (8) weeks for the dry season in each sampling year (2011 and 2012). A total number of ten (10) filtered wastewater samples were collected at each sampling time resulting in 160 wastewater samples per year and 320 samples for the whole study.

During the sampling and laboratory analysis periods, sterile sampling containers, hand gloves, water and standard chemical reagents were used. Samples were stored over ice in cool box for transportation to the laboratory for analysis.

Helminth eggs were enumerated using the concentration method as described by Schwartzbrod (1998). This is a modified USEPA method, but the same principle of floatation and sedimentation as in the method of Ayres and Mara (1996) was followed.

4.3 Results and Discussion

4.3.1 Identified Helminth Eggs

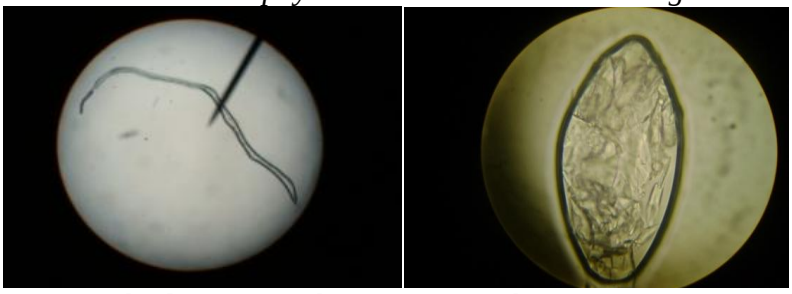
During the study, helminth eggs were identified using the WHO (1994) Bench Aid for the Diagnosis of Intestinal Parasites. Thirteen (13) different helminths were identified for both the wet and dry season samples with the dry season recording eight (8) different helminths and the wet season recording nine (9) different helminths (Table 4.1). According to Awuah *et al.* (2002), in Ghana high levels of faecal and helminth eggs were isolated in both grey and black water.

Table 4.1: Seasonal Occurrence of Helminth Eggs

Types of Helminths (Dry Season)	**Types of Helminths (Wet Season)**
Ascaris lumbricoides	*Ascaris lumbricoides*
Paragonimus westermani	*Enteroblus vermicularis*
Clonorchis sinensis	*Trichuris trichura*
Fasciola hepatica	*Diphyllobothrium latum*
Strongyloides stercoralis	*Strongyloides stercoralis*
Ancylostoma spp	*Ancylostoma spp*
Schistosoma mansoni	*Schistosoma mansoni*
Schistosoma japonicum	*Paragonimus uterobilateralis*
	Schistosoma haematobium

The typical fertile *Ascaris* and *Strongyloides stercoralis* as well as *Schistosoma mansoni* were observed to be the most predominant types of helminths in both seasons and this is attributed to their environmental tolerance and resistance. In a study by Ackerson and Awuah (2012) in Kumasi, Ghana different types of helminth eggs were isolated in irrigation water and they included *Ascaris lumbricoides*, which was the most predominant; *Schistosoma* spp; *Trichuris trichiura*; and *Strongyloides* larvae. According to the authors, the high population of helminth eggs was attributed to the high poultry manure run-off from the field and also poor sanitation and hygiene on the various farm sites. Jiménez (2009) reported that helminthiasis are transmitted through the ingestion of helminth eggs which are the ova of a wide variety of pathogenic worms and they are considered to be the most resistant biological particles in the field of environmental engineering (Navarro, *et al.*, 2010).

Ascaris lumbricoides *Diphyllobothrium latum* *Paragonimus uterobilateralis*



Strogyloides stercoralis *Schistosoma mansoni*

Figure 4.1: Pictorial Presentation of Observed Helminths Eggs under Microscope

According to Jiménez *et al.* (2010a) the most common diseases associated with wastewater and excreta are the diarrhoeic ones. Examples include several kinds of helminthiasis that are caused by intestinal infestation of parasitic worms. Ascariasis (produced by Ascaris worms)

is the most common one and is endemic in Africa, Latin America and the Far East. The report indicated that an estimated 133 million people suffer from high-intensity ascariasis infections, which often lead to severe consequences such as cognitive impairment, severe dysentery or anaemia.

4.3.2 Seasonal Concentrations of Helminths

In the dry season, the commonest occurring types of helminths in reducing order were *Ascaris lumbricoides, Ancylostoma spp, Strongyloides stercoralis, Schistosoma mansoni* and *Schistosoma japonicum. Fasciola hepatica, Clonorchis sinensis* and *Paragonimus westermani,* however recorded the same level of occurrence in the dry season.

Also, observed in decreasing order during the wet season were *Ascaris lumbricoides, Strongyloides stercoralis, Schistosoma haematobium, Ancylostoma spp* and *Schistosoma mansoni* but with the last two being at the same level. *Paragonimus uterobilateralis, Diphyllobothrium latum, Trichuris trichura* and *Enteroblus vermicularis* were also observed in very low levels during the wet season.

It was observed from both seasons that *Ascaris lumbricoides* was common and as reported by Nolf (1932) *Trichuris* eggs require a more highly saturated atmosphere before they could develop than *Ascaris* eggs, and that under fractional relative humidity, the eggs of *Trichuris* succumb more readily to environmental changes than those of *Ascaris.* The difference may be due to two (2) basic differences in the eggs:

1. the comparative sizes: *Ascaris* eggs are larger and have a considerably greater surface of the fibrous membrane through which the diffusion of gases occurs
2. The difference in time required to complete embryonation under optimum conditions: *Trichuris* eggs require more time to complete their development than *Ascaris*.

The wet season was observed to have recorded much more different helminth eggs as compared to the dry season and this could be attributed to favourable environmental

conditions during the period. According to Arene (1986), *Ascaris* develop in the egg between temperatures 16-34 °C. Ovicidal fungi are capable of attacking and destroying *Ascaris lumbricoides* eggs under experimental conditions during several days or weeks (Lysek and Bacovsky, 1979). Also as reported by Sobenina (1978), *Cylindrocarpon radicola* is known to penetrate and destroy *Ascaris* eggs. Invertebrates, particularly insects and gastropods, can also destroy helminth eggs by mechanically breaking the eggs and ingesting them (Miller *et al.,* 1961).

The conditions during the wet season may therefore be seen as being favourable for the development of these parasites in attacking and destroying the helminth eggs. Largely, the dry season recorded a higher level of concentration of helminth eggs compared to the wet season and the difference in concentration can be attributed to the absence of rainfall in the dry season thus resulting in the concentration of the eggs per unit volume of wastewater. The effect of the dilution factor from rainfall is therefore eliminated in the dry season, thus increasing the egg population per litre of wastewater as presented in Table 4.2.

Table 4.2: Arithmetic Means and Coefficients of Variation of Seasonal Concentration of Helminth Eggs in Wastewater Used for Peri-Urban Vegetable Crop Irrigation in Tamale

Type	Dry Season		Wet Season	
	$\bar{X}$ (σ_X)	CV (%)	$\bar{X}$ (σ_X)	CV (%)
Ascaris lumbricoides	17 (9)	85	12 (8)	66
Schistosoma mansoni	7 (3)	11	4 (2)	4
Schistosoma japonicum	3 (1)	0	0 (-)	0
Strongyloides stercoralis	10 (8)	67	10 (6)	32
Ancylostoma spp	13 (7)	44	4 (1)	1
Fasciola hepatica	2 (-)	0	0 (-)	0
Clonorchis sinensis	2 (-)	0	0 (-)	0
Paragonimus westermani	2 (1)	0	0 (-)	0
Schistosoma haematobium	0 (-)	0	8 (5)	25
Paragonimus uterobilateralis	0 (-)	0	3 (1)	1
Diphyllobothrium latum	0 (-)	0	3 (1)	0
Trichuris trichura	0 (-)	0	2 (2)	4
Enteroblus vermicularis	0 (-)	0	2 (2)	2

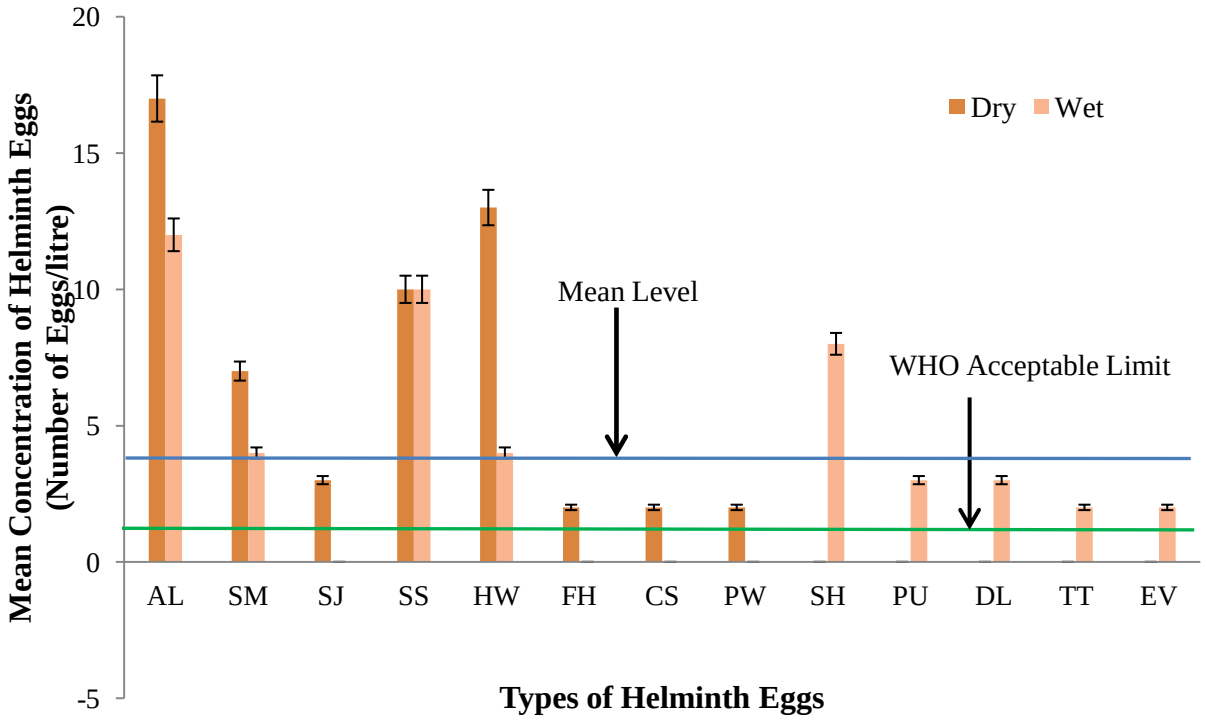
Figures in parentheses are standard deviation; values were rounded to the nearest whole number. $\bar{X}$ is mean concentration

In a study by Amoah *et al*. (2005) from different irrigation water sources in Kumasi and Accra of Ghana, the identified helminth eggs included *Ascaris lumbricoides, Hymenolepis diminuta, Trichuris trichura, Facsiola hepatica* and *Strogyloides* larvae.

In the current study, the dry and wet seasons recorded four (4) and three (3) types of eggs respectively having concentrations higher than five (5) eggs per litre and these are clearly shown in Figure 4.2 against WHO recommendations for irrigation water. In a study by Cornish *et al.* (1999) in urban and peri-urban irrigation water sources, 1–5 helminth eggs per litre was recorded. Helminth eggs and protozoa cysts in ponds have been reported to mainly be removed by sedimentation (Sperling, *et al.,* 2004).

In this study, all the recorded helminths eggs were noted to have a population density ranging from 2 to 17 with a coefficient of variation being between 0 and 85% as shown Table 4.2. *Ascaris lumbricoides* was realised to be the most predominant species recorded with arithmetic mean population of 12 and 17 for the wet and dry seasons respectively. All the observed egg concentrations as presented in Table 4.2 and Figure 4.2 exceeded the recommended level of <1 egg/litre for unrestricted irrigation (WHO, 2006b).

These high concentrations therefore indicate a high risk for farmers, farm workers (irrigators) with a high risk of parasitic infections.



Ascaris lumbricoides (AL), Strongyloides stercoralis (SS), Schistosoma mansoni (SM), Schistosoma haematobium (SH), Clonorchis sinensis (CS), Paragonimus uterobilateralis (PU), Paragonimus westermani (PW), Schistosoma japonicum (SJ) Diphyllobothrium latum (DL), Trichuris trichiura (TT), Fasciola hepatica (FH), Enteroblus vermicularis (EV) and Hookworm (HW).

Figure 4.2: Mean Concentration of Helminth Eggs

4.3.3 Diversity of Helminth Eggs in Wastewater

Attributes of helminth egg seasonal variation as compared with different diversity, dominance and richness indices are presented in Table 4.3. Simpson Index **(λ)** is a measurement that accounts for the richness and the percent of each species from a biodiversity sample within an area. It ranges from 0-1, with 0 implying no diversity and 1 meaning infinite diversity. The index assumes that the proportion of individuals in an area indicates their importance to diversity. Shannon-Wiener index (H') - similar to the Simpson's Index, is a measurement that takes into account sub-species richness and proportion of each sub-species within an area.

From the results of the study, for species diversity both Simpson Index (λ) and Shannon Wiener Index (H') showed a higher helminth egg species diversity of 0.42 and 1.76 respectively for the wet season and 0.48 and 1.57 respectively for the dry season. This could be attributed to the favourable environmental conditions such as low temperature, sunshine, humidity, etc. which are considered necessary for the development of the helminth eggs.

Berger-Parker Dominance Index (D_{BP}) analysis showed that there are more dominant species of the helminth eggs in the wet season (0.40) compared to the dry season (0.37). This therefore indicates that there were more dominant species of the helminth eggs in the highly diverse wet season than in the dry season. Dominant species observed were *Ascaris lumbricoides* (AL) and *Strongyliodes stercoralis* (SS)

Species Richness, which indicates the number of species per sample of wastewater and meaning the more species present in a sample, the 'richer' the sample. Using the Margalef Richness Index (D_{Mg}), a significant difference in species richness with wet season showed a richer species index of 2.29 and the dry season showed a richness index of 1.88.

Equitability or Evenness is a measure of the relative abundance in terms of distribution of the different species making up the richness of an area. Equitability assumes a value between 0 and 1 with 1 being complete evenness. The results indicates more equitable distribution of the helminth egg species in the wet season (0.80) than the dry season (0.75). Table 4.4 presents the seasonal variation in diversity indices of helminth eggs during the study.

Table 4.3: Seasonal Variation in Diversity Indices of Helminth Eggs

Characteristics	Season	
	Dry	**Wet**
Number of Species (n)	8	9
Simpson Index (λ)	0.48	0.42
Shannon-Wiener Index (H')	1.57	1.76
Berger-Parker Dominance Index (D_{BP})	0.37	0.40
Margalef Richness Index (D_{Mg})	1.88	2.29
Equitability Index (E_H)	0.75	0.80
Dominant Species	AL, SS	AL, SS

AL = *Ascaris lumbricoides* SS= *Strongyloides stercoralis*

The indices results of the study revealed that helminth egg type diversity is very useful in looking at their distribution seasonally and influenced by environmental factors. It is clear that the wet season shows higher species diversity, more dominant in species, richer in species counts and is equitability or evenly distributed within the area as compared to the dry season. The Shannon-Weiner Index is controlled largely by equitability than by species richness as indicated by Wolda (1981). The higher level of these diversity indices for the wet season is largely attributed to the favourable environmental conditions of low temperature, short sunshine duration, high humidity and other conditions necessary for helminth egg development.

4.4. Factors Influencing Helminth Egg Occurrence

Low temperature coupled with high humidity, rainfall and pH were realised to influence helminth egg occurrence for the wet season compared to the dry season. Factors that affect the occurrence and concentrations of helminth eggs and protozoan cysts observed in raw wastewater have been reported to include the endemicity of the disease within the indigenous animal and human populations, the size and socio-economic status of the population, the percentage of population sewered, the percentage of wastewater contributed by industry, the volume of influent sampled and the recovery efficiency of the sampling method (Grimason *et al.*, 1995). Table 4.4 presents the prevailing environmental factors during sampling of the wastewater for analysis.

Table 4.4: Environmental Factors Influencing Helminth Egg Concentration

Environmental Factor	Season			
	Dry		Wet	
	Range	Average	Range	Average
Temperature (^{o}C)	23.5 – 32.8	28.15	21.8 – 23.9	22.85
Relative Humidity (%)	20.5 – 48.0	34.25	72.5 – 92.5	82.50
Sunshine Duration (h)	6.3 – 10.3	8.30	0.0 – 10.2	5.10
Rainfall (mm)	0.0 – 1.5	0.75	0.0 – 32.6	16.30
pH	5.6 – 8.5	7.05	4.0 – 9.1	6.55

Environmental factors such as temperature, sunshine amount and duration, rainfall, etc have been noted to impact greatly on the occurrence and concentration of helminth eggs contained in wastewater of a particular locality. These were noted to have contributed largely to a higher number of helminth eggs in the wet season as compared to the dry season. Helminth eggs according to WHO (2006a) have a longer persistence in the environment.

4.5 Conclusions

Various types of helminth eggs occurred in the wastewater used by resource poor farmers in the Zagyuri community, a peri-urban area of the Tamale Metropolis. Seasonal variation in the number of eggs was observed and this was mainly due to the effect of the environmental factors. Limited water supply as a result of irregularity of flow of domestic pipe water especially during the dry season was said to influence greatly the concentration of the helminth eggs per litre of sampled wastewater. The use of protective clothing during crop watering and performance of other crop production cultural practices is expected to help reduce infection of farmers and contamination of vegetables produced. Farmer education and adoption of simple on-farm techniques will play a key role in reducing irrigated vegetable crop contamination.

CHAPTER FIVE

MODELLING THE EFFICIENCY OF AN ON-FARM SAND FILTER SYSTEM IN MICROBIAL CONTAMINANT REMOVAL

5.1 Introduction

Sand-filters remove pathogenic micro-organisms from polluted water by first retaining them in the filtration media before they are eliminated (Stevic *et al.,* 2004). According to Keraita *et al.* (2010), retention is achieved mainly through straining, in which larger micro-organisms (protozoans and helminths) are physically blocked as they move through the well-packed filter media, and adsorption, in which smaller ones like bacteria get attached to the filtration media. The authors also indicated that, elimination of pathogenic micro-organisms is achieved mainly by exposing them to unfavourable environmental conditions such as high temperature and also through predation by other organisms like protozoans.

WHO (2006b) reported that, typical pathogenic removal range for slow sand-filters is 0-3 log units and 1-3 log units for bacteria and helminths respectively. Keraita *et al.* (2010) reported that when wastewater is allowed to pass through sand-filter trenches, sand embankments, column sand-filters and simple sandbags as farmers channel irrigation water to collection storage ponds will greatly affect protozoa and helminths.

5.2 Filter Design and Wastewater Sampling

The on-farm sand filter units were designed using cylindrical containers with a diameter of 6.5 cm and of varying lengths (8.5 cm, 17 cm and 25.5 cm). Filter gauze and mosquito netting were used to cover both the inlet and outlet units whilst the filter columns were filled with six (6) different grades (2-45 mm in diameter) of filter media. Channels were designed in a staircase fashion to convey the filtered wastewater from the outlet point of the filter units

to the stabilization ponds. Plates 5.1a and 5.1b show the filter media used for the various filtration layers and the three (3) different sizes of filters respectively.

Plate 5.1a: Six (6) Grades of Filter Media Used

Plate 5.1b: Different Sizes of Filter Containers Used

The staircase design was aimed at cascading the water to improve the oxygen levels contained in the wastewater to promote the activity of micro-organisms. Construction in the field was done using concrete blocks, sand and cement as shown in Plate 5.2.

Plate 5.2: Constructional Process of Experimental Set-up in the Field

Computer aided design of the filter units (Figure 5.1) and the entire experimental field set-up (Figure 5.2) were achieved using AutoCAD 2009 version. According to Sasse (1998), most filters have a double function:

- they provide a fixed surface for the treatment of bacteria and
- they form a physical obstacle for smaller solid particles.

Stevic *et al.* (2004) also noted that sand filters remove pathogenic micro-organisms from polluted water by first retaining them in the filtration media before being eliminated.

Filter material of spherical and almost equal grain size is more efficient and renders longer service than filters of mixed grain size. Large grain size with a high percentage of voids prevents clogging but reduces treatment performance. To prevent clogging, the front portion must have voids that are small enough to distribute the filtered suspended solids over a longer distance (Sasse, 1998).

Filtered wastewater sampling was done at weekly (7 days) intervals for a period of sixteen (16) weeks that is eight (8) weeks for the rainy season and eight (8) weeks for the dry season in each sampling year (2011 and 2012). A total number of ten (10) filtered wastewater samples were collected at each sampling time resulting in 160 wastewater samples per year and 320 samples for the whole study.

During the sampling and laboratory analysis periods, sterile sampling containers, hand gloves, water and standard chemical reagents were used. Samples were stored over ice in cool box for transportation to the laboratory for analysis.

Helminth eggs were enumerated using the concentration method as described by Schwartzbrod (1998) whilst the Heterotrophic Plate Count (HPC) method was used for the determination of faecal and total coliforms.

5.3 Results and Discussion

5.3.1 Characteristics of Filter Media and Design of On-Farm Sand Filter System

The six (6) filter media used had different void spaces or porosity thus translating to different efficiencies in the removal of various contaminants. Table 5.1 presents the physical characteristics of the filter media used for the design of the experiment. The average dry bulk density and particle density of the filter media were 1.58 gcm^{-3} and 2.66 gcm^{-3} respectively. Total average filter porosity was 39.4 % but this ranged widely from a low porosity of 16.5 % to 52.5 %. A positive relation between filter media size and porosity was observed for the

media used in the experiment. In a study in Uganda by Katukiza *et al.* (2014) using two step filtration for grey water, the media size ranged from 2.56 to 5 mm for the first step and 1.18-2.56 mm for the second step with 65.6 % and 62 % porosity respectively. Sasse (1998) reported that the permeability and durability of filters always is reciprocal to its treatment efficiency.

Table 5.1: Physical Characteristics of Filter Media Used in Filter Columns

Diameter (mm)	Dry Bulk Density (g/cm^3)	Particle Density (g/cm^3)	Porosity (%)
2.0	1.66	1.99	16.5
4.75	1.79	2.95	39.3
8.0	1.69	2.90	41.7
19.0	1.48	2.57	42.5
37.5	1.47	2.62	43.8
45.0	1.39	2.93	52.5
Average	**1.58**	**2.66**	**39.4**

These filter materials were placed into the nine (9) cylindrical filter units of three (3) dimensions as shown in Figure 5.1.

The smallest diameter of 2 mm served as the first layer of each column whilst the biggest size filter media of 45 mm was at the bottom of the filter column. Rapid sand filtration removes 90-99 % of helminth ova from coagulated primary effluent (Jiménez, *et al.,* 2001). This is considered under specific media size of sand medium of 0.8-1.2 mm and minimum filter depth of 1 m with filtration rates of 7-10 m^3/m^2h and filtration cycles of 20-35 hours. Jiménez (2007a) and Landa *et al.,* (1997) observed that under these conditions, the effluent consistently contains < 0.1 helminth egg per litre.

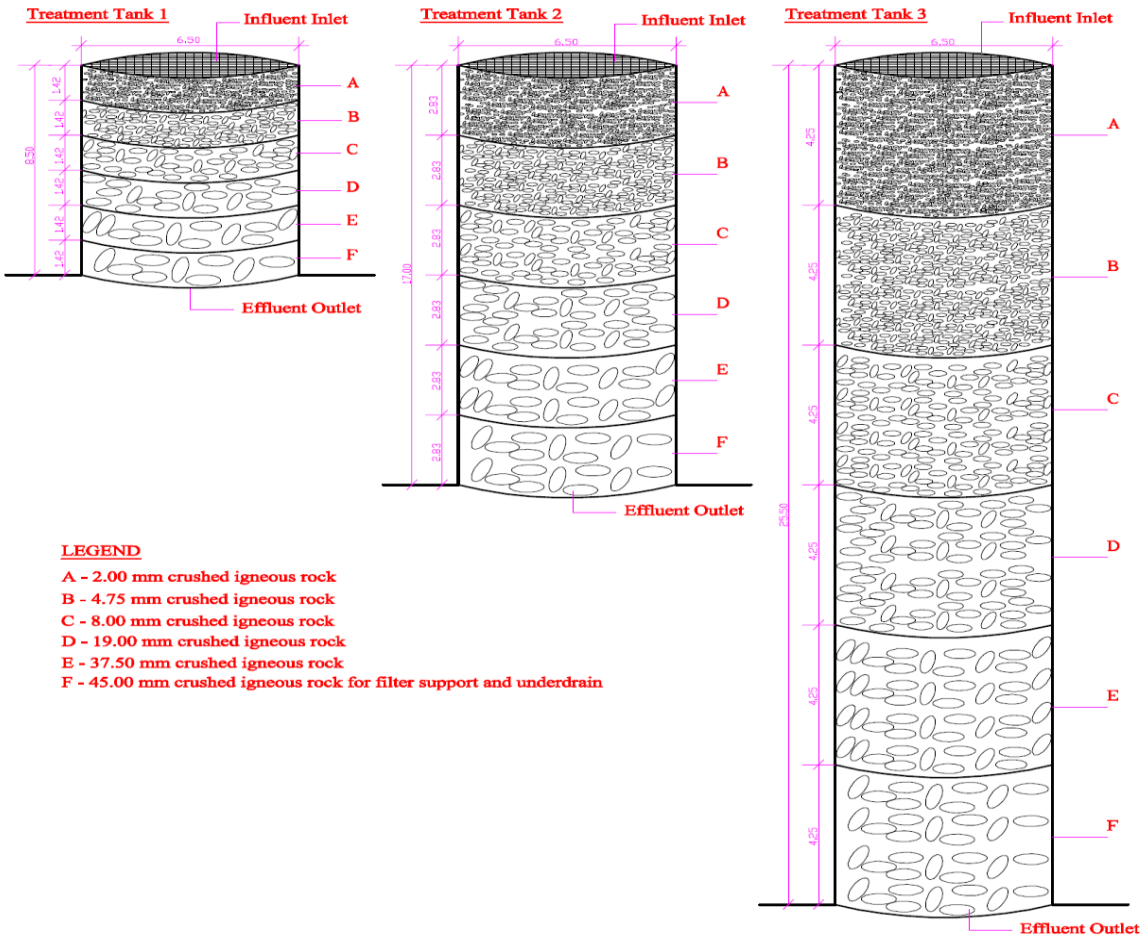


Figure 5.1: Designed Experimental Filters Indicating the Various Layers

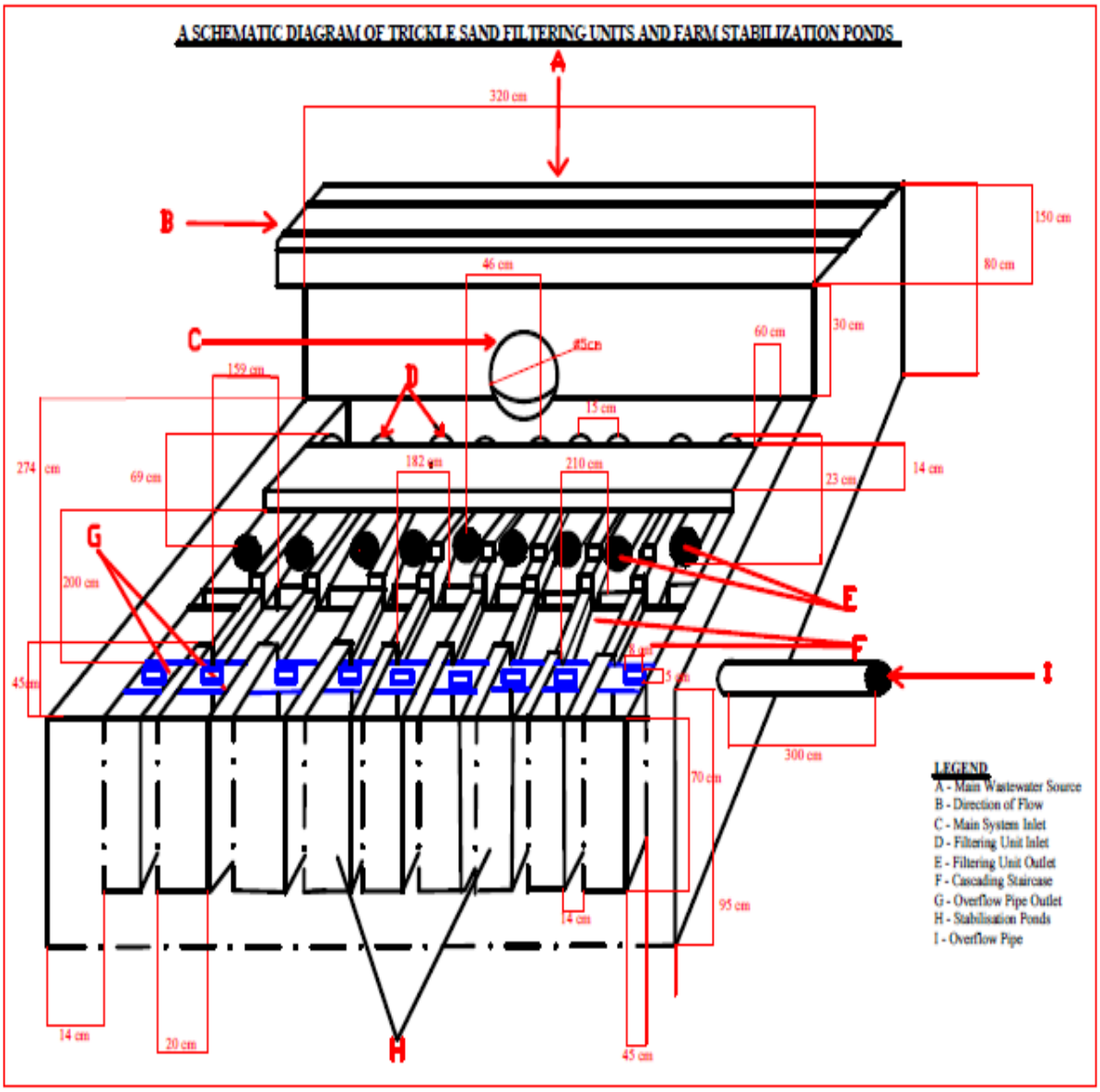


Figure 5.2: A Schematic Diagram of On-Farm Sand Filter Units and Farm Stabilisation Ponds

5.3.2 Microbial Levels in Wastewater and their Reduction Using On-Farm Sand Filter

The concentration of faecal and total coliforms as well as helminth eggs was 24,444 MPN/l, 56,930 MPN/l and 56 eggs/l for the wet season respectively. In the dry season however, faecal coliform recorded a mean concentration of 13,780 MPN/l, total coliform was 41,113 MPN/l whilst helminth eggs were 74 eggs/l. These mean concentrations were noted to be higher than the recommended levels of less than 1000/100 ml of coliforms and <1 egg/l for unrestricted irrigation (WHO, 2006b). Except helminth eggs which experienced low number of eggs per litre in the wet season, coliform bacteria was observed to be generally high in the wet season as compared to the dry season (Tables 5.2, 5.3 and 5.4). In a study by *Obuobie et al.* (2006) in Kumasi Ghana, a general increase in levels of faecal coliforms was observed after the first rains. Similarly, Faruqui *et al.* (2004) observed in Dakar, Senegal the effects of "laundry days" and "Friday prayers" on stream water quality.

Table 5.2: Mean Concentration and Removal Level of Faecal Coliform by Season

Treatment	Wet Season		Dry Season	
	Mean Concentration (MPN/l)	% Removal	Mean Concentration (MPN/l)	% Removal
T_1	24,444	68.0	13,780	62.6
T_2	24,444	75.7	13,780	67.2
T_3	24,444	80.9	13,780	69.7

It is clear from Table 5.2 that filter column length has a great influence on the reduction level of faecal coliform bacteria in wastewater. T_3 recorded highest levels of reduction in faecal coliform levels of 80.9 % and 69.7 % for the wet and dry season respectively. T_1 with the least filter material length recorded the lowest removal rate of coliform bacteria for both seasons (68.0 % for wet season and 62.6 % for the dry season).

Table 5.3: Mean Concentration and Removal Level of Total Coliform by Season

Treatment	Wet Season		Dry Season	
	Mean Concentration (MPN/l)	% Removal	Mean Concentration (MPN/l)	% Removal
T_1	56,930	62.2	41,113	50.3
T_2	56,930	64.9	41,113	54.0
T_3	56,930	73.8	41,113	59.6

The effect of the on-farm sand filter system on total coliform bacteria was observed to be higher in T_3 with percentage removal of 73.8% and 59.6% for the wet and the dry seasons respectively. T_1 with a container length of 8.5 cm recorded the least effect on the removal of total coliform contained in the wastewater with percentage removal rate of 62.2% for the wet season and 50.3% for the dry season.

For coliform bacteria it can be seen clearly (Tables 5.2 and 5.3) that container length which translates to the amount of filter material contained in the filter column had a positive linear effect on the removal rate of total coliform bacteria in wastewater.

Also, the effect of the on-farm sand filter was largely efficient in coliform bacteria removal in the wet season compared with the dry season. This can be attributed to the favourable environmental conditions which led to the growth and optimal maturation of the surface microbiological layer (the *'schmutzdecke'*) thus improving the efficiency of bacteria removal.

Table 5.4: Mean Concentration and Removal Level of Helminth Eggs by Season

Treatment	Wet Season		Dry Season	
	Mean Concentration (eggs/litre)	% Removal	Mean Concentration (eggs/litre)	% Removal
T_1	56	70.2	74	57.6
T_2	56	71.0	74	72.6
T_3	56	73.9	74	74.1

The concentrations of helminth eggs per litre was observed to be lower in the wet season (56 eggs/litre) compared to the values in the dry season with 74 eggs/litre (Table 5.4). The results of the treatment effect on the removal of helminth eggs indicated that, the longer the filter material the more efficient the system. T_3 with total length of 25.5 cm recorded the highest level of helminth egg removal of 73.9 % and 74.1 % for the wet and dry seasons respectively. T_1 with a filter length of 8.5 cm, however, recorded the lowest level of removal of helminths with values of 70.2 % and 57.6 % for the wet and dry seasons respectively. Bos *et al.* (2010) noted that very good performance of farm-based options of wastewater treatment is normally achieved in the dry season compared to the wet season due to rainfall, shorter duration of sunshine and generally low temperatures.

Tables 5.5 and 5.6 present the ANOVA of the reduction levels of microbial contaminants in the wastewater and the treatment effects. It is clear from the Tables (5.5 and 5.6) that there were significant differences in the reduction in the levels of microbial contaminants using the three (3) different treatments. With respect to the main source, both seasons (dry and wet) recorded an Fpr value of < 0.001 at 5 % significance level.

Table 5.5: ANOVA of Microbial Reduction Levels in the Wet Season

Parameter	MS	T_I	T_2	T_3	Grand Mean	LSD	CV (%)	F pr.
Faecal Coliform	12222	4394	3011	2521	5537	2810.5	49.6	<0.001
Total Coliform	28465	11942	10225	7714	14586	7745.6	51.8	<0.001
Helminths Eggs	28	8	8	7	13	3.474	26.5	<0.001

Table 5.6: ANOVA of Microbial Reduction Levels in the Dry Season

Parameter	MS	TI	T2	T3	Grand Mean	LSD	CV (%)	F pr.
Faecal Coliform	6890	2569	2334	2385	3544	1672.4	46.1	<0.001
Total Coliform	20557	9692	9231	7221	11675	5567.5	46.6	<0.001
Helminths Eggs	37	15	10	9	18	4.950	27.1	<0.001

Helminth eggs have been reported to be very resistant and behave quite differently from bacteria and viruses during treatment (Jiménez *et al.*, 2010a).

According to Jiménez *et al.* (2010b), during filtration, pathogens and other particulate matter are removed as they pass through sand or other porous granular media.

5.3.3 Prediction Models for Faecal Coliform Removal

From the multivariate regression analysis on the performance of the designed sand filter system, six (6) factors were considered in the evaluation of the system. These were the length of the container (L), the relative humidity (RH), temperature (T), sunshine hours (Ra), rainfall (P) and pH of the wastewater. Bos *et al.* (2010) noted that very good performance of

farm-based options of wastewater treatment is normally achieved in the dry season compared to the wet season due to rainfall, shorter duration of sunshine and generally low temperatures. The model equation for the design of the on-farm sand filter system for the removal of faecal coliform (FC) during the study was obtained as Equation 5.1. This prediction model was developed as a multivariate linear regression model using the output data from the treatment systems in SPSS version 16.00.

$$FC = 13.715 - 0.039L - 0.074RH - 0.017\,T + 0.180\,Ra + 0.044\,P - 0.584\,pH \quad \text{..... 5.1}$$

$$R^2 = 0.461$$

The R^2 suggests that about 46% of the variables explain the FC levels contained in wastewater during the dry season after treatment. This indicates that other factors influenced the reduction in concentration of faecal coliform levels in the wastewater during the dry season. The results show that an increase in the length of the treatment filters by a unit decrease the FC concentration level by 3.9 % in the dry season. An increase in the RH, T and pH by a unit results in the reduction of FC by 7.4 %, 1.7% and 58.4 % respectively. However, in the dry season as observed from the prediction Equation 5.1, an inverse linear relationship existed between the variables Ra and P. This is because an increase by a unit of Ra and P results in a corresponding increase in the FC levels by 18 % and 4.4 % respectively of the factors. The results indicate statistical significance at the 0.05 level for L, RH, Ra and pH.

In the wet season of the study, the multivariate linear regression model that can be adopted for the reduction of the faecal coliform contained in wastewater of the area is Equation 5.2.

$$FC = -0.587 - 0.082L + 0.003RH + 0.329T - 0.056Ra + 0.17P + 0.22pH \quad \text{..... 5.2}$$

$$R^2=0.411$$

From Equation 5.2, 41.1 % of the reduction levels of FC are explained by the regression line. L and Ra can be seen to be contributing to the reduction in the concentration of the faecal coliform contained in the wastewater. A unit increase in L and Ra results in a corresponding reduction in FC concentration by 8.2 % and 5.6 %. The other environmental factors influencing the survival of faecal coliform were RH, T, P and pH and it is clear from Equation 5.2 that a unit increase in these parameters will have a corresponding unit increase in the FC contained in the treated wastewater. 0.3 %, 32.9 %, 17 % and 22 % increase in FC concentration corresponding to a unit increase in RH, T, P and pH respectively are observed from the equation. Unlike the dry season, an increase in Ra during the wet season results in a unit decrease in FC concentration.

It has been reported that the higher the temperature, the higher the rate at which the degrading bacteria that are responsible for purification multiply. At the same time, the intake of oxygen via surface and oxygen solubility drops with increasing temperature. The most important factors considered to be controlling the rate of decay of faecal coliform are temperature, solar intensity and pH (Mayo, 1989; Auer and Niehaust, 1993).

5.3.4 Prediction Models for Total Coliform Removal

The results of the dry season showed that about 48% of the removal of total coliform (TC) using the designed treatment system is explained by the factors influencing TC as in the model. The results of the model indicated that the parameters L, RH, T, P and pH have an inverse relationship with TC concentration in wastewater (Equation 5.3).

$$TC = 11.088 - 0.037L - 0.021RH - 0.037T + 0.039Ra - 0.297P - 0.004pH \quad \text{.....} \quad 4.3$$

$$R^2 = 0.478$$

From the model (Equation 5.3) a unit increase in L, RH, T, P and pH results in the reduction of TC concentration in the raw wastewater by 3.7 %, 2.1 %, 3.7 %, 29.7 % and 0.4 % respectively. Also, the Ra is realised to have direct impact or positive linear relationship on TC levels as a unit increase in Ra results in a 3.9 % increase in TC. Except P which is not statistically significant (p value > 0.05), L, RH and Ra are significant at 0.05 level whilst T and pH are significant at 0.10 level.

TC concentration reduction in the wet season was characterized by a unit increase in L, Ra, and P. Equation 5.4 shows that with a unit increase in L, Ra and P, a respective 5.8 %, 4.8 % and 0.6 % reduction levels can be achieved. The effect of increase in RH, T and pH on the reduction was, however, seen to be directly related.

$$TC = 2.593 - 0.058L + 0.017RH + 0.185T - 0.048Ra - 0.006P + 0.186pH \quad \text{..... 5.4}$$

$$R^2 = 0.325$$

An increase in RH, T and pH rather provided favourable environmental conditions for the survival and multiplication of the TC as shown by the prediction Equation 5.4. From the model (Equation 5.4), only 32.5 % of the variables are explained by the regression equation with 67.5 % factors that have not been accounted for. According to Sasse (1998) pathogen removal rates increase with long retention times, but all high rate plants work proudly on short retention times.

The WHO (2006b) guidelines and other independent surveys describe transmission of worm infections as the greatest risk in relation to wastewater. Worm eggs, helminths, are well removed from effluent by sedimentation but accumulate in the bottom sludge. The long retention times of 1 to 3 years in septic tanks and anaerobic filters provide sufficient protection against helminths infection in practice. High pathogen removal rates are reported from constructed wetlands and shallow aerobic ponds. This effect is attributed to longer

retention times, exposure to UV rays in ponds, and various bio-chemical interactions in constructed wetlands (Sasse, 1998). Also, exposure to UV rays has a substantial hygienic effect. The highest rate of pathogen removal can be expected from shallow ponds with long retention times, e.g. 3 ponds in a row with HRT of 8 to 10 days each. Effluents from aerobic ponds or constructed wetlands is suitable for surface irrigation, even in domestic gardens. However, the better the treatment effect of the system, the lower is the fertiliser value of the effluent (Sasse, 1998).

5.3.5 Prediction Models for Helminth Egg Removal

The prediction model for helminth (H) eggs recorded a 55 % (R^2 value) as shown by Equation 5.5. The results show that L, RH, T, Ra and pH are inversely related to the concentration of H. This indicates that, a unit increase in L, RH, T, Ra and pH results in the reduction of H concentration by 6.1 %, 11 %, 8 %, 10 % and 13.3 % respectively whilst a unit increase in P results in 8 % increase in helminth egg concentration. Equation 5.5 presents the model parameters and the effect of variation in levels of these parameters on the concentration of helminth eggs in wastewater used by the resource poor farmers. However, except L which is found to be significant at 0.05 level, the other parameters were not statistically significant.

$$H = 4.959 - 0.061L - 0.11RH - 0.08T - 0.010Ra + 0.08P - 0.133pH \quad \text{..... 5.5}$$

$$R^2 = 0.545$$

In the wet season the R^2 value of 43.4 % was obtained and slightly lower than the dry season as per the model equations 5.5 and 5.6 for the removal of helminth eggs. It is also clear as in Equation 5.6 that aside the length of the container which indicates that the more filter

material contained in it, the higher the filtering efficiency, the rest of the factors did not positively reduce the concentration of the helminth eggs in the wastewater during treatment.

$$H = -1.283 - 0.054L + 0.028RH + 0.061T + 0.07Ra + 0.009P + 0.01pH \quad \text{..... 5.6}$$

$$R^2 = 0.434$$

A unit increase in the length of container was observed to reduce the concentration of helminth eggs by 5.4 %. RH, T, Ra, P and pH were observed as per equation 5.6 to rather provide conducive environment for the growth and multiplication of helminth eggs during the wet season.

5.4 Conclusions

Designing a wastewater treatment system involves selection of a very good filter material and sizing the filter column rightly. Varying lengths of filter columns and depths of filter material were used in the design of the on-farm sand filter columns. Average dry bulk density and particle density of the filter media were 1.58 gcm^{-3} and 2.66 gcm^{-3} respectively whilst total average filter porosity was 39.4 %. Mathematical models are therefore employed in the determination of the right size of filter container needed for the efficient removal of microbial (faecal and total coliforms, helminth eggs) contaminants. These models consider largely the prevailing environmental conditions in the locality for which the filters will be installed. The results indicated the level to which microbial contaminants in wastewater can be removed. Longer filter columns were more efficient in the removal of microbial contaminants contained in the wastewater. The concentration of faecal and total coliforms as well as helminth eggs was 24,444 MPN/l, 56,930 MPN/l and 56 eggs/l for the wet season respectively. In the dry season, however, faecal coliform recorded a mean concentration of 13,780 MPN/l, total coliform was 41,113 MPN/l whilst helminth eggs were 74 eggs/l. These

mean concentrations were noted to be higher than the recommended levels of less than 1000/100 ml of coliforms and <1 egg/l for unrestricted irrigation (WHO, 2006b).

CHAPTER SIX

CHEMICAL QUALITY OF WASTEWATER AFTER FILTRATION USING AN ON-FARM SAND FILTER SYSTEM

6.1 Introduction

Wastewater treatment according to Frans *et al.* (2006) implies the purification of a given wastewater until its characteristics achieve a certain objective, generally related to health, environmental, or economic matters. Rapidly increasing water supply and sanitation coverage generates large volumes of wastewater, which is often released untreated into the environment (streams, drains, etc.) (GSS, 2012).

The need for year-round production of vegetables in or near urban areas makes irrigation necessary; hence, farmers in search of water for irrigation often rely on wastewater (Amoah, 2008). Aside microbiological hazards, the practice can pose a variety of potential risks, excessive and often imbalanced addition of nutrients to the soil. However, maintaining adequate levels of nutrients in wastewater according to Manzoor and Christopher (2010) is a challenging task because of the possible negative impacts of their excessive addition to the wastewater-irrigation soils. Urine has been reported by Meinzinger and Oldenburg (2008) to constitute the major fraction of nitrogen, phosphorus and potassium in domestic wastewater which are essential components of plant fertilizers.

According to Helmer and Hespanho, (1997), contaminants in irrigation water may accumulate in the soil and after a period of years, render the soil unfit for agriculture. This situation of rapid population growth coupled with scarcity of water and increase in the use of wastewater for irrigation of vegetables with its associated toxicity has called for frantic efforts to safeguard the risks posed by these chemical properties in the use of wastewater on both the farmer and the consumer.

6.2 On-Farm Filter System

On-farm sand filter system combined with farm stabilization ponds were designed with the aim of reducing the level of chemical contaminants of wastewater used for vegetable crop production and to serve as a timely intervention to help avert the phenomenon of chemical effects with wastewater usage for poor peri-urban farmers.

The study designed and used eighteen cylindrical containers with a diameter of 6.5 cm of varying lengths. Each on-farm sand filter unit was designed and fabricated to contain the following: mosquito netting at inflow and outflow ends to sieve out debris to prevent clogging.

Stabilization ponds were designed at 2 m x 7 m with a staircase design at 1 m interval for 2 m at intake point of the tank unit with the remaining 4.5 m being the depth of the stabilization pond. Cement and concrete blocks were used for the construction of a staircase connecting the filter units to the stabilization ponds and the water source.

The experiment had three (3) treatments with equal diameters:

Treatment one (T_1) where the length of the filtering container was 8.5 cm,

Treatment two (T_2) where the length of the filtering container was 17 cm,

Treatment three (T_3) where the length of the filtering container was 25.5 cm, and

The Control (Main Source - MS) where the wastewater was without any filtration.

Each treatment had three (3) replications.

Each filtering unit was filled with six (6) different sizes of the filter media as presented in Table 6.1 and wastewater from the Kamina Barracks sewage system was directed to the designed treatment system.

Table 6.1: Design Filter Media Sizes

Layer	Filter Media Size (mm)
Topmost	2.00
First	4.75
Second	8.00
Third	19.0
Fourth	37.5
Lowest	45.0

Filtered wastewater sampling was done at weekly (7 days) intervals for a period of sixteen (16) weeks that is eight (8) weeks for the rainy season (August and September) and eight (8) weeks for the dry season (January and February) in each sampling year. Data collection was done in the years 2011 and 2012. A total number of ten (10) filtered wastewater samples were collected at each sampling time resulting in 160 wastewater samples per year and 320 samples for the whole study.

6.3 Chemical Contaminants Reduction in Wastewater Using the On-Farm Sand Filter

After the filtration of the wastewater, the key physico-chemical parameters affecting wastewater for irrigation were monitored over time. The various chemical concentrations and reduction or increase in concentration in the effluent were then considered.

6.3.1 Variation of Ammonia (NH_3) Concentration in Wastewater

The levels of NH_3 in the wet season for weeks 2, 3, 4 and 5 were lower ($\leq$ 20 mg/l) than the other weeks which recorded higher levels > 20 mg/l in the main source. The three (3) treatments (T_1, T_2 and T_3) applied to the wastewater supplied from the main source observed varying degrees of reduction in levels of NH_3. Ammonia is reported to be removed by adsorption and nitrification-denitrification (Bayley *et al.*, 2003). Except weeks 2, 4 and 5 of

T_3, the other weeks were able to achieve reductions in levels of NH_3 compared to T_1 and T_2 (Figure 6.1). With respect to the main source, T_3 recorded very much reduced levels of NH_3 and an example is in week 8 when the main source had 33.25 mg/l but reduced to 10.83 mg/l when filtered using T_3. The treatments T_1 and T_2 also achieved high levels of reduction in the concentration of NH_3 compared to the main source.

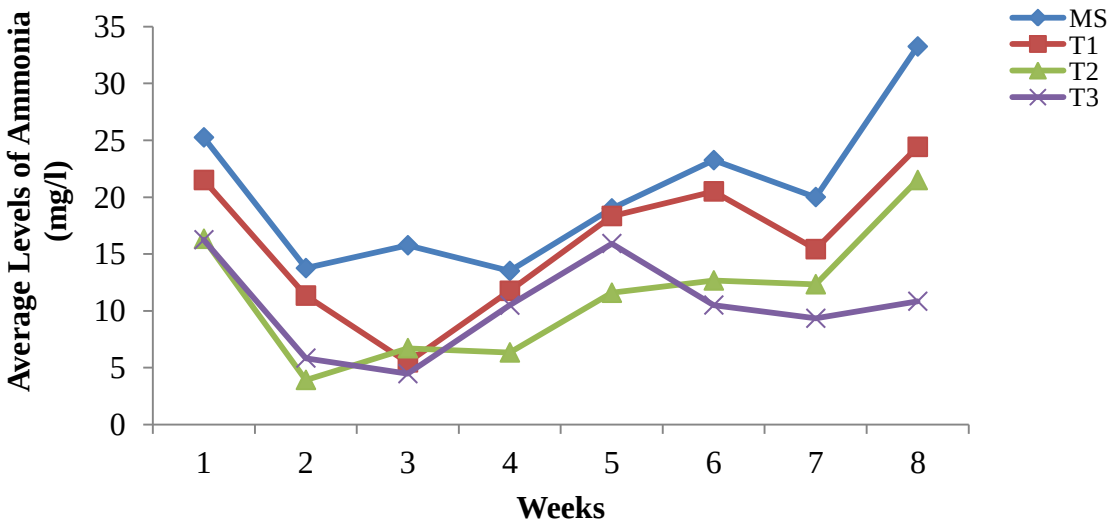


Figure 6.1: Weekly Occurrence and Treatment Effects on NH_3 in the Wet Season

In the dry season, NH_3 levels were comparatively higher over the 8 week period as it recorded an average of 26.29 mg/l whilst the wet season recorded an average of 20.47 mg/l. With respect to weeks 3 and 8 where T_1 recorded lower levels of NH_3 than the T_3, the other Weeks recorded lower levels of NH_3 for T_3. Weeks 2, 4 and 7 saw the NH_3 levels to be more concentrated in the stabilisation ponds being higher than the main source (Figure 6.2). This could be attributed to the relatively higher concentrations of ammonia in the weekly accumulated volumes of water in the stabilization ponds compared to the main source (MS).

The volatility nature of NH_3 could also contribute greatly to the variation in concentration especially for the main source of the wastewater.

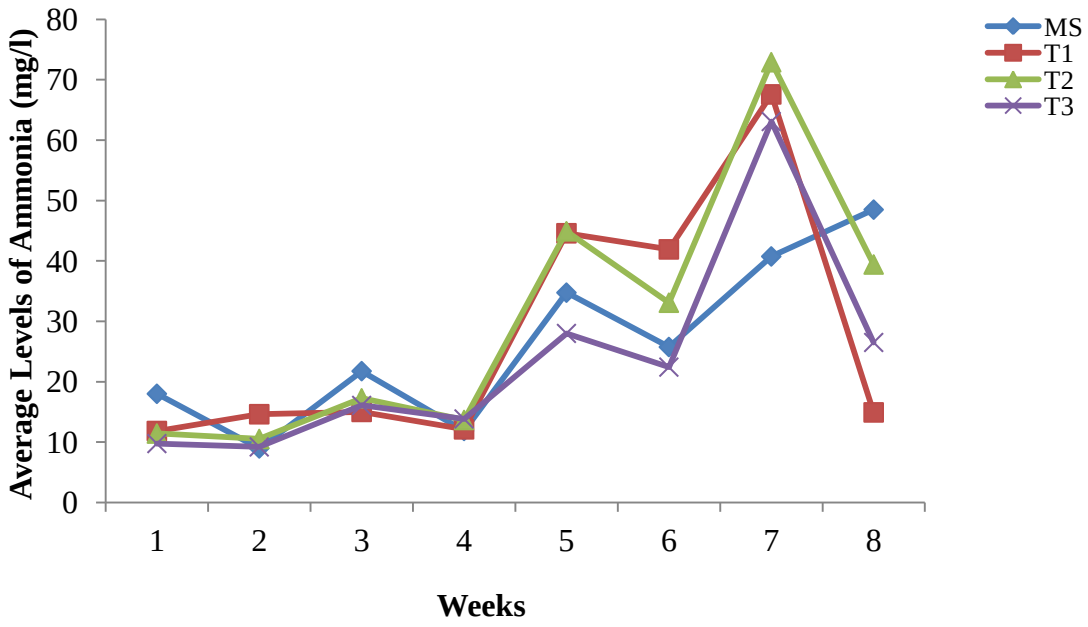


Figure 6.2: Weekly Occurrence and Treatment Effects on NH_3 in the Dry Season

Obuobie *et al.* (2006) in a study on water quality in Kumasi, Ghana observed significant difference in NH_4 between upstream and downstream. Drangert (1998) estimated the concentration of nutrients in human excreta for N, P, K and carbon as 4.5 kg, 0.6, 1.2 and 11.7 in faecal sludge applied.

ANOVA on data for both seasons indicated the reduction in NH_3 levels was statistically significant for only ammonia in the wet season with f-probability of 0.006. The variation was observed between the MS, T_2 and T_3 but not T_1.

In the dry season, NH_3 was observed not to be statistically significant in concentration but variations in levels. Ammonia (NH_3) losses in settling tanks and ponds may occur through volatilization if overall hydraulic retention times are sufficiently long (weeks to months) and pH rises above 8, enabling the formation of NH_3 in the pH-dependant NH_4/NH_3 equilibrium (Heinss *et al.,* 1998). In the current study the pH of the wastewater averaged 7.52 and 7.33

for the dry and wet seasons respectively. These higher pH levels coupled with the weekly retention times could be contributing to some losses in the NH_3. Figure 6.3 presents the mean levels of ammonia with respect to the various treatments for the wastewater.

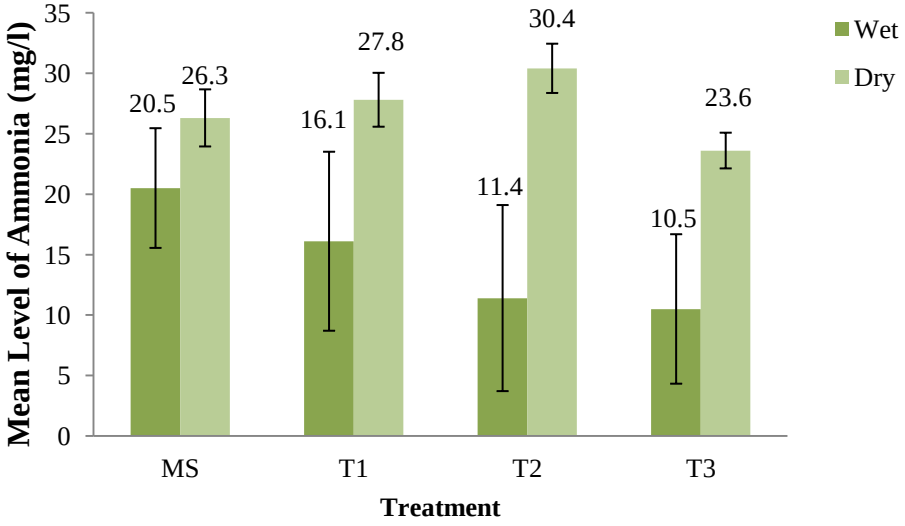


Figure 6.3: Variation in NH_3 Levels

According to Deborah (1996) unpolluted waters contain small amount of ammonia and ammonia compounds, usually < 0.1 mg/l as nitrogen. Total ammonia concentrations measured in surface waters are typically < 0.2 mg/l N but may reach 2-3 mg/l N. Higher concentrations could be an indication of organic pollution such as from domestic sewage, industrial waste and fertilizer run-off. Ammonia is, therefore, a useful indicator of organic pollution.

6.3.2 Nitrate (NO_3^-) Concentration in Wastewater

Average NO_3^- concentration in the main source of the wastewater was 0.433 mg/l and 4.84 mg/l for the dry and wet seasons respectively. Nitrates are highly soluble and can easily be moved through wastewater-irrigated soils. The implication of the retention of nutrients and

other wastewater contaminants in soil is that they do not reach water bodies into which wastewater would otherwise be disposed (Qadir and Scott, 2010).

The Weekly trend for NO_3^- in the wet season (Figure 6.4) was highest for Week 1 (MS = 28.16 mg/l, T_1=17.89 mg/l, T_2 = 22.45 mg/l and T_3 = 20.89 mg/l) and Week 3 (MS = 8.71 mg/l, T_1 = 5.75 mg/l, T_2 = 4.99 mg/l and T_3 = 6.01 mg/l) and uniformly low levels below 1.00 mg/l for the other weeks. The response to treatments though was not statistically significant, yet was quite positive with some level of reduction for the treatments.

The situation for the dry season was different with the response to treatment being statistically significant with f-probability of 0.001.

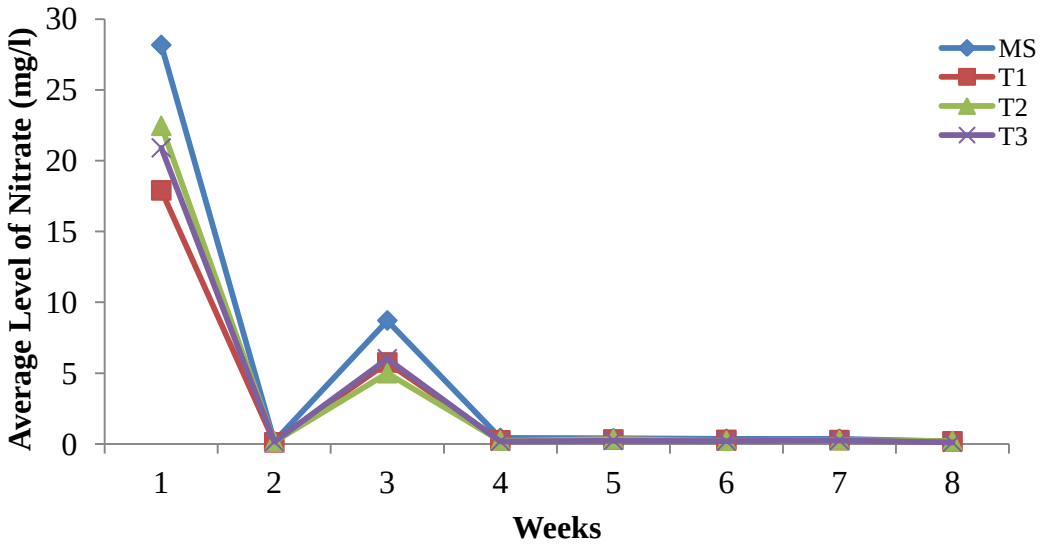


Figure 6.4: Weekly Occurrence and Treatment Effect on NO_3^- in the Wet Season

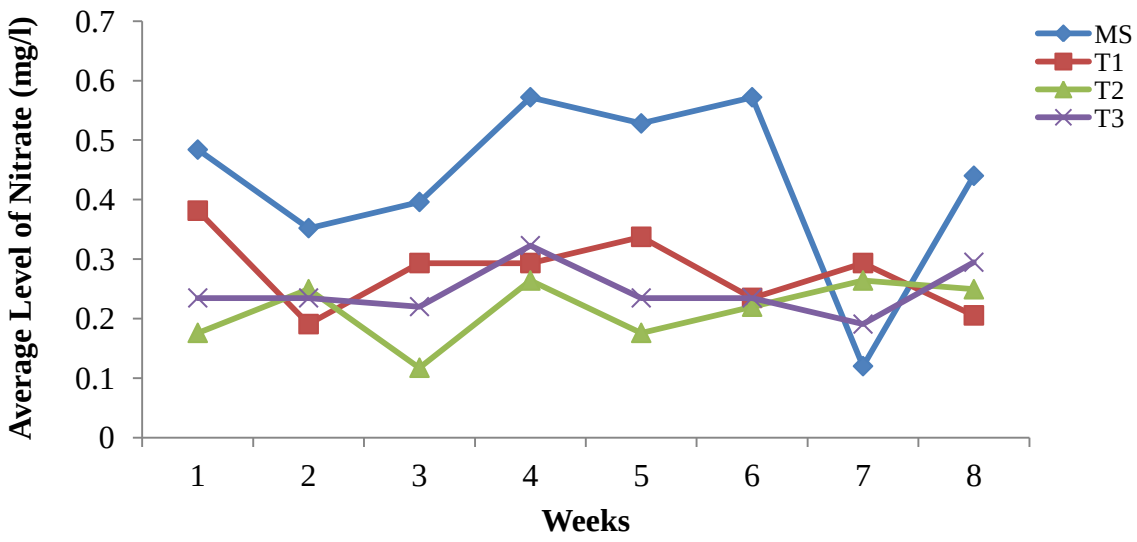


Figure 6.5: Weekly Occurrence and Treatment Effects on NO_3^- in the Dry Season

Comparing Figures 6.4 and 6.5 it is clear that Figure 6.4 followed a uniform trend and this may be attributed to equal volumes of dilution from rainwater aiding uniform solubility for the wet season.

ANOVA of the treatment effects of the designed system indicated that NO_3^- experienced some level of reduction in concentration but this was observed not to be statistically significant at 5%.

The level of reduction of NO_3^- concentration in the dry season was statistically significant with f-probability of 0.001. This difference was observed between the control (MS) and the treatments. The mean level of concentration of nitrate for the main source and the treatments is as presented in Figure 6.6.

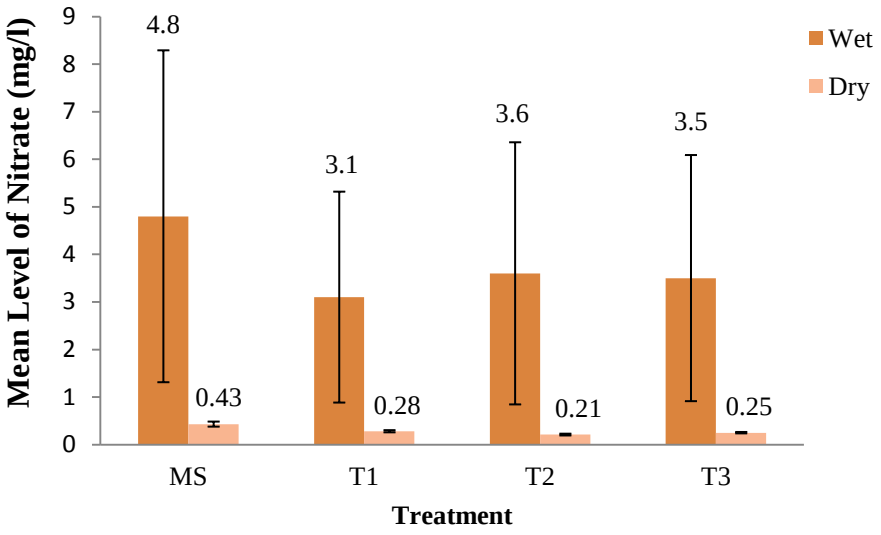


Figure 6.6: Variation in NO_3^- Levels

According to Helmer and Hespanho (1997), the most widely used water quality standard for nitrate (NO_3^-) is the 50 mg/l limit adopted by World Health Organisation (WHO) as a precautionary level to safeguard babies from the risks of contracting *methaemoglobinaemia* (WHO, 1993). In Ghana, the standard of 50 mg/l concentration of NO_3^- is being used by the Environmental Protection Agency (EPA) for wastewater discharge into water bodies or water courses. Most national authorities also regard the 50 mg /l concentration as a realistic target in relation to eutrophication. According to Sasse (1998) nitrate is the most stable form of nitrogen and its presence indicates complete oxidation. During nitrification, NH_3 (ammonia) is oxidised by a special group of bacteria (*nitrobacter*) to NO^-_3. Because the bacteria grows slowly, longer retention time is required for oxidation of the nitrogen as compared with the oxidation of carbon. Incomplete denitrification may lead to formation of poisonous nitrite (NO^-_2), instead of nitrate (NO^-_3). This may be due to the time left for the bacteria to consume all the oxygen not being enough or because there is not enough organic material left to absorb the NO^-_3 oxygen.

According to Tuikolongahau (2008), under normal conditions, both nitrites (except the ammonium salt) and nitrates are stable compounds. In nitrogen removal, longer retention times of wastewater alone do not solve the problem because the nitrifying phase needs an aerobic environment, while denitrification requires an anoxic environment. Anoxic means that nitrate (NO_3) oxygen is available, but free oxygen is not (Sasse, 1998).

6.3.3 Nitrite (NO_2^-) Concentration and Variation

In the dry season of the experiment, mean levels of NO_2^- concentration measured in the main source of the wastewater was 0.13 mg/l whilst the wet season recorded a mean of 2.50 mg/l.

As a result of the behavioural characteristics, both nitrate and nitrite showed similar characteristics by virtue of occurrence and response to treatment. Week 1 (MS = 9.57 mg/l, T_1 = 9.02 mg/l, T_2 = 9.24 mg/l and T_3 = 8.14 mg/l) and Week 3 (MS = 9.90 mg/l, T_1 = 4.84 mg/l, T_2 = 6.60 mg/l and T_3 = 7.70 mg/l) of the wet season recorded the highest levels and a uniform low level for the other weeks. The level of reduction was statistically significant with f-probability of 0.002 in the dry season. This difference could be attributed to microbial activities and stability for the various seasons, with the highest stability in the dry season. Figures 6.7 and 6.8 depicts weekly mean nitrite levels with respect to treatment. The uniform pattern or trend of concentration reduction from the main source and treatment units as shown in Figure 6.7 may result from the equal volumes of dilution from rainwater coupled with uniformity of dilution of nitrite in the wet season.

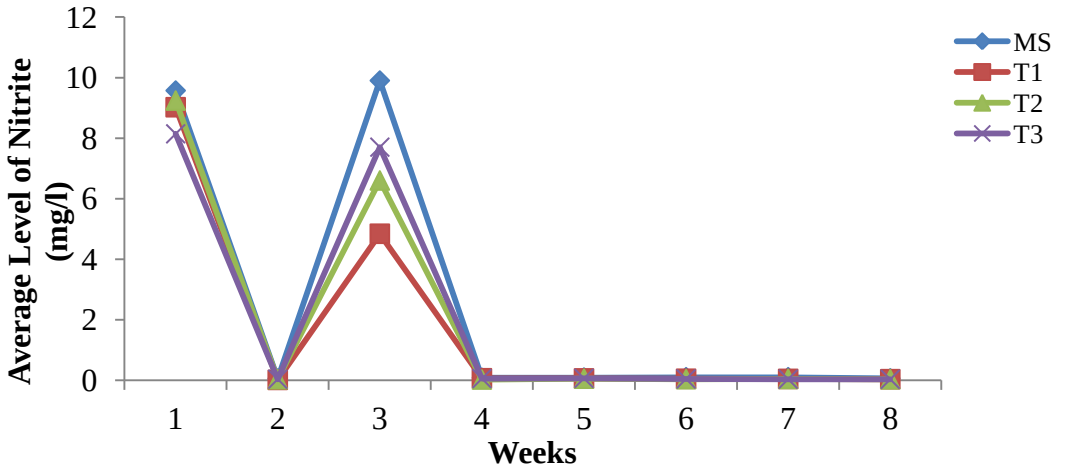


Figure 6.7: Weekly Nitrite Levels and Treatment Effect in the Wet Season

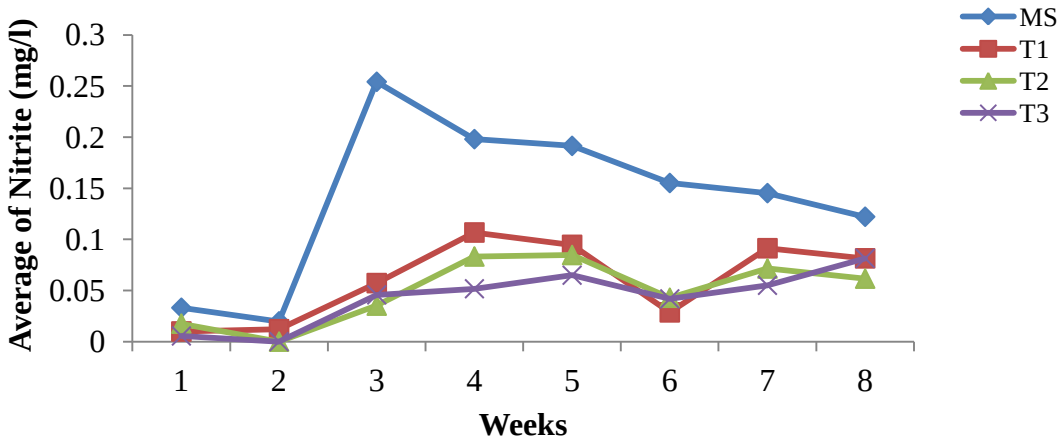


Figure 6.8: Weekly Nitrite Levels and Treatment Effect in the Dry Season

No significant difference was observed in the concentration levels of NO_2^- when ANOVA at 5% was performed. With f-probability of 0.001 in the dry season, the level of reduction in the concentration of NO_2^- was observed to be statistically significant. The difference was largely between the control (MS) and the treatments. The mean variation of nitrite of the treatment and control for both the dry and wet seasons is as presented in Figure 6.9.

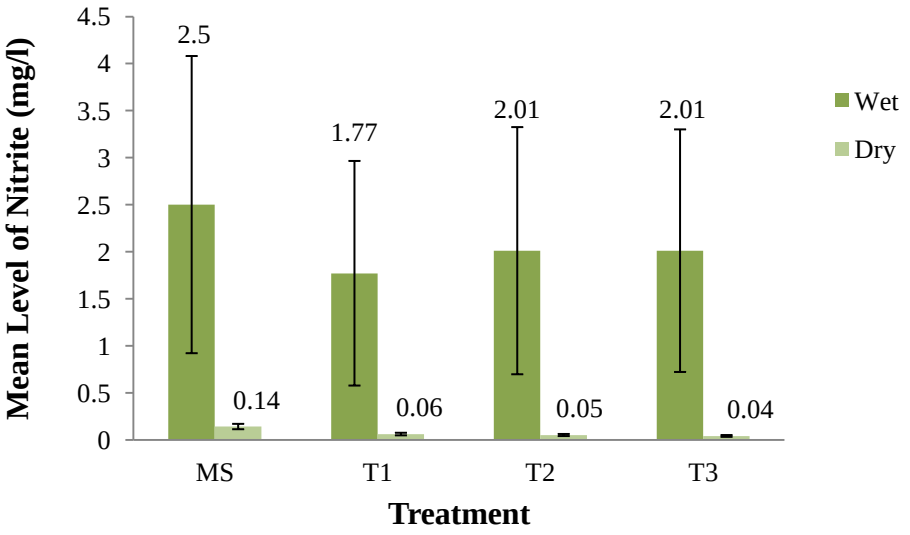


Figure 6.9: Variation in Nitrite Levels

Deborah (1996) indicated that nitrite concentrations in freshwaters are usually very low, 0.001 mg/l NO_2^-N and rarely higher than 1 mg/l NO_2^-N. High nitrite concentrations are generally indicative of industrial effluents and are often associated with unsatisfactory microbiological quality of water.

According to Tuikolongahau (2008) in nature nitrates are readily converted to nitrites and vice versa. Nitrite is a conjugate base of a weak acid HNO_2 with p*K*a = 3.4. It is highly soluble in water and mobile in the environment (WHO, 2007). Under normal conditions, both nitrites (except the ammonium salt) and nitrates are stable compounds. Generally, the presence of chlorides, some metals and organic material destabilize both nitrates and nitrites. Nitrites oxidize slowly to nitrates when exposed to air (Williams, 2001). Unlike ammonia, nitrites do not evaporate and remain in water until they are taken up by plants or consumed by micro-organisms (Hill, 1996; Bockman *et al*., 1999). Chemical and biological processes can further reduce nitrite to various compounds or oxidize it to nitrate (ICAIR Life Systems Inc., 1987).

6.3.4 Phosphorus (P) Concentration and Variation

During the study, average concentration of phosphorus was 1.80 mg/l and 2.02 mg/l for dry and wet seasons respectively in the raw wastewater. The different treatments applied to the raw wastewater did not record any significant level of reduction for both seasons. Phosphorus according to Meinzeinger and Oldenburg (2008) is present in greywater in high concentrations due to detergents used in kitchens, especially in developing countries where phosphates in detergents have not yet been replaced with other ingredients. However, there were some weekly variations in concentration levels regarding the treatments. In the wet season, week 1 (MS = 4.60 mg/l, T_1 = 3.60 mg/l, T_2 = 4.60 mg/l and T_3 = 4.60 mg/l) recorded the highest level of concentration with a decreased concentration in week 3 (MS = 1.20 mg/l, T_1 = 0.20 mg/l, T_2 = 0.86 mg/l and T_3 = 1.29 mg/l) and a slight increase in concentration in the treatments in week 4 (MS = 0.81 mg/l, T_1 = 1.30 mg/l, T_2 = 1.06 mg/l and T_3 = 1.61 mg/l) for all the treatments. Weeks 5, 6 and 7, however, experienced irregular concentrations in the levels of phosphorous. Week 8 (MS = 2.3 mg/l, T_1 = 1.10 mg/l, T_2 = 0.72 mg/l and T_3 = 0.61 mg/l) observed a uniform decrease in levels for all the treatment and a rise for the control (MS). These observations are as presented in Figure 6.10. It is estimated that 1000 m^3 of municipal wastewater used to irrigate one hectare can contribute 16–62 kg total nitrogen, 4–24 kg phosphorus, 2–69 kg potassium, 18–208 kg calcium, 9–110 kg magnesium and 27–182 kg sodium (Qadir *et al.*, 2007).

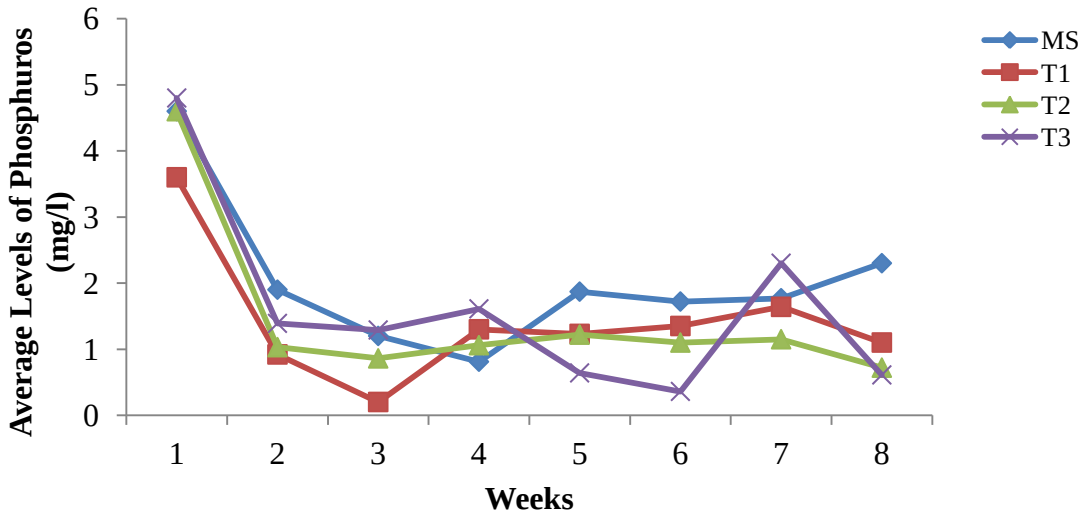


Figure 6.10: Weekly Trend of Phosphorus in the Wet Season

Phosphorous concentration in the dry season was observed to be opposite to that of the wet season. Figure 6.11 clearly indicates that phosphorus recorded the lowest levels for Week 1, 2 and 3 followed by an increase in concentration from Weeks 3 and 4 for all the treatments and the control. Non-uniform concentration levels were observed for Weeks 5, 6 and 7. Week 8 recorded a decrease in levels for T_1 = 1.87 mg/l and T_3 = 2.08 mg/l and a higher concentration for the MS = 3.43 mg/l and T_2 = 2.73 mg/l. The major factor which alters the behaviour of phosphorus in wastewater treatment system is attributed to the activities of micro-organisms. According to Sotirakou *et al*. (1999), there are certain micro-organisms capable of storing phosphorus (in the form of polyphosphates), metabolize it for energy reduction and cell synthesis, resulting in the removal of phosphorus from wastewater treatment system through activated sludge. Thus, the overall behaviour and variation of phosphorus levels may be attributed to the different rate of microbial activities of the seasons in both the filtering units and the stabilization pond.

Phosphorus is often the limiting factor for the utilisation of other nutrients by plants. Its presence in surface waters is dangerous, as even in small doses may lead to an over-supply of

nutrients (Sasse, 1998). Nitrogen that is normally available needs 10 % of phosphorus to be of use to plants. That means phosphorus activates ten times as much nitrogen and by that effect may be considered the most polluting element to any receiving water. For the same reason, wastewater rich in phosphate is a good fertilizer when used for crop irrigation in agriculture. Sasse (1998) indicated that salts like nitrate and phosphate being soluble in water cannot be eliminated by physical filtration when passing through soil or sand layers.

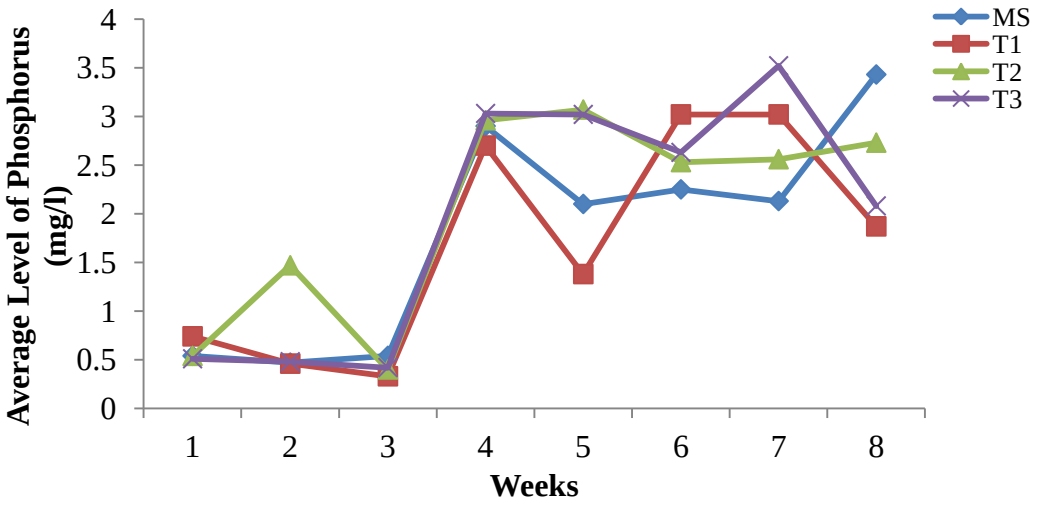


Figure 6.11: Weekly Trend of Phosphorus in the Dry Season

At 5% level of significance, phosphorus levels were noted not to be statistically significant even though reductions in concentration levels were observed.

In the dry season, phosphorus concentration was observed to have recorded variation in concentration levels but this was not statistically significant. Depending on the concentration of phosphorus in wastewater, its requirements in the soil for good plant growth may be reduced or eliminated. Mean seasonal concentration and variation in treatment with respect to the main source of wastewater did not actually indicate a wide range of variation. This presents the system as efficient in maintaining the level of phosphorus contained in the

wastewater as most of the soils in the area are deficient in phosphorus. Figure 6.12 presents the concentration of phosphorus for the seasons with the treatments.

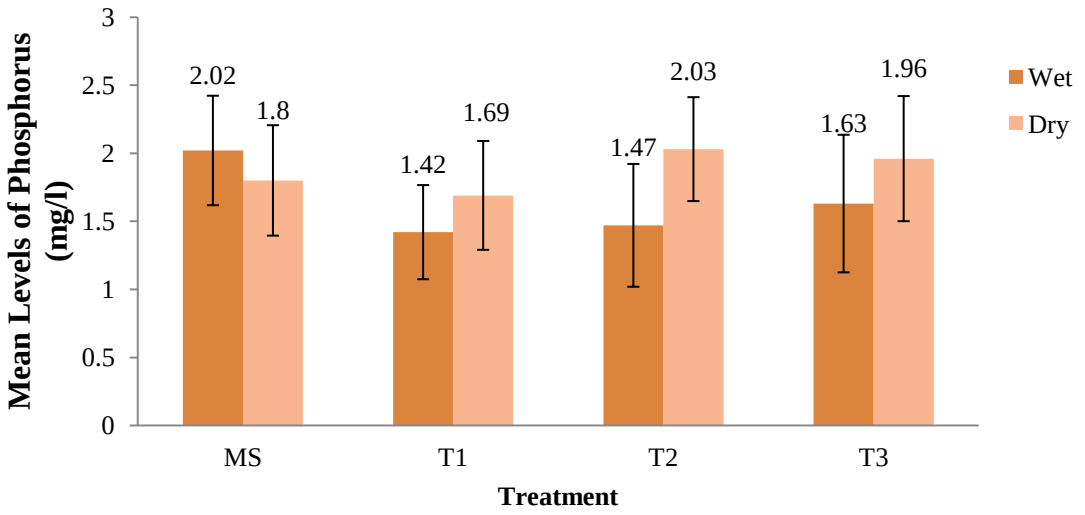


Figure 6.12: Variation in Phosphorus Levels

In filter systems, phosphorus is said to be removed through chemical precipitation and adsorption (Bayley *et al.*, 2003). According to Sotirakou *et al*. (1999), phosphorus (P) occurs in natural waters and in wastewaters almost solely as phosphates. These phosphates include organic phosphate, polyphosphate (particulate P) and orthophosphate (inorganic P). Sasse (1998) indicated that, bacteria cannot transform phosphorus into a form in which it loses its fertiliser quality permanently. Critical levels of phosphorus in water above which eutrophication is likely to be triggered, are approximately 0.03 mg/l of dissolved phosphorus and 0.1 mg/l of total phosphorus. The discharge of raw or treated wastewater, agricultural drainage, or certain industrial wastes that contain phosphates to a surface water body may result in a highly eutrophic state, in which the growth of photosynthetic aquatic micro and macro organisms is stimulated to nuisance levels. Phosphates are typically present in raw wastewaters at concentrations near 10 mg/l as P.

Phosphorus is a good fertilizer, and therefore dangerous in rivers and lakes. Removing phosphorus in DEWATS is limited, like in most treatment plants. However, constructed wetlands could be helpful when filter media contains iron or aluminium compounds. It should be noted that phosphorus can be accumulated by sedimentation or fixed in bacteria mass, but can hardly be removed or transformed into harmless substances (Sasse, 1998).

6.3.5 Potassium (K) Concentration and Variation

In the dry season potassium (K) recorded a high mean of 70.78 mg/l with the wet season recording 51.37 mg/l. According Qadir *et al.* (2007) it is estimated that 1000 m^3 of municipal wastewater used to irrigate one hectare can contribute 16–62 kg total nitrogen, 4–24 kg phosphorus, 2–69 kg potassium, 18–208 kg calcium, 9–110 kg magnesium, and 27–182 kg sodium.

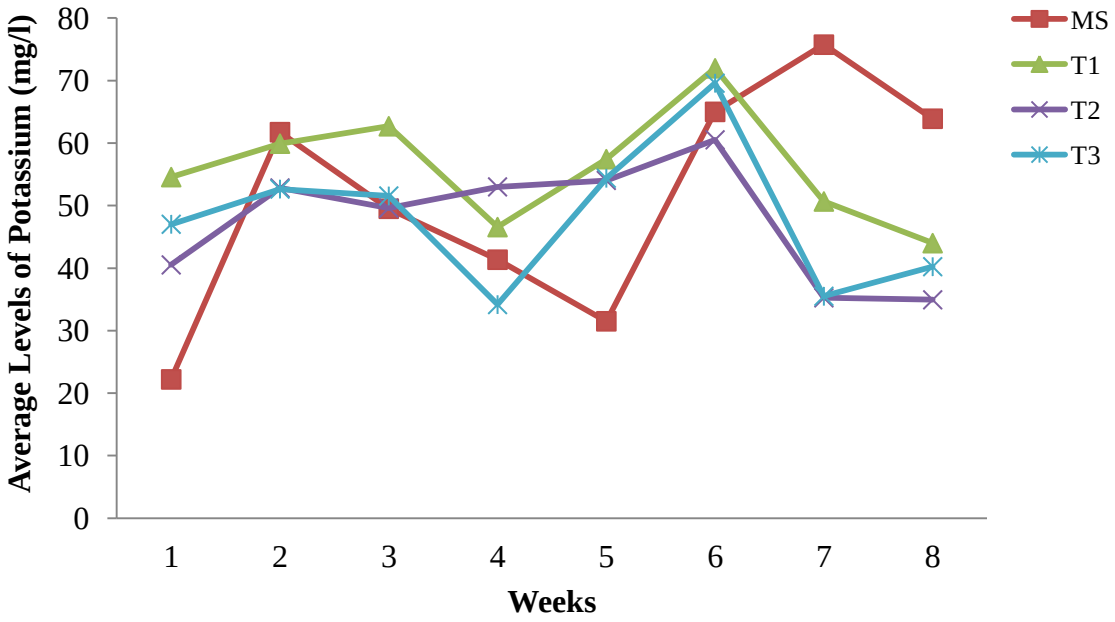


Figure 6.13: Weekly Variation of Potassium in the Wet Season

The nature and behaviour of potassium in the wet season was unstable (Figure 6.13). There was a general increase from Week 1 to Week 2 and a sharp decrease from Week 2 to Week 5 for all the treatments and control. There was a change of behaviour with another sharp increase from Week 5 to Week 6 and a decrease in Week 7 and Week 8.

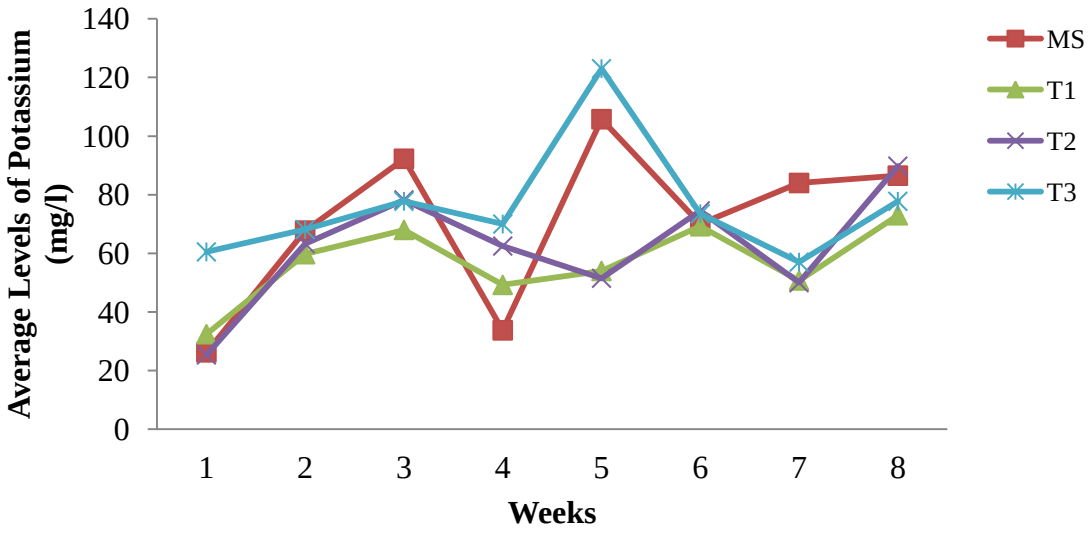


Figure 6.14: Weekly Variation of Potassium for Dry Season

The behaviour of potassium in the dry season was not too different from that of the wet season (Figure 6.14). Potassium levels increased for all the treatments from week 1 to week 3 and a decrease at week 4. Treatment 3 at week 4 recorded the highest level of 123 mg/l during the study. Main source (control) also increased for the same Week to 70 mg/l, which was the highest for the season. At week 6, there was a decrease with virtually equal levels for all the treatment which continuously decreased at Week 7 except for MS. Week 8 ended with an appreciable increase in concentration levels for all the parameters. Generally, the behaviour of potassium can be associated with its non-water solubility, and the ability to rapidly and intensely react with water.

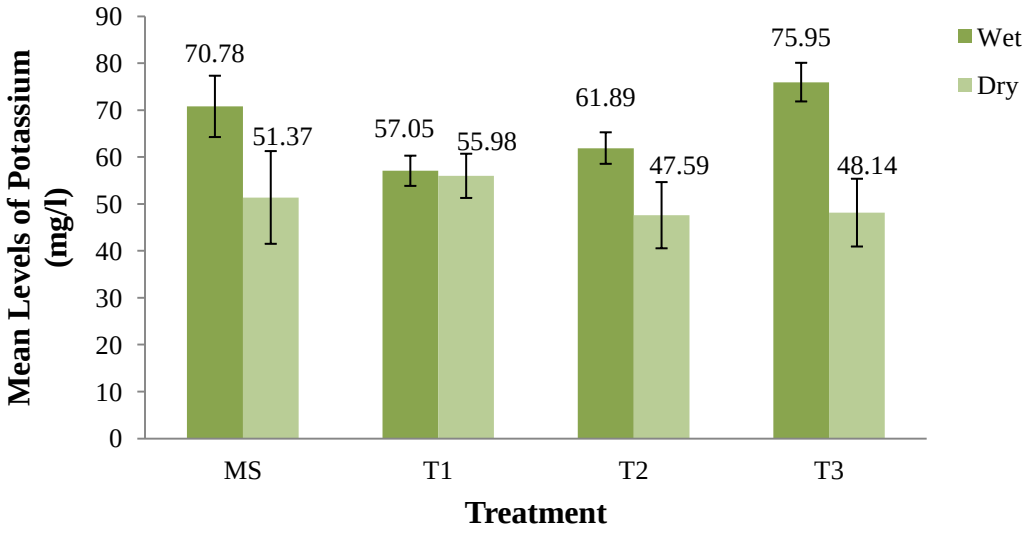


Figure 6.15: Mean Concentration of Potassium

Mean concentration levels of potassium in the wet season were generally higher than those of the dry season (Figure 6.15). This observation was mainly significant for the main source (MS) as well as treatments two and three (T_2 and T_3).

According to Arienzo *et al.* (2008) potassium compounds may end up in wastewater through urine and the potential for accumulation of potassium in soil from wastewater disposal (irrigation) is high since the element has a low leachability. Arienzo *et al.* (2008) also added that potassium is weakly hazardous in water, but it does spread pretty rapidly, because of its relatively high mobility and low transformation potential. Concentration in effluents and sewage from domestic sources are in the order of 10–30 mg/l. Irrigation with wastewaters may result in potassium availability that can correspond to or be in excess to plant requirements.

Together with nitrogen and phosphorous, potassium is one of the essential macro minerals for plant survival. Its presence is of great importance for soil health, plant growth and animal nutrition. Potassium is ubiquitous in wastewaters and in some wastewaters is present at

several hundred to several thousand mg/l. Its biochemical functions improve the tolerance of the plant to various stress situations such as drought, low temperature or salinity (Arienzo *et al.,* 2008). Potassium is non-water soluble, but it does react rapidly and intensely with water, forming a colourless basic potassium hydroxide solution and hydrogen gas, according to the following reaction mechanism (Lenntech, 2013): $2K(s) + 2H2O (l) \longrightarrow 2KOH (aq) + H2 (g)$

6.3.6 Treatment Efficiency on Reduction of Chemical Contaminants

Phosphorus deficiency is widespread and is a major constraint to crop production in the semi-arid savanna zone of northern Ghana (Halm, 1968; Owusu-Bennoah and Acquaye, 1989). According to Owusu-Bennoah *et al.,* (1995) in some soils, the deficiency is so acute that plant growth ceases as soon as the P stored in the seed is exhausted.

Except for phosphorus and potassium, treatment three (T_3) was most efficient in the reduction of the other chemical parameters. NH_3, NO^-_3 and NO^-_2 recorded reduction percentages of 48.80 %, 41.90 % and 71.40 % respectively. Table 6.2 presents the percentage reduction of the various chemical parameters.

Nitrogen and phosphorus deficiencies in the savanna soils of northern Ghana have been widely reported (FAO, 1967; Acquaye, 1973; Tiessen, 1988). Some of the causes of this situation include the fact that most soils in Ghana are developed on well weathered parent materials that have been leached over a long period of time (Halm and Asiamah, 1992). The reduction level of phosphorus by the three (3) treatments was observed to be below 30% which is generally good for the study area as the soils are lacking in phosphorus. Treatment three (T_3) recorded the least reduction of 19.80% whilst treatment one (T_1) recorded the highest of 29.70%.

For potassium, treatment three (T_3) rather increased the concentration instead of reducing it whilst the other two treatments (T_1 and T_2) recorded 7.47 % and 10.38 % reduction in concentration respectively.

Table 6.2: Reduction Levels of Chemical Contaminants by Filters

Parameters										
Treatment	NH_3		NO_3^-		NO_2^-		Phosphorus		Potassium	
	mg/l	% Reduction	mg/l	% Reduction	mg/l	% Reduction	mg/l	% Reduction	mg/l	% Reduction
MS	20.5	100	0.43	100	0.14	100	2.02	100	61.08	100
T_1	16.1	21.50	0.30	30.20	0.06	57.10	1.42	29.70	56.52	7.47
T_2	11.4	44.40	0.24	44.20	0.05	64.30	1.47	27.20	54.74	10.38
T_3	10.5	48.80	0.25	41.90	0.04	71.40	1.62	19.80	62.04	-1.57

6.3.7 Allowable Limits of Chemical Contaminants

From Table 6.3 the level of ammonia contained in the wastewater was above the range of EPA (Ghana) guideline whilst nitrate on the other hand was far below the acceptable limit. The acceptable limit for nitrite, though not yet defined by EPA Ghana recorded a wide range of reduction from the wet season to the dry season. Phosphorus levels were also below the EPA (Ghana) standard.

Table 6.3: Grand Means and EPA Ghana Standard Guidelines/Limits

Chemical Parameters	Grand Mean Levels		EPA Ghana Standard Limits (mg/l)
	Wet Season (mg/l)	Dry Season (mg/l)	
Ammonia	14.60	27.00	1.00
Nitrate	3.80	0.29	50.00
Nitrite	2.07	0.07	_
Phosphorus	1.63	1.87	2.00
Potassium	51.37	70.78	-

6.4 Conclusions

Based on the Environmental Protection Agency of Ghana (2003) guidelines, the level of NH_3 in the wastewater is too high for irrigation purposes. The level of NO_3^- is lower and therefore safe for agricultural purposes. The wider difference between seasonal NO_2^- levels is a signal of potential health risk at the study site. Phosphorus (P) levels though below standard, stand the chance of exceeding the limits since levels are closer to the EPA standards thus posing future risk. The study revealed that, with the exception of NO_3^-, all other parameters had relatively higher levels in the wet season as compared to that of the dry season. The study realised that the treatment effect on NO_4^-, NO_3^- and NO_2^- by the on-farm sand filter system combined with stabilization ponds varied seasonally. The design also had significant impact on level of reduction and behaviour of the chemical parameters of wastewater in the study area. Treatment two (T_2) and three (T_3) of the system have similar capability with respect to reduction of the level of chemical parameters, however treatment three (T_3) emerged the best in reduction of the chemical parameters.

CHAPTER SEVEN

MICRO NUTRIENT CONCENTRATION IN WASTEWATER USED FOR PERI-URBAN IRRIGATION

7.1 Introduction

Beside pathogens, wastewater and sludge can also be a source of high levels of heavy metals and organic toxic compounds (Abaidoo *et al.,* 2009). Qadir and Scott (2010) reported that when the concentrations of constituents such as heavy metals or organic contaminants are known in the plant tissue, or in food in general, which is eventually consumed by a particular consumer group, it is possible to calculate human exposure (intake). Excessive concentrations of some trace elements may also cause plant toxicity and sometimes become a health risk for crop farmers (Jiménez *et al*., 2010b). According to Qadir and Scott (2010), wastewater irrigation also adds a range of micronutrients such as iron (Fe), zinc (Zn), manganese (Mn) and copper (Cu) to the soil.

Hamilton *et al.* (2007) described increasing total heavy metal concentrations in soils irrigated with sewage for up to a century. The authors found that potentially bio-available forms of the metals have increased and plant tissue showed relatively low concentrations as the metals were strongly absorbed in the soil.

Some of these heavy metals are picked up by the roots of plants growing in soils and are stored in different parts of the plants in different concentrations based on the type of plant (Chang *et al.,* 1997; Kulli *et al.,* 1999). Some metals and metalloids are essentially required for adequate plant growth, but are toxic at elevated concentrations e.g. Copper (Cu), Zinc (Zn), Iron (Fe), Aluminium (Al) and Manganese (Mn) (Qadir and Scott, 2010).

7.2 Water Sampling and Analytical Techniques

Filtered wastewater sampling was done at weekly (7 days) intervals for a period of sixteen (16) weeks that is eight (8) weeks for the rainy season (August and September) and eight (8) weeks for the dry season (January and February) in each sampling year. Data collection was done in the years 2011 and 2012. A total number of ten (10) filtered wastewater samples were collected at each sampling time resulting in 160 wastewater samples per year and 320 samples for the whole study.

Trace metals were determined using standard methods and the values read with a DR 2800 Spectrophotometer. Zinc was determined using the Zincon method with digestion by ZincoVer 5 reagent powder pillow. Aluminon method used ascorbic acid powder pillow and AluVer 3 Aluminium reagent powder pillow. In the determination of Manganese, the Pan method was used with Ascorbic acid and Alkaline Cyanide as reagents. Copper and Iron were determined using CuVer 1 Copper reagent and FerruVer Iron reagent respectively.

7.3 Trace Metals Concentration in Wastewater

Liu *et al.* (2005) studied the impact of sewage irrigation on trace metal contamination in Beijing and reported that the trace metals were enriched in the soil due to sewage irrigation. The results of the mean concentration of aluminium, copper, iron, manganese and zinc in the current study for the wet and dry seasons are presented in Table 7.1.

Table 7.1: ANOVA of Trace Metals in the Wastewater

Trace Metal	Mean Wet Season Levels (mg/l)	Mean Dry Season Levels (mg/l)	L.s.d	Fp>0.05	EPA Ghana Limits (mg/l)	Recommended maximum concentrations (mg/l) (WHO, 2006a)
Al	0.146	0.070	0.064	0.024	5.0	5.0
Cu	0.010	0.158	0.137	0.037	2.5	0.2
Fe	0.800	0.660	0.546	0.588	-	5.0
Mn	0.233	0.101	0.101	0.014	2.5	0.2
Zn	0.066	0.015	0.044	0.026	5.0	5.0

7.3.1 Concentration of Aluminium (Al)

Aluminium was observed to have a mean concentration level of 0.146 mg/l in the wet season during the study whilst the level recorded in the dry season was 0.070 mg/l. This indicated that wet season recorded relatively higher concentration of aluminium in the wastewater than the dry season. An analysis of variance (ANOVA) at 5 % gave an F-probability value of 0.024. This indicated that a significant difference existed between the concentrations of aluminium in both seasons. According to Jiménez *et al.* (2010b) excessive concentrations of some trace elements may cause plant toxicity and sometimes become a health risk for crop consumers. Ayers and Westcot (1985) and Pescod (1992) reported that higher levels of Al can cause non-productivity in acid soils (pH < 5.5), but more alkaline soils at pH > 7.0 will precipitate the ion and eliminate any toxicity.

DWARF (1996) reported that when soluble aluminium complexes are present, the dissolved aluminium concentration may be significantly high compared to the situation where insoluble aluminium compounds are present in the wastewater.

According to Delhaize and Ryan (1995), the most easily recognized symptom of Al toxicity is the inhibition of root growth, and this has become a widely accepted measure of A1 stress in plants. Higher concentration of aluminium in the soil reduces plant vigour and yield as reported by Delhaize and Ryan (1995).

The wastewater samples from Zagyuri in both seasons had low aluminium concentrations and below the limit of 5 mg/l required for irrigation of vegetables. This implies that, the use of wastewater for irrigation in the study area has insignificant effect on Al concentration in the soil, since the mean values recorded were below the recommended maximum concentration levels.

7.3.2 Concentration of Copper (Cu)

The study results indicated mean Cu concentrations of 0.010 mg/l in the wet season and 0.158 mg/l in the dry season. This implies that the dry season recorded relatively higher concentration of Cu than the wet season. ANOVA on the concentration of Cu at 5 % level of significance for wet season and dry season gave an Fpr value of 0.037 (Table 7.1). This indicates a significant difference in the concentration of Cu between the seasons. The higher concentration may be as a result of corrosion of copper pipes used in plumbing works in the barracks.

According to Silva and Uchida (2000) low levels of Cu reduced growth, distortion of younger leaves, and possible necrosis of the apical meristem. In forage grass, young leaf tips and growing points are affected. First, the plant becomes stunted and chlorotic. Solberg *et al*. (1999) reported that Cu deficient plants are prone to increased disease, specifically ergot (a fungus causing reduced yield, and grain quantity). Cu at high concentration in plants causes a stress factor triggering physiological responses (Yruela, 2005).

As shown in Table 7.1 the mean values recorded for both seasons were below the recommended maximum concentrations of 0.20 mg/l (WHO, 2006a). EPA Ghana have also set a limit of 2.5 mg/l for wastewater to be discharged into water bodies and water courses. This indicates that Cu concentration in wastewater at Zagyuri have insignificant risks to the soils, vegetable crops and aquatic life in water courses.

7.3.3 Concentration of Iron (Fe)

The mean concentration of Fe was 0.80 mg/l and 0.66 mg/l for the wet and dry seasons respectively (Table 7.1). The mean concentration of iron in the wet season was relatively higher in the wastewater samples compared to the dry season. A statistical analysis performed at 5% level of significance gave Fpr value of 0.588. This indicated that there is no significant difference in Fe concentrations in both seasons. The lower concentration of iron in the dry season may be due to the fact that the pH of the wastewater was high as an average pH of 7.52 and 7.33 were recorded for the dry and wet seasons respectively.

Fe is essential in the synthesis and maintenance of chlorophyll in plants and has been strongly associated with protein metabolism. At low concentrations, younger leaves develop interveinal chlorosis (Silva and Uchida, 2000). According to Cook *et al.* (1990), excessive oral uptake of Fe has been shown to induce gastrointestinal distress including vomiting, diarrhoea and abdominal pain. Wastewater samples in both seasons recorded lower Fe concentrations which was below the limit of 5 mg/l (WHO, 2006a) required for irrigation of vegetable crops.

7.3.4 Concentration of Manganese (Mn)

The mean value of Mn was 0.233 mg/l in the wet season whilst the level in the dry season was 0.101 mg/l (Table 7.1). This implies that the mean concentration in the wet season was relatively higher than the dry season. Analysis of variance (ANOVA) at 5 % level of significance yielded Fpr value of 0.01, which indicated a significant difference in the concentration of Mn between the seasons. Mn is known to function in plants as components of enzymes involved in photosynthesis and other processes. Mn deficiency has very serious effects on non-structural carbohydrates and root carbohydrates especially. Crops quality and quantity decrease due to Mn deficiency and this is due to the low fertility of pollen and low carbohydrates during grain filling (Mousavi *et al*., 2011).

The Mn in the wastewater samples collected in the wet season was observed to be greater in the wet season whilst the dry season was below the recommended maximum concentrations of 0.20 mg/l required for irrigation of vegetables. This implies that the wastewater for vegetable crop irrigation is safe in terms of the Mn concentration. Also the limit of 2.5 mg/l for release of wastewater into the environment as set by EPA Ghana shows that Mn concentration on the wastewater was very low. However, the effect of bioaccumulation in future has to be considered seriously.

7.3.5 Concentration of Zinc (Zn)

Mean zinc value of 0.066 mg/l in the wet season and 0.015 mg/l in the dry season was observed in the wastewater (Table 7.1). This implies that the mean concentration in the wet season was relatively higher than the dry season. ANOVA on the concentration of Zn at 5% level of significance for wet and the dry seasons gave an Fpr value of 0.026. This indicates that the concentration of Zn in both seasons was significant.

According to Alloway (2008) Zn as a micronutrient is an essential element to maintain metabolic functions of living organisms. In plants, Zn plays a key role as a structural constituent or regulatory co-factor of a wide range of different enzymes and proteins in many important biochemical pathways and these are mainly concerned with:

1. Carbohydrate metabolism, both in photosynthesis and in the conversion of sugars to starch,
2. Protein metabolism,
3. Auxin (growth regulator) metabolism,
4. Pollen formation,
5. Maintenance of the integrity of biological membranes and
6. The resistance to infection by certain pathogens.

When the supply of plant-available Zn is inadequate, crop yields are reduced and the quality of crop products is frequently impaired. Zn deficient in leaves display interveinal chlorosis, especially midway between the margin and midrib, producing a striping effect; some mottling may also occur (McCauley *et al.,* 2003). At high levels in the soil, Zn concentration causes phytotoxicity problems to the plants (Pérez-Novo *et al.,* 2011).

As shown in Table 7.1, the concentration of Zn in the wastewater samples was below the limit of 5.00 mg/l set by EPA Ghana and WHO (2006) in both seasons.

7.4 Conclusions

Except the concentration of Cu in the wastewater which did not record any significant difference in levels between the wet and dry seasons, Al, Cu, Mn and Zn were significantly different in concentration between the seasons.

Also, except the mean concentration of Mn (0.233 mg/l) in the wet season, the other micro nutrients where below the recommended maximum concentrations as set by WHO (2006a) and the limits of EPA Ghana for release of wastewater into water courses in the environment. Bioaccumulation of these micro nutrients is however possible and can create an imbalance in the nutrient levels of the soils.

CHAPTER EIGHT

SEASONAL VARIATION OF ORGANIC POLLUTANT LOADS IN WASTEWATER

8.1 Introduction

Of all parameters, Chemical Oxygen Demand (COD) is the most general parameter to measure organic pollution and it describes how much oxygen is required to oxidise all organic and inorganic matter found in water (Sasse, 1998). The author indicated that Biochemical Oxygen demand (BOD) is always a fraction of the COD and it describes what can be oxidised biologically with the help of bacteria.

Kulabako *et al.* (2011), and Sall and Takahashi (2006) mentioned that grey water can be categorised as high strength wastewater because of its high COD concentration (> 2 g/l). Wastewater for treatment in aerobic ponds should have a BOD_5 content below 300 mg/l and a limit of 50 mg/l must be taken before being discharged into the environment (Sasse, 1998). Tchobanoglous and Burton (1995) indicated that the most widely used parameter of organic pollution applied to both wastewater and surface water is the 5-day BOD (BOD_5).

8.2 Biochemical Oxygen Demand and Chemical Oxygen Demand

BOD_5 averaged 92.97 mg/l for the dry season and ranged from 55 to 159.1 mg/l during the sampling period of the experiment. The treatment effects were widely effective in the reduction of BOD_5 indicating that the activity of micro-organisms in the degradation of the organic component of the wastewater reduced greatly with increase in length of the filter column. This means that as the length of the container increased, micro-organisms which demand higher level of oxygen for oxidation of organic matter contained in the wastewater are filtered out. The concentration of the micro-organisms therefore corresponded well with

the length of the filter. The weekly variation of the concentration of BOD_5 with respect to the main source for the wastewater supply is presented in Figure 8.1.

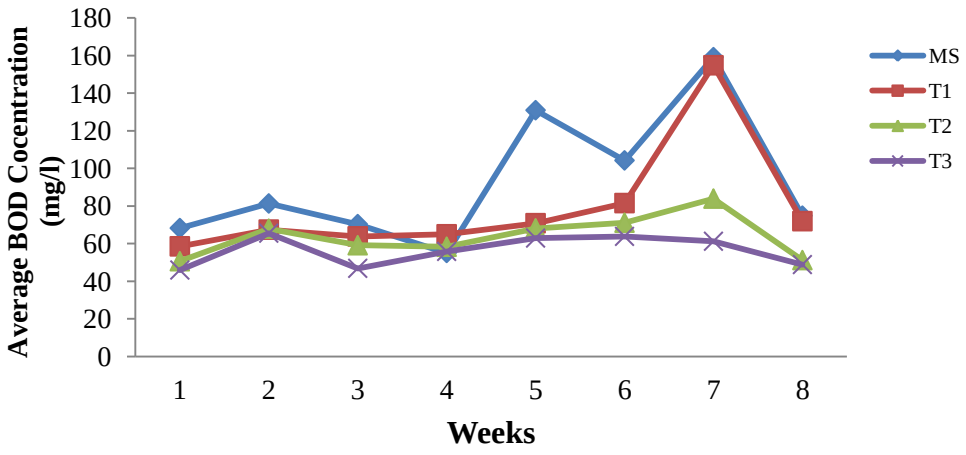


Figure 8.1 : Variation of BOD_5 in the Dry Season

In the wet season, however, the concentration of the BOD_5 averaged 103.54 mg/l and ranged from 47.1 to 191.7 mg/l. The results indicate that the wet season was favourable for the activity of the micro-organisms responsible for the degradation of organic matter. It is therefore evident that the effect of environmental factors on the micro-organisms activity influenced the concentration of BOD in the wastewater. BOD_5 concentration in the main source, however, varied widely in the wet season and sometimes falling below the concentrations of the treatments (Figure 8.2). The effect of the length of the filter column was therefore realised to also affect the levels of the BOD during the 8 week period. The environmental conditions together with filter length favoured the growth and activity of micro-organisms in the oxidation of organic matter.

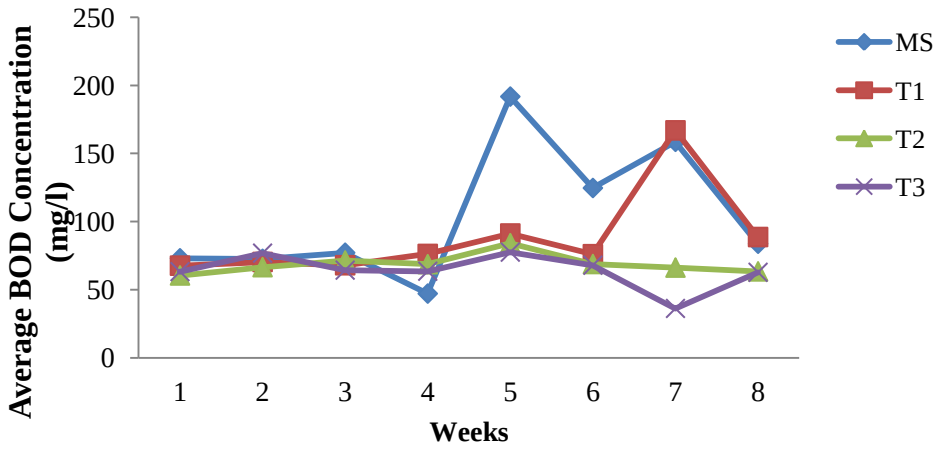


Figure 8.2: Variation of BOD_5 in the Wet Season

According to Sasse (1998), effluent standards for discharge into receiving water may tolerate 30 to 70 mg/l BOD. The results, however, indicated that for both seasons the average concentration of BOD released into the stream at Zagyuri was 92.97 mg/l and 103.54 mg/l for the dry and wet seasons respectively. With reference to Sasse (1998) report on the limit of BOD to be discharged into the environment, the average values of BOD recorded for both seasons were relatively higher. These higher values, however, indicate that the micro-organisms are active in the degradation process of the organic matter. Low BOD was noted to indicate low level of the activity of biodegradable bacteria contained in the wastewater.

Tchobanoglous and Burton (1995) indicated that the most widely used parameter of organic pollution applied to both wastewater and surface water is the 5-day BOD (BOD_5). This determination involves the measurement of the dissolved oxygen used by micro-organisms in the biochemical oxidation of organic matter.

Chemical Oxygen Demand (COD) of the wastewater ranged from 105.15 to 205.90 mg/l for the dry season with an average COD of 132.78 mg/l (Figure 8.3).

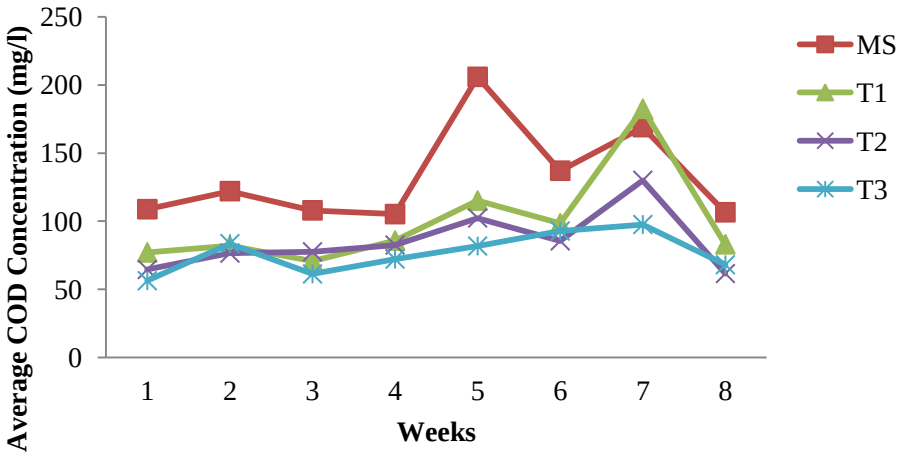


Figure 8.3: Variation of COD in the Dry Season

Except in Week 7 when the COD concentration of T_1 was slightly higher than the main source. The COD of the various weeks of the main source was observed to be generally higher than the treatments. The length of filter unit was also observed to affect the level to which the COD was reduced.

In the wet season, however, the lowest level of COD was 102.5 mg/l and the highest was 203.00 mg/l with an average concentration of 143.75 mg/l. Even though the limits were below that of the dry season, the average concentration of COD for the wet season was observed to be higher than that of the dry season. The variation of COD in the wet season with time is as shown in Figure 8.4.

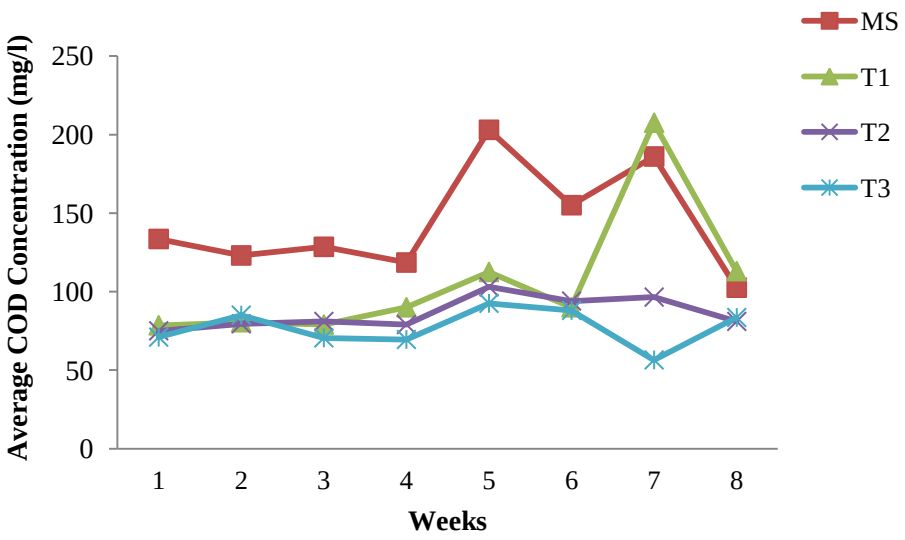


Figure 8.4: Variation of COD in the Wet Season

A similar trend of concentration of COD in the wet season like that of the dry season was observed. Generally, this trend indicated that T_3 was effective in reducing the level of COD contained in the wastewater. Sasse (1998) noted that COD for the final effluent standards for discharge into receiving waters may tolerate from 100 to 200 mg/l and with the average concentration of COD in the dry season being 132.78 mg/l and wet season of 143.75 mg/l, it implies that the COD level was within range and can be discharged safely. As the most general parameter to measure for organic pollution, COD describes how much oxygen is required to oxidise all organic and inorganic matter in water.

8.3 COD/BOD Relations

The COD/BOD ratio vaguely indicates the relation of total oxidisable matter to organic matter which is first degraded by the most common bacteria (Sasse, 1998). Easily degradable wastewater has a COD/BOD_5 relation of about 2. The COD/BOD ratio widens after biological, especially anaerobic treatment, because BOD is biologically degradable. A weak

wastewater from domestic sources for example, may have a COD below 500 mg/l while a strong industrial wastewater may contain up to 80, 000 mg/l BOD (Sasse, 1998).

The relation between COD and BOD_5 for the dry and wet seasons indicated that except for Week 4 of the wet season which recorded a COD/BOD_5 ratio of 2.52, the remaining weeks were below a ratio of 2 (Table 8.1).

Table 8.1: COD/BOD_5 Relation of Wastewater of the Treatment Units

	Dry Season				Wet Season			
Week	MS	T_1	T_2	T_3	MS	T_1	T_2	T_3
1	1.59	1.31	1.27	1.23	1.83	1.16	1.24	1.12
2	1.50	1.22	1.13	1.27	1.69	1.15	1.20	1.11
3	1.53	1.11	1.31	1.31	1.67	1.16	1.13	1.10
4	1.91	1.32	1.41	1.29	2.52	1.18	1.15	1.09
5	1.57	1.63	1.50	1.30	1.06	1.23	1.22	1.19
6	1.31	1.21	1.20	1.45	1.24	1.18	1.37	1.30
7	1.06	1.18	1.55	1.59	1.17	1.24	1.46	1.56
8	1.42	1.15	1.20	1.39	1.22	1.28	1.28	1.33

8.4 Conclusions

The results indicated that for both seasons, the average concentration of BOD released into the stream at Zagyuri was 92.97 mg/l and 103.54 mg/l for the dry and wet season respectively whilst the COD was averaged 132.78 mg/l and 102.5 mg/l for the dry and wet seasons respectively. These values were higher than the recommended levels reported by Sasse (1998). The indication of the concentration means that the wet season was favourable for the activity of the micro-organisms responsible for the degradation of the organic matter.

CHAPTER NINE

SUMMARY OF FINDINGS, CONCLUSIONS AND RECOMMENDATIONS

9.1 Introduction

This chapter presents a summary of the findings, conclusions and suggestions especially for future research.

9.2 Summary of Findings

9.2.1 Diversity of Identified Helminth Eggs, Contamination and Risk of Wastewater Use

The study found thirteen (13) different helminths for both the wet and dry seasons. The dry season recorded eight (8) different helminths whilst the wet season recorded nine (9). The typical fertile *Ascaris, Strongyloides stercoralis* and *Schistosoma mansoni* were the predominant types of helminths in both seasons and this is attributed to their environmental tolerance and resistance. *Ascaris lumbricoides* recorded a mean population of 12 and 17 for the wet and dry season respectively.

On the whole, the dry season recorded higher levels of concentration of helminth eggs compared to the wet season. Population densities of helminths ranged from 2 to 17 eggs with a coefficient of variation between 0 and 85 %.

Simpson Index (λ) was estimated to be 0.48 for the dry season and 0.42 for the wet season indicating that helminth egg diversity was highest in the wet season compared to the dry season. The favourable environmental conditions of low temperature, sunshine, humidity, etc are considered necessary for the development of the eggs of helminths.

Shannon-Wiener Index (H') was also observed to be high in the wet season with a value of 1.76 compared to a dry season value of 1.57. The Berger-Parker Dominance Index (D_{BP}) of 2.29 and 1.88 were recorded for the wet and dry seasons respectively. These statistics confirm well the high level of diversity of the eggs in the wet season compared to the low diversity for the dry season.

Margalef Richness Index (D_{Mg}) indicated that the wet season was helminth egg richer than the dry season with richness index values of 2.29 and 1.88 respectively.

Commonly observed dominant species of *Ascaris lumbricoides* and *Strongyloides stercoralis* for both seasons as well as a higher dominance index of 0.58 for the wet season was recorded compared to 0.52 for the dry season.

9.2.2 Efficiency of Treatment System in Biological Contaminant Removal

The multivariate analysis of the faecal coliform data indicates that an increase in the length of the treatment filter by a unit decreases the FC concentration level by 3.9 % in the dry season. An increase in the RH, T and pH by a unit results in the reduction of FC by 7.4 %, 1.7 % and 58.4 % respectively. However, in the dry season an inverse linear relationship between the variables Ra and P was realised. This is because an increase by a unit of Ra and P results in a corresponding increase in the FC levels by 18 % and 4.4 % respectively of the factors. The results indicate statistical significance at the 0.05 level for L, RH, Ra and pH.

A unit increase in L and Ra results in a corresponding reduction in FC concentration by 8.2 % and 5.6 % in the wet season. The other environmental factors influencing the survival of faecal coliform were RH, T, P and pH and a unit increase in these parameters will have a corresponding unit increase in the FC contained in the treated wastewater. 0.3 %, 32.9 %, 17 % and 22 % increase in FC concentration corresponded to a unit increase in RH, T, P and pH

respectively. Unlike the dry season, an increase in Ra during the wet season resulted in a unit decrease in FC concentration.

The model for the TC indicated that the parameters L, RH, T, P and pH have an inverse relationship with TC concentration in wastewater. A unit increase in L, RH, T, P and pH resulted in the reduction of TC concentration in the raw wastewater by 3.7 %, 2.1 %, 3.7 %, 29.7 % and 0.4 % respectively. Also, the Ra was realised to have direct impact or positive linear relationship on TC levels as a unit increase in Ra resulted in a 3.9 % increase in TC. Except P which was not statistically significant, L, RH and Ra were significant at 0.05 level whilst T and pH were significant at 0.10 level.

TC concentration reduction in the wet season was characterized by a unit increase in L, Ra, and P. A unit increase in L, Ra and P resulted in respective 5.8 %, 4.8 % and 0.6 % reduction levels of total coliform. An increase in RH, T and pH provided favourable environmental conditions for the survival and multiplication of the TC. In the dry season L, RH, T, Ra and pH were inversely related to the concentration of H levels in the multivariate analysis. This indicates that, a unit increase in L, RH, T, Ra and pH results in the reduction of H concentration levels by 6.1 %, 11 %, 8 %, 10 % and 13.3 % respectively whilst a unit increase in P results in 8 % increase in helminth egg concentration. However, except L which was found to be significant at 0.05 level, the other parameters were not statistically significant.

In the wet season, however, aside the length of the container which indicated that the more filter material contained in it, the higher the filtering efficiency, the rest of the factors did not positively reduce the concentration of the helminth eggs in the wastewater during treatment.

A unit increase in the length of container was observed to reduce the concentration of helminth eggs by 5.4 %. RH, T, Ra, P and pH were observed to rather provide conducive environment for the growth and multiplication of helminth eggs during the wet season.

The mean concentration levels of faecal coliform varied and were 24,444 CFU for the wet season and 13,780 CFU for the dry season. With the three (3) treatments applied which had variation in length of filter material being the main factor, T_3 with a length of 25.5 cm achieved higher removal efficiency of faecal coliform by 80.9 % and the least being T_1 with length of 8.5 cm and an efficiency of 68.0 %.

In the dry season, however, T_2 with filter length of 17 cm recorded a removal efficiency of 67.2 % compared to the least of T_3 with removal percentage of 61.7 %.

The mean concentration of total coliform in the wastewater for the period under consideration was noted to vary with the wet season (56,930 CFU) recording an average higher than the dry season (41,113 CFU). The treatment effect was, however, observed to be high in T_3 (25.5 cm) with percentage removal of 73.8 % and 59.6 % for the wet and the dry seasons respectively. T_1 with a container length of 8.5 cm was observed to have the least effect on the removal of total coliform contained in the wastewater with percentage removal rates of 62.2 % for the wet season and 50.3 % for the dry season. From these results, it is clear that container length which translates into the amount of filter material contained in the filter unit has a positive linear effect on the removal rate of total coliform bacteria contained in wastewater.

The concentration of helminth eggs per litre was observed to be lower in the wet season (56 eggs/litre) compared to the dry season (74 eggs/litre). The results of the treatment effect on the removal of helminth eggs indicated that, the longer the filter material the more efficient

the system. T_3 with total length of 25.5 cm recorded the highest level of helminth egg removal of 73.9% and 74.1% for the wet and dry seasons respectively. T_1 with a filter length of 8.5 cm, however, recorded the lowest level of removal of helminths being 70.2% and 57.6% for the wet and dry seasons respectively.

9.2.3 Chemical Contaminants in Wastewater

The average levels of ammonia in the dry season were relatively high. ANOVA on data of both seasons indicated that reduction in NH_3 levels was statistically significant for only ammonia in the wet season with f-probability of 0.006. The variation was observed between the MS, T_2 and T_3 but not T_1. In the dry season, NH_3 was observed not to be statistically significant in concentration but variation in levels were generally observed.

The dry season recorded relatively higher NO_3^- concentrations. Variation in stability and solubility by virtue of different environmental conditions like temperature, relative humidity among others for the respective seasons affected NO_3^- concentrations. ANOVA of the treatment effects of the designed system indicated that NO_3^- experienced some level of reduction in concentration but this was observed not to be statistically significant at 5 %. The level of reduction of NO_3^- concentration in the dry season was statistically significant with f-probability of 0.001.

The level of reduction of NO_2^- was statistically significant with f-probability of 0.002 in the dry season. No significant difference was observed in the concentration levels of NO_2^- when ANOVA at 5 % was performed. With f-probability of 0.001 in the dry season, the level of reduction in the concentration of NO_2^- was observed to be statistically significant.

Phosphorous concentration in the dry season was observed to be opposite to that of the wet season. At 5 % level of significance, phosphorus levels were noted not to be statistically significant even though reduction in concentration levels was observed. In the dry season, phosphorus concentration was observed to have recorded variations in concentration levels but this was not statistically significant. Mean seasonal concentration and variation in treatment with respect to the main source of wastewater did not actually indicate a wide range of variation. This presents the system as efficient in maintaining the level of phosphorus contained in the wastewater as most of the soils in the area are deficient in phosphorus.

The behaviour of potassium in the dry season was not too different from that of the wet season. Generally, the behaviour of potassium can be due to its non-water solubility, and the ability to rapidly and intensely react with water.

9.2.4 Treatment Efficiency on Reduction of Chemical Contaminants

Except phosphorus and potassium, treatment three (T_3) was the most efficient in the reduction of the other chemical parameters. NH_3, NO_3^- and NO_2^- recorded reduction percentages of 48.80 %, 41.90 % and 71.40 % respectively. The reduction level of phosphorus by the three treatments was observed to be below 30 % which is generally good for the study area as the soils are lacking in phosphorus. Treatment three (T_3) recorded the least level of reduction of 19.80 % whilst treatment one (T_1) recorded the highest of 29.70 %.

For potassium, treatment three (T_3) increased the concentration instead of its reduction, whilst the other two treatments ($T_{1 \text{ and } 2}$) recorded 7.47 % and 10.38 % reduction in concentration.

The level of ammonia contained in the wastewater was, however, above the range of EPA Ghana guideline whilst nitrate on the other hand was far below the acceptable limit. The acceptable limit of nitrite though not yet defined by EPA Ghana, recorded a wide range of reduction from the wet season to the dry season. Phosphorus levels were also below the EPA Ghana standard.

9.2.5 Biochemical Oxygen Demand and Chemical Oxygen Demand

The results indicated that for both seasons, the average concentration of BOD released into the stream at Zagyuri was 92.97 mg/l and 103.54 mg/l for the dry and wet season respectively. These values were higher than the recommended levels reported by Sasse (1998). The indication of the concentration means that the wet season was favourable for the activity of the micro-organisms responsible for the degradation of organic matter. It is therefore evident that the effect of environmental factors on the micro-organisms activity influenced the concentration of BOD in the wastewater. The environmental conditions together with filter length favoured the growth and activity of micro-organisms in the oxidation of organic matter.

These higher values, however, indicate that the micro-organisms were active in the degradation process of the organic matter. Low BOD is noted to indicate low level of activity of biodegradable bacteria contained in the wastewater.

Chemical Oxygen Demand (COD) of the wastewater averaged 132.78 mg/l and 102.5 mg/l for the dry and wet seasons respectively. Sasse (1998) noted that for COD, the final effluent standards for discharge into receiving water bodies may tolerate from 100 to 200 mg/l COD. With the average concentration of COD in the dry season being 132.78 mg/l and wet season

of 143.75 mg/l, it implies that the COD levels for both seasons were within range and could be discharged safely. As the most general parameter to measure organic pollution, COD describes how much oxygen is required to oxidise all organic and inorganic matter in water.

9.2.6 Trace Metal Concentrations in Wastewater

Aluminium recorded a mean concentration level of 0.146 mg/l in the wet season during the study period whilst the level recorded in the dry season was 0.070 mg/l. The wastewater samples from Zagyuri in both seasons had low aluminium concentration and below the FAO and WHO limit of 5 mg/l required for irrigation of vegetables. This implies that, the use of wastewater for irrigation in the study area has insignificant effect on aluminium concentration in the soil, since the mean values recorded were below the recommended maximum concentration levels.

Copper recorded a varied mean concentration level of 0.010 mg/l in the wet season and that of the dry season levels was 0.158 mg/l. This implies that the dry season recorded relatively higher concentration of copper than the wet season. The mean values recorded for both seasons were however below the recommended maximum concentrations of 0.20 mg/l by the FAO and WHO. This indicates that copper concentration in wastewater at Zagyuri had insignificant risks to the soil and vegetable crops produced.

The mean concentration of iron was 0.80 mg/l and 0.66 mg/l for the dry and wet seasons. Wastewater samples in both seasons recorded lower iron concentrations which was below the limit of 5 mg/l by FAO and WHO required for the irrigation of vegetable crops.

Manganese recorded a mean value of 0.233 mg/l in the wet season whilst the level recorded in the dry season was 0.101 mg/l. This implies that the mean concentration in the wet season was relatively higher than that of the dry season. The manganese in the wastewater samples collected in the wet season were observed to be higher in the wet season whilst the dry season was below the recommended maximum concentrations of 0.20 mg/l by the FAO and WHO required for irrigation of vegetables. This implies that the wastewater for vegetable crop irrigation was safe in terms of manganese concentration but bioaccumulation effect must be guarded against.

Zinc concentration determined had a mean value of 0.066 mg/l in the wet season whilst the level recorded in the dry season was 0.015 mg/l. The concentration of Zn in the wastewater samples was below the limit of 5.00 mg/l by the FAO and WHO in both seasons.

9.3 Conclusions

The following conclusions are drawn based on the objectives of the study:

9.3.1 Types and Seasonal Diversity of Helminth Eggs in Wastewater

Various types of helminth eggs occurred in the wastewater used by resource poor farmers in the Zagyuri community, a peri-urban area of the Tamale Metropolis. Seasonal variation in the number of eggs was observed and this was mainly due to the effect of the environmental factors. The typical fertile *Ascaris* and *Strongyloides stercoralis* as well as *Schistosoma mansoni* were observed to be the most predominant types of helminths in both seasons and this is attributed to their environmental tolerance and resistance. Limited water supply as a result of irregularity of flow of domestic pipe water especially during the dry season was

found to influence greatly the concentration of the helminth eggs per litre of sampled wastewater.

9.3.2 Efficiency of On-Farm Sand Filter System in Microbial Contaminant Removal

Designing a wastewater treatment system involves selection of a very good filter material and sizing the filter column rightly. Varying lengths of filter columns and depths of filter material were used in the design of the on-farm sand filter columns. Average dry bulk density and particle density of the filter media were 1.58 gcm^{-3} and 2.66 gcm^{-3} respectively, whilst total average filter porosity was 39.4 %. Mathematical models are therefore employed in the determination of the right size of filter column needed for the efficient removal of microbial (faecal and total coliforms, helminth eggs) contaminants. The models developed considered largely the prevailing environmental conditions in the locality for which the filters were installed. The results indicated the level to which microbial contaminants in wastewater can be removed. Longer filter columns were more efficient in the removal of microbial contaminants contained in the wastewater. The concentration of faecal and total coliforms as well as helminth eggs were 24,444 MPN/l, 56,930 MPN/l and 56 eggs/l for the wet season respectively. In the dry season, however, faecal coliform recorded a mean concentration of 13,780 MPN/l, total coliform had 41,113 MPN/l whilst helminth eggs were 74 eggs/l. These mean concentrations were noted to be higher than the recommended levels of less than 1000/100 ml of coliforms and <1 egg/l for unrestricted irrigation (WHO, 2006b).

ANOVA of the reduction levels of microbial contaminants in the wastewater and the treatment effects indicated that there were significant differences in the reduction in the levels of microbial contaminants using the three (3) different treatments. With respect to the main source both seasons (dry and wet) recorded an Fpr value of < 0.001 at 5 % significance level.

9.3.3 Chemical Quality of Wastewater After Filtration

Based on the Environmental Protection Agency of Ghana (2003) guidelines, the level of NH_3 in the wastewater was found to be too high for irrigation purposes. The level of NO_3^- is lower and therefore safe for agricultural purposes. The wide difference between seasonal NO_2^- levels is a signal of potential health risk at the study site. Phosphorus (P) levels, though below standard, stand the chance of exceeding the limits since levels are closer to the EPA standards, thus posing future risk. The study revealed that, with the exception of NO_3^-, all other parameters have relatively higher levels in the wet season as compared to that of the dry season. The study realised that the treatment effect of NO_4^-, NO_3^- and NO_2^- by the on-farm sand filter system combined with stabilization ponds varied seasonally. The design also had significant impact on level of reduction and behaviour of the chemical parameters of wastewater in the study area. Treatment two (T_2) and three (T_3) of the system have similar capability with respect to reduction of the level of chemical parameters, however, treatment three (T_3) emerged as the best in the reduction of the chemical parameters.

9.3.4 Micro Nutrient Concentration in Wastewater Used For Peri-Urban Irrigation

Except the concentration of Cu in the wastewater which did not record any significant difference in levels between the wet and dry seasons, Al, Mn and Zn were significantly different in concentrations between the seasons.

Also, except the mean concentration of Mn (0.233 mg/l) in the wet season, the other micro nutrients were below the recommended maximum concentrations as set by WHO (2006a) and the limits of EPA Ghana for the release of wastewater into water courses in the environment. Bioaccumulation of these micro nutrients is therefore possible and can create an imbalance in the nutrient levels of the soils.

9.3.5 Seasonal Variation of Organic Pollution Loads in Wastewater

The results indicated that for both seasons, the average concentration of BOD released into the stream at Zagyuri was 92.97 mg/l and 103.54 mg/l for the dry and wet seasons respectively whilst the COD was averaged 132.78 mg/l and 102.5 mg/l for the dry and wet seasons respectively. These values were higher than the recommended levels reported by Sasse (1998). The indication of the concentration means that the wet season was favourable for the activity of the micro-organisms responsible for the degradation of organic matter.

9.4 Recommendations

Realising the importance of wastewater in the production of vegetable crops for urban and peri-urban consumption and the contaminants contained in it, the following recommendations are being proposed to safeguard human health.

1. The use of protective clothing during crop watering is expected to help reduce infection of farmers and their families.

2. The use of non-treatment options of wastewater used by the farmers has the potential of reducing the risk that farmers, farm families and consumers face in the consumption of vegetables produced using wastewater from the area.

3. Local government level regulation need to be developed and enforced to reduce the risk associated with the use of wastewater for crop irrigation.

9.5 Suggestions for Further Research

The following are also suggested in the area of research:

1. Research should be conducted on the bioaccumulation of heavy metals on vegetables and soils of wastewater irrigated sites in the study area.

2. Further research on improving the current design should be undertaken to provide farmers with a low cost option for treating wastewater on-farm such as the determination of optimum length and size for filtering.

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APPENDICES

APPENDIX I: LEVELS OF CHEMICAL PARAMETERS MEASURED IN WASTEWATER

Table 10.1: Weekly Average Levels of Ammonia

Ammonia (mg/l)- Wet season								
Treatment	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**
MS	25.25	13.75	15.76	13.5	19	23.25	20	33.25
T_1	21.5	11.33	5.46	11.75	18.333	20.5	15.417	24.417
T_2	16.333	3.9167	6.7067	6.33	11.583	12.667	12.333	21.5
T_3	16.25	5.833	4.46	10.483	15.91667	10.5	9.333	10.8
Treatment	**Dry season**							
MS	18	8.95	21.75	11.85	34.75	25.75	40.75	48.5
T_1	11.83	14.67	15	12.117	44.583	41.9167	67.583	14.917
T_2	11.47	10.57	17.25	13.667	44.9167	33.0833	72.917	39.417
T_3	9.75	9.2	16.0833	13.833	28	22.4167	63.083	26.5

Table 10.2: Temperature Variation and Ammonia Levels – Wet Season

AMMONIA (mg/l) / Temperature (^oC) Wet season								
Treatment / Weeks	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**
MS	25.25	13.75	15.76	13.5	19	23.25	20	33.25
MSt	**32.26**	**27.32**	**29.11**	**29.9**	**28.76**	**28.67**	**27.09**	**28.97**
T_1	21.5	11.33	5.46	11.75	18.333	20.5	15.417	24.417
T_1t	**30.58**	**26.36**	**27.6167**	**28.0067**	**26.55**	**27.0267**	**26.2367**	**27.38**
T_2	16.33	3.9167	6.7067	6.33	11.583	12.667	12.333	21.5
T_2t	**28.77**	**26.07**	**27.35**	**28.09**	**26.31**	**26.82**	**26.02**	**27.273**
T_3	16.25	5.833	4.46	10.483	15.9167	10.5	9.33	10.83
T_3t	**28.71**	**26.153**	**28.0967**	**28**	**26.1233**	**26.77**	**25.8933**	**27.36**

t-temperature

Table 10.3: Weekly Average Levels of Nitrate

Nitrate (mg/l) - Wet Season								
Treatment / Weeks	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**
MS	28.16	0.176	8.71	0.42	0.396	0.352	0.352	0.188
T_1	17.893	0.103	5.7467	0.2493	0.308	0.2787	0.264	0.176
T_2	22.453	0.161	4.9867	0.2347	0.337	0.22	0.264	0.205
T_3	20.8967	0.147	6.013	0.176	0.235	0.1907	0.249	0.103
	Dry Season							
MS	0.484	0.32	0.396	0.572	0.528	0.572	0.12	0.441
T_1	0.383	0.197	0.293	0.293	0.337	0.235	0.2933	0.205
T_2	0.176	0.249	0.1173	0.264	0.176	0.22	0.264	0.249
T_3	0.237	0.235	0.22	0.323	0.2347	0.235	0.191	0.295

Table 10.4: Weekly Average Nitrite Levels

Nitrite (mg/l) - Dry Season								
Treatment / Week	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**
MS	0.0331	0.0198	0.2541	0.1980	0.1914	0.1551	0.1452	0.1221
T_1	0.0099	0.0121	0.0572	0.1067	0.0946	0.0286	0.0913	0.0814
T_2	0.0176	0	0.0352	0.0832	0.0847	0.0429	0.0715	0.0616
T_3	0.0055	0	0.0457	0.0517	0.0649	0.0418	0.0550	0.0814
	Wet Season							
MS	9.5700	0.0594	9.900	0.0825	0.0896	0.1023	0.1023	0.0629
T_1	9.0200	0.0121	4.8400	0.0671	0.0616	0.0506	0.0462	0.0362
T_2	9.2400	0.033	6.600	0.0250	0.0528	0.0363	0.0429	0.0330
T_3	8.1400	0.0363	7.700	0.0556	0.064	0.0440	0.0363	0.0319

Table 10.5: Weekly Average of Phosphorus Levels

Phosphorus (mg/l) - Wet Season								
Treatment / Week	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**
MS	4.6	1.9	1.2	0.81	1.87	1.72	1.77	2.3
T_1	3.6	0.92	0.2	1.3	1.23	1.35	1.64	1.1
T_2	4.6	1.03	0.86	1.06	1.22	1.1	1.15	0.72
T_3	4.8	1.39	1.29	1.61	0.64	0.36	2.3	0.61
	Phosphorus (mg/l) - Dry Season							
MS	0.54	0.47	0.54	2.9	2.1	2.25	2.13	3.43
T_1	0.74	0.46	0.33	2.7	1.38	3.02	3.02	1.87
T_2	0.54	1.47	0.4	2.96	3.07	2.53	2.56	2.73
T_3	0.51	0.48	0.42	3.03	3.02	2.63	3.52	2.08

Table 10.6: ANOVA of Chemical Parameters for Wet Season

	Control	**Treatments**				
Parameters	MS	T_1	T_2	T_3	LSD	FP<0.05
AmmoniaNH_4 (mg/l)	20.5^{a}	16.1^{a}	11.4^{b}	10.5^{b}	5.95	0.006
Nitrate NO_3^- (mg/l)	4.8	3.1	3.6	3.5	8.11	0.975
Nitrite NO_2^- (mg/l)	2.50	1.77	2.01	2.01	3.917	0.984
Phosphorus P (mg/l)	2.02	1.42	1.47	1.62	1.246	0.751

Values with different superscripts **a** **o**r **b** imply significant difference for each rows whilst common superscripts have no significant difference.

Table 10.7: ANOVA of Chemical Parameters for Dry Season

	Control	Treatments				
Parameters	**MS**	**T_1**	**T_2**	**T_3**	**LSD**	**FP<0.05**
AmmoniaNH_4 (mg/l)	26.3	27.8	30.4	23.6	19.25	0.907
Nitrate NO_3^- (mg/l)	0.433^{a}	0.297^{b}	0.214^{b}	0.246^{b}	0.0904	0.001
Nitrite NO_2^- (mg/l)	0.1399^{a}	0.0602^{b}	0.0496^{b}	0.0433^{b}	0.05057	0.002
Phosphorus P (mg/l)	1.79	1.69	2.03	1.96	1.196	0.934

Values with different superscripts **a** or **b** imply significant difference for each rows whilst common superscripts have no significant difference.

Table 10.8: Relationship between Ammonia and pH

AMMONIA (mg/l) /pH -Wet season								
Treatment / Week	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**
MS	25.25	13.75	15.76	13.5	19	23.25	20	33.25
MS_{PH}	**8.18**	**1.02**	**5.59**	**7.94**	**7.59**	**6.35**	**6.84**	**6.47**
T1	21.5	11.33	5.46	11.75	18.33	20.5	15.42	24.42
$T1_{PH}$	**8.38**	**4.08**	**5.53**	**8.43**	**8.44**	**8.29**	**7.87**	**7.87**
T2	16.33	3.92	6.71	6.33	11.58	12.67	12.33	21.5
$T2_{PH}$	**8.98**	**6.39**	**6.17**	**9.023**	**8.28**	**7.90**	**7.28**	**6.78**
T3	16.25	5.83	4.46	10.48	15.92	10.5	9.33	10
$T3_{PH}$	**9.1**	**5.15**	**5.95**	**8.45**	**8.01**	**6.83**	**6.84**	**6.51**

pH Value for Treatments

Table 10.9: Seasonal Averages, Standard Deviation and Errors of Chemical Parameters

	Ammonia					
Treatment	**Dry Season**			**Wet Season**		
	AV	SD	SE	AV	SD	SE
MS	26.2875	14.003896	4.951125	20.47	6.678434	2.361183
T1	27.820833	20.935932	7.4019696	16.08875	6.301934	2.22807
T2	30.397917	21.763475	7.6945504	11.421588	5.763782	2.037805
T3	23.608333	17.481312	6.1805771	10.45125	4.176733	1.476698
	Nitrate					
	Dry Season			**Wet Season**		
	Av	SD	SE	AV	SD	SE
MS	0.433	0.1493873	0.0528164	4.84425	9.868876	3.489175
T1	0.2786667	0.0651211	0.0230238	3.1273	6.271134	2.217181
T2	0.2145	0.053135	0.0187861	3.60775	7.794068	2.755619
T3	0.2458333	0.0422536	0.0149389	3.5012505	7.319032	2.587668
	Nitrite					
	Dry Season			**Wet Season**		
	AV	SD	SE	AV	SD	SE
MS	0.13985	0.080601	0.0284968	2.496125	4.468829	1.57997
T1	0.060225	0.0389386	0.0137669	1.766725	3.377021	1.193957
T2	0.0495917	0.0309913	0.0109571	2.007875	3.716639	1.31403
T3	0.0432542	0.0278709	0.0098538	2.0135166	3.647472	1.289576
	Phosphorus					
	Dry Season			**Wet Season**		
	AV	SD	SE	AV	SD	SE
MS	1.795	1.147183	0.40559	2.02125	1.13771	0.402241
T1	1.69	1.130828	0.399808	1.4175	0.978114	0.345816
T2	2.0325	1.079547	0.381677	1.4675	1.275872	0.451089
T3	1.96125	1.299994	0.459617	1.625	1.429515	0.50541
	Potassium					
	Dry Season			**Wet Season**		
	AV	SD	SE	AV	SD	SE
MS	70.78125	27.95323	9.882958	51.36875	18.49521	6.539044
T1	57.05313	13.33788	4.715652	55.97708	9.108094	3.220198
T2	61.89375	19.96317	7.058047	47.5875	9.50448	3.360341
T3	75.95313	20.42625	7.221771	48.13542	11.64698	4.117829

Table 10.10: BOD and COD Seasonal Concentration

COD (AV)								
Treatment/ Week	Dry Season				Wet Season			
	MS	T_1	T_2	T_3	MS	T_1	T_2	T_3
1	108.75	77	64.5	56.25	133.5	78.5	75	71
2	122	82	76.5	83.5	123	80.5	79.5	85
3	107.9	70.8	77.5	61.25	128.5	79	81	70.5
4	105.15	85.75	82.45	72.1	118.5	90	79	69.5
5	205.9	115.1	102.3	81.7	203	112.5	103	92.5
6	137	98.4	85.5	92.75	155	90	94	88
7	169	182.5	130	97.5	186	207.5	96.5	56.5
8	106.5	83	61.5	68	102.5	113	81	83.5
BOD_5 Concentration								
Treatment/ Week	Dry				Wet			
	MS	T_1	T_2	T_3	MS	T_1	T_2	T_3
1	68.2	58.5	50.6	45.9	73	67.6	60.4	63.2
2	81.3	67.4	67.9	65.5	72.6	70.3	66.5	76.8
3	70.3	63.8	59.1	46.8	77.1	67.9	71.4	64.3
4	55	64.9	58.3	55.8	47.1	76.2	68.7	63.5
5	130.9	70.8	68.1	62.9	191.7	91.2	84.1	77.5
6	104.2	81.5	71.1	63.8	124.6	76	68.8	67.9
7	159.1	154.8	83.9	61.2	158.5	166.9	66.2	36.2
8	74.8	71.9	51.2	48.8	83.7	88.6	63.4	62.7

Table 10.11: COD/BOD_5 Relation of Wastewater of the Treatment Units

	Dry Season				Wet Season			
Treatment	**MS**	**T_1**	**T_2**	**T_3**	**MS**	**T_1**	**T_2**	**T_3**
1	1.59	1.31	1.27	1.23	1.83	1.16	1.24	1.12
2	1.50	1.22	1.13	1.27	1.69	1.15	1.20	1.11
3	1.53	1.11	1.31	1.31	1.67	1.16	1.13	1.10
4	1.91	1.32	1.41	1.29	2.52	1.18	1.15	1.09
5	1.57	1.63	1.50	1.30	1.06	1.23	1.22	1.19
6	1.31	1.21	1.20	1.45	1.24	1.18	1.37	1.30
7	1.06	1.18	1.55	1.59	1.17	1.24	1.46	1.56
8	1.42	1.15	1.20	1.39	1.22	1.28	1.28	1.33

Table 10.12: BOD_5/COD Relation of Wastewater of the Treatment Units

	Dry Season				Wet Season			
Treatment	**MS**	**T_1**	**T_2**	**T_3**	**MS**	**T_1**	**T_2**	**T_3**
1	0.63	0.76	0.78	0.82	0.55	0.86	0.81	0.89
2	0.67	0.82	0.89	0.78	0.59	0.87	0.84	0.90
3	0.65	0.90	0.76	0.76	0.60	0.86	0.88	0.91
4	0.52	0.76	0.71	0.77	0.40	0.85	0.87	0.91
5	0.64	0.62	0.67	0.76	0.94	0.81	0.82	0.84
6	0.76	0.83	0.83	0.69	0.80	0.84	0.73	0.77
7	0.94	0.85	0.65	0.63	0.85	0.80	0.69	0.64
8	0.70	0.87	0.83	0.72	0.82	0.78	0.78	0.75

Table 10.13: Heavy Metals Concentration in the Wet Season

	Heavy metal (mg/l)				
Weeks	**Al**	**Mn**	**Fe**	**Zn**	**Cu**
1	0.076	0.189	0.600	0.020	0.070
2	0.070	0.319	1.030	0.090	0.000
3	0.147	0.355	0.730	0.000	0.000
4	0.156	0.245	0.490	0.000	0.000
5	0.210	0.274	0.530	0.050	0.000
6	0.261	0.162	0.580	0.130	0.000
7	0.106	0.297	2.060	0.120	0.000
8	0.139	0.024	0.360	0.120	0.010

Table 10.14: Heavy Metals Concentration in the Dry Season

	Heavy metal (mg/l)				
Weeks	**Al**	**Mn**	**Fe**	**Zn**	**Cu**
1	0.106	0.201	0.600	0.020	0.000
2	0.103	0.042	0.010	0.040	0.200
3	0.174	0.000	0.210	0.000	0.300
4	0.020	0.088	0.570	0.020	0.020
5	0.058	0.168	0.700	0.000	0.000
6	0.039	0.000	0.570	0.000	0.000
7	0.039	0.133	1.640	0.040	0.270
8	0.019	0.174	0.860	0.000	0.470

APPENDIX 2

Table 11.1: Multivariate Regression Analysis Dry Season

Faecal Coliform

Dry Season

Model Summary[b]

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate	Change Statistics				
					R Square Change	F Change	df1	df2	Sig. F Change
1	0.679[a]	0.461	0.404	.83263498 4718321	0.461	8.109	6	57	0.000

a. Predictors: (Constant), pH, Filter_Length, Temp, Sunshine, Rainfall, RH

b. Dependent Variable: ln_FC

ANOVA[b]

Model		Sum of Squares	Df	Mean Square	F	Sig.
1	Regression	33.732	6	5.622	8.109	0.000[a]
	Residual	39.517	57	0.693		
	Total	73.249	63			

a. Predictors: (Constant), pH, Filter_Length, Temp, Sunshine, Rainfall, RH

b. Dependent Variable: ln_FC

Coefficients[a]

Model		Unstandardized Coefficients		Standardized Coefficients	t	Sig.	95% Confidence Interval for B	
		B	Std. Error	Beta			Lower Bound	Upper Bound
1	(Constant)	13.715	1.727		7.939	0.000	10.256	17.174
	Filter_Length	-0.039	0.011	-0.348	-3.576	0.001	-0.061	-0.017
	RH	-0.074	0.014	-0.641	-5.251	0.000	-0.103	-0.046
	Temp	-0.017	0.036	-0.047	-0.463	0.645	-0.089	0.055
	Sunshine	0.180	0.090	0.239	2.002	0.050	0.000	0.359
	Rainfall	0.044	0.298	0.015	0.148	0.883	-0.552	0.640
	pH	-0.584	0.171	-0.342	-3.407	0.001	-0.926	-0.241

a. Dependent Variable: ln_FC

Residuals Statistics[a]

	Minimum	Maximum	Mean	Std. Deviation	N
Predicted Value	6.28628540039062E0	9.28894805908203E0	7.71850894347626E0	.731730042735277	64
Residual	-2.030933618545532E0	1.715940833091736E0	-2.248201624865942E-15	.791993847311379	64
Std. Predicted Value	-1.957	2.146	0.000	1.000	64
Std. Residual	-2.439	2.061	0.000	0.951	64

a. Dependent Variable: ln_FC

Total Coliform
Dry Season

Regression

Model Summary[b]

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate	Change Statistics				
					R Square Change	F Change	df1	df2	Sig. F Change
1	0.691[a]	0.478	0.423	0.467024243431510	0.478	8.694	6	57	0.000

a. Predictors: (Constant), pH, Filter_Length, Temp, Sunshine, Rainfall, RH

b. Dependent Variable: ln_TC

ANOVA[b]

Model		Sum of Squares	Df	Mean Square	F	Sig.
1	Regression	11.377	6	1.896	8.694	0.000[a]
	Residual	12.432	57	0.218		
	Total	23.810	63			

a. Predictors: (Constant), pH, Filter_Length, Temp, Sunshine, Rainfall, RH

b. Dependent Variable: ln_TC

Coefficients[a]

Model		Unstandardized Coefficients		Standardized Coefficients	t	Sig.	95% Confidence Interval for B	
		B	Std. Error	Beta			Lower Bound	Upper Bound
1	(Constant)	11.088	0.969		11.444	0.000	9.148	13.028
	Filter_Length	-0.037	0.006	-0.575	-6.001	0.000	-0.049	-0.025
	RH	-0.021	0.008	-0.317	-2.642	0.011	-0.037	-0.005
	Temp	-0.037	0.020	-0.184	-1.846	0.070	-0.078	0.003
	Sunshine	0.039	0.050	0.092	0.783	0.437	-0.061	0.140
	Rainfall	-0.297	0.167	-0.177	-1.782	0.080	-0.632	0.037
	pH	-0.004	0.096	-0.004	-0.036	0.971	-0.196	0.189

a. Dependent Variable: ln_TC

Residuals Statistics[a]

	Minimum	Maximum	Mean	Std. Deviation	N
Predicted Value	8.14487552642822E0	9.92775344848633E0	9.17223174081741E0	.424964679566606	64
Residual	-1.00166440010070 8E0	1.14143097400665 3E0	-6.47919218277337 4E-16	.44422866457879 8	64
Std. Predicted Value	-2.418	1.778	0.000	1.000	64
Std. Residual	-2.145	2.444	0.000	0.951	64

a. Dependent Variable: ln_TC

Dry Season
Helminth

Model Summary[b]

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate	Change Statistics				
					R Square Change	F Change	df1	df2	Sig. F Change
1	0.738[a]	0.545	0.497	0.576243759466635	0.545	11.391	6	57	0.000

a. Predictors: (Constant), pH, Filter_Length, Temp, Sunshine, Rainfall, RH

b. Dependent Variable: ln_H

ANOVA[b]

Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	22.694	6	3.782	11.391	0.000[a]
	Residual	18.927	57	0.332		
	Total	41.621	63			

a. Predictors: (Constant), pH, Filter_Length, Temp, Sunshine, Rainfall, RH

b. Dependent Variable: ln_H

Coefficients[a]

Model		Unstandardized Coefficients		Standardized Coefficients	t	Sig.	95% Confidence Interval for B	
		B	Std. Error	Beta			Lower Bound	Upper Bound
1	(Constant)	4.959	1.196		4.148	0.000	2.565	7.353
	Filter_Length	-0.061	0.008	-0.718	-8.030	0.000	-0.076	-0.046
	RH	-0.011	0.010	-0.126	-1.129	0.264	-0.031	0.009
	Temp	-0.008	0.025	-0.029	-0.311	0.757	-0.057	0.042
	Sunshine	-0.010	0.062	-0.017	-0.155	0.878	-0.134	0.115
	Rainfall	0.080	0.206	0.036	0.387	0.700	-0.333	0.492
	pH	-0.133	0.119	-0.103	-1.121	0.267	-0.370	0.104

a. Dependent Variable: ln_H

Residuals Statistics[a]

	Minimum	Maximum	Mean	Std. Deviation	N
Predicted Value	1.61692845821381E0	3.63575768470764E0	2.58203126845730E0	.600186341191531	64
Residual	-1.329246401786804E0	1.029529333114624E0	.000000000000000	.548117146679282	64
Std. Predicted Value	-1.608	1.756	0.000	1.000	64
Std. Residual	-2.307	1.787	0.000	0.951	64

Wet Season

Helminths

Model Summary[b]

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate	Change Statistics				
					R Square Change	F Change	df1	df2	Sig. F Change
1	0.659[a]	0.434	0.374	.645507396837198	0.434	7.279	6	57	0.000

a. Predictors: (Constant), pH, Sunshine, Filter_Length, Rainfall, Temp, RH

b. Dependent Variable: ln_H

Coefficients[a]

Model		Unstandardized Coefficients		Standardized Coefficients	t	Sig.	95% Confidence Inte B	
		B	Std. Error	Beta			Lower Bound	Upper
1	(Constant)	-1.283	3.066		-0.419	0.677	-7.424	
	Filter_Length	-0.054	0.009	-0.628	-6.149	0.000	-0.071	
	RH	0.028	0.033	0.211	0.840	0.405	-0.038	
	Temp	0.061	0.063	0.109	0.963	0.340	-0.066	
	Sunshine	0.070	0.066	0.279	1.051	0.298	-0.063	
	Rainfall	0.009	0.009	0.117	1.053	0.297	-0.008	
	pH	0.010	0.076	0.014	0.127	0.899	-0.142	

a. Dependent Variable: ln_H

ANOVA[b]

Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	18.198	6	3.033	7.279	0.000[a]
	Residual	23.751	57	0.417		
	Total	41.949	63			

a. Predictors: (Constant), pH, Sunshine, Filter_Length, Rainfall, Temp, RH

b. Dependent Variable: ln_H

Residuals Statistics[a]

	Minimum	Maximum	Mean	Std. Deviation	N
Predicted Value	1.22393190860748E0	3.28992295265198E0	2.24240011484582E0	.537459368599184	64
Residual	-1.81708323955359E0	1.13107883930206E0	-2.74953670942323E-16	.614000007292507	64
Std. Predicted Value	-1.895	1.949	0.000	1.000	64
Std. Residual	-2.815	1.752	0.000	0.951	64

a. Dependent Variable: ln_H

Total Coliform
Wet Season

Model Summary[b]

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate	Change Statistics				
					R Square Change	F Change	df1	df2	Sig. F Change
1	0.570[a]	0.325	0.254	.941668814639421	.325	4.570	6	57	0.001

a. Predictors: (Constant), pH, Sunshine, Filter_Length, Rainfall, Temp, RH

b. Dependent Variable: ln_TC

ANOVA[b]

Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	24.315	6	4.053	4.570	0.001[a]
	Residual	50.544	57	0.887		
	Total	74.859	63			

a. Predictors: (Constant), pH, Sunshine, Filter_Length, Rainfall, Temp, RH

b. Dependent Variable: ln_TC

Coefficients[a]

Model		Unstandardized Coefficients		Standardized Coefficients	t	Sig.	95% Confidence Interval for B	
		B	Std. Error	Beta			Lower Bound	Upper Bound
1	(Constant)	2.593	4.473		.5800	0.564	-6.364	11.551
	Filter_Length	-0.058	0.013	-0.512	-4.590	0.000	-0.084	-0.033
	RH	0.017	0.048	0.095	0.346	0.731	-0.079	0.112
	Temp	0.185	0.092	0.249	2.014	0.049	0.001	0.369
	Sunshine	0.048	0.097	0.144	0.496	0.622	-0.145	0.241
	Rainfall	-0.006	0.012	-0.061	-0.498	0.620	-0.031	0.019
	pH	0.186	0.110	0.204	1.686	0.097	-0.035	0.407

a. Dependent Variable: ln_TC

Residuals Statistics[a]

	Minimum	Maximum	Mean	Std. Deviation	N
Predicted Value	7.816291809 08203E0	1.045708274 84131E1	9.10660531 348863E0	.62125371212506 9	64
Residual	-2.617539882 659912E0	1.871400594 711304E0	-5.72458747 0723463E-16	.89570570668697 4	64
Std. Predicted Value	-2.077	2.174	0.000	1.000	64
Std. Residual	-2.780	1.987	0.000	0.951	64

a. Dependent Variable: ln_TC

Faecal Coliform

Wet Season

Model Summary[b]

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate	Change Statistics				
					R Square Change	F Change	df1	df2	Sig. F Change
1	0.641[a]	0.411	0.349	1.12146869 2684476E0	0.411	6.626	6	57	0.000

a. Predictors: (Constant), pH, Sunshine, Filter_Length, Rainfall, Temp, RH

b. Dependent Variable: ln_FC

ANOVA[b]

Model		Sum of Squares	Df	Mean Square	F	Sig.
1	Regression	50.002	6	8.334	6.626	0.000[a]
	Residual	71.688	57	1.258		
	Total	121.691	63			

a. Predictors: (Constant), pH, Sunshine, Filter_Length, Rainfall, Temp, RH

b. Dependent Variable: ln_FC

Coefficients[a]

Model		Unstandardized Coefficients		Standardized Coefficients	t	Sig.	95% Confidence Interval for B	
		B	Std. Error	Beta			Lower Bound	Upper Bound
1	(Constant)	-0.587	5.327		-0.110	0.913	-11.254	10.081
	Filter_Length	-0.082	0.015	-0.567	-5.437	0.000	-0.112	-0.052
	RH	0.003	0.057	0.014	0.053	0.958	-0.111	0.117
	Temp	0.329	0.110	0.347	3.008	0.004	0.110	0.549
	Sunshine	-0.056	0.115	-0.131	-0.483	0.631	-0.286	0.175
	Rainfall	0.017	0.015	0.133	1.173	0.246	-0.012	0.047
	pH	0.227	0.131	0.195	1.730	0.089	-0.036	0.490

a. Dependent Variable: ln_FC

Residuals Statistics[a]

	Minimum	Maximum	Mean	Std. Deviation	N
Predicted Value	6.12807035446167E0	9.89497280120850E0	7.87327729218380E0	.890889472124117	64
Residual	-2.710520267486572E0	1.938316941261292E0	-5.341213582532589E-15	1.066729504356482E0	64
Std. Predicted Value	-1.959	2.269	0.000	1.000	64
Std. Residual	-2.417	1.728	0.000	0.951	64

a. Dependent Variable: ln_FC

APPENDIX 3

Table 12.1: ANOVA of Trace Elements in Treatments

Parameter	Mean	MEANS		LSD	F>(0.05)
		Wet Season	Dry Season		
Aluminium	0.137	0.148	0.127	0.0665	0.526
Copper	0.065	0.013	0.117	0.1510	0.007
Iron	0.783	0.801	0.766	0.3844	0.856
Manganese	0.252	0.297	0.207	0.1510	0.232
Zinc	0.081	0.086	0.076	0.0818	0.804

```
Analysis of variance *****

Variate: Aluminium

Source of variation     d.f.       s.s.       m.s.    v.r.  F pr.
TREATMENT                  1   0.003486   0.003486    0.41  0.526
Residual                  30   0.254611   0.008487
Total                     31   0.258097


* MESSAGE: the following units have large residuals.

*units* 22          0.234   s.e. 0.089


***** Tables of means *****

Variate: Aluminium

Grand mean  0.137

 TREATMENT        1        2
             0.148    0.127


*** Standard errors of means ***

Table            TREATMENT
rep.                    16
d.f.                    30
```

```
e.s.e.              0.0230

*** Standard errors of differences of means ***

Table            TREATMENT
rep.                   16
d.f.                   30
s.e.d.              0.0326

*** Least significant differences of means (5% level) ***

Table            TREATMENT
rep.                   16
d.f.                   30
l.s.d.              0.0665


***** Stratum standard errors and coefficients of variation *****

Variate: Aluminium

   d.f.          s.e.          cv%
     30        0.0921        67.2

  43  "One-way ANOVA (no Blocking)."
  44  BLOCK "No Blocking"
  45  TREATMENTS TREATMENT
  46  COVARIATE "No Covariate"
  47  ANOVA [PRINT=aovtable,information,means,%cv; FPROB=yes;
PSE=diff,lsd,means; LSDLEVEL=5]\

 48   Copper

48.....................................................................
.....

***** Analysis of variance *****

Variate: Copper

Source of variation     d.f.       s.s.       m.s.    v.r.  F pr.
TREATMENT                  1    0.08653    0.08653    8.45  0.007
Residual                  30    0.30710    0.01024
Total                     31    0.39363


* MESSAGE: the following units have large residuals.

*units* 32          0.353   s.e. 0.098


***** Tables of means *****

Variate: Copper

Grand mean  0.065

 TREATMENT        1        2
             0.013    0.117
```

```
*** Standard errors of means ***

Table            TREATMENT
rep.                    16
d.f.                    30
e.s.e.              0.0253

*** Standard errors of differences of means ***
 Table            TREATMENT
rep.                    16
d.f.                    30
s.e.d.              0.0358

*** Least significant differences of means (5% level) ***

Table            TREATMENT
rep.                    16
d.f.                    30
l.s.d.              0.0731


***** Stratum standard errors and coefficients of variation *****

Variate: Copper

   d.f.          s.e.         cv%
     30        0.1012       156.7

  49  "One-way ANOVA (no Blocking)."
  50  BLOCK "No Blocking"
  51  TREATMENTS TREATMENT
  52  COVARIATE "No Covariate"
  53  ANOVA [PRINT=aovtable,information,means,%cv; FPROB=yes;
PSE=diff,lsd,means; LSDLEVEL=5]\
  54   Iron

54.....................................................................
.....

***** Analysis of variance *****

Variate: Iron

Source of variation     d.f.       s.s.       m.s.    v.r.  F pr.
TREATMENT                  1     0.0095     0.0095    0.03  0.856
Residual                  30     8.5039     0.2835
Total                     31     8.5133


* MESSAGE: the following units have large residuals.

*units* 7           1.349   s.e. 0.516
*units* 15          1.259   s.e. 0.516
*units* 23          1.314   s.e. 0.516


***** Tables of means *****

Variate: Iron
```

```
Grand mean  0.783

 TREATMENT        1        2
             0.801    0.766


*** Standard errors of means ***

Table            TREATMENT
rep.                    16
d.f.                    30
e.s.e.              0.1331

*** Standard errors of differences of means ***

Table            TREATMENT
rep.                    16
d.f.                    30
s.e.d.              0.1882

*** Least significant differences of means (5% level) ***

Table            TREATMENT
rep.                    16
d.f.                    30
l.s.d.              0.3844


***** Stratum standard errors and coefficients of variation *****

Variate: Iron

   d.f.          s.e.         cv%
     30        0.5324        68.0

  55  "One-way ANOVA (no Blocking)."
  56  BLOCK "No Blocking"
  57  TREATMENTS TREATMENT
  58  COVARIATE "No Covariate"
  59  ANOVA [PRINT=aovtable,information,means,%cv; FPROB=yes;
PSE=diff,lsd,means; LSDLEVEL=5]\
  60   Manganese

60.....................................................................
.....

***** Analysis of variance *****

Variate: Manganese

Source of variation     d.f.       s.s.       m.s.    v.r.  F pr.
TREATMENT                  1    0.06498    0.06498    1.49  0.232
Residual                  30    1.31202    0.04373
Total                     31    1.37700


* MESSAGE: the following units have large residuals.

*units* 2           0.616   s.e. 0.202
```

```
*units* 21          0.533   s.e. 0.202


***** Tables of means *****

Variate: Manganese

Grand mean  0.252

 TREATMENT        1        2
             0.297    0.207


*** Standard errors of means ***

Table            TREATMENT
rep.                    16
d.f.                    30
e.s.e.              0.0523

*** Standard errors of differences of means ***

Table            TREATMENT
rep.                    16
d.f.                    30
s.e.d.              0.0739

*** Least significant differences of means (5% level) ***

Table            TREATMENT
rep.                    16
d.f.                    30
l.s.d.              0.1510


***** Stratum standard errors and coefficients of variation *****

Variate: Manganese

   d.f.          s.e.         cv%
     30        0.2091        83.1

  61  "One-way ANOVA (no Blocking)."
  62  BLOCK "No Blocking"
  63  TREATMENTS TREATMENT
  64  COVARIATE "No Covariate"
  65  ANOVA [PRINT=aovtable,information,means,%cv; FPROB=yes;
PSE=diff,lsd,means; LSDLEVEL=5]\
  66   Zinc

66.....................................................................
.....

***** Analysis of variance *****

Variate: Zinc

Source of variation     d.f.       s.s.       m.s.    v.r.  F pr.
TREATMENT                  1    0.00080    0.00080    0.06  0.804
Residual                  30    0.38479    0.01283
```

```
Total                    31    0.38559

* MESSAGE: the following units have large residuals.

*units* 19          0.484   s.e. 0.110


***** Tables of means *****

Variate: Zinc

Grand mean  0.081

 TREATMENT        1        2
             0.086    0.076


*** Standard errors of means ***

Table            TREATMENT
rep.                    16
d.f.                    30
e.s.e.              0.0283

*** Standard errors of differences of means ***

Table            TREATMENT
rep.                    16
d.f.                    30
s.e.d.              0.0400

*** Least significant differences of means (5% level) ***

Table            TREATMENT
rep.                    16
d.f.                    30
l.s.d.              0.0818


***** Stratum standard errors and coefficients of variation *****

Variate: Zinc

   d.f.          s.e.         cv%
     30        0.1133       140.5
```

ANOVA of Trace Elements in Main Source

PARAMETER	GRAND	MEAN 2010		MEAN 2011		LSD	F-P(0.05)
	MEAN	WET	DRY	WET	DRY		
Aluminium	0.137	0.150	0.183	0.146	0.070	0.0872	0.077
Copper	0.065	0.015	0.076AC	0.010	0.158	0.1025	0.021*
Iron	0.783	0.804	0.876	0.797	0.656	0.5580	0.876
Manganese	0.252	0.360	0.313	0.233	0.100	0.1998	0.063
Zinc	0.081	0.105	0.136	0.066	0.015	0.1095	0.150

*-SIGNIFICANT DIFFRENCE

***** Analysis of variance *****

Variate: Aluminium

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
TREATMENT	3	0.055079	0.018360	2.53	0.077
Residual	28	0.203018	0.007251		
Total	31	0.258097			

* MESSAGE: the following units have large residuals.

units 6 0.171 s.e. 0.080
units 14 0.177 s.e. 0.080

***** Tables of means *****

Variate: Aluminium

Grand mean 0.137

```
 TREATMENT        1        2        3        4
             0.150    0.183    0.146    0.070




*** Standard errors of means ***

Table            TREATMENT
rep.                     8
d.f.                    28
e.s.e.              0.0301

*** Standard errors of differences of means ***

Table            TREATMENT
rep.                     8
d.f.                    28
s.e.d.              0.0426

*** Least significant differences of means (5% level) ***

Table            TREATMENT
rep.                     8
d.f.                    28
l.s.d.              0.0872


***** Stratum standard errors and coefficients of variation *****

Variate: Aluminium

   d.f.          s.e.         cv%
     28        0.0852        62.1

  43  "One-way ANOVA (no Blocking)."
  44  BLOCK "No Blocking"
  45  TREATMENTS TREATMENT
  46  COVARIATE "No Covariate"
  47  ANOVA [PRINT=aovtable,information,means,%cv; FPROB=yes;
PSE=diff,lsd,means; LSDLEVEL=5]\

  48   Copper
48.....................................................................
.....

***** Analysis of variance *****

Variate: Copper

Source of variation     d.f.       s.s.       m.s.    v.r.  F pr.
TREATMENT                  3    0.11345    0.03782    3.78  0.021
Residual                  28    0.28018    0.01001
Total                     31    0.39363


* MESSAGE: the following units have large residuals.
```

```
*units* 32          0.312   s.e. 0.094


***** Tables of means *****

Variate: Copper

Grand mean  0.065

 TREATMENT        1        2        3        4
             0.015    0.076    0.010    0.158


*** Standard errors of means ***

Table            TREATMENT
rep.                    8
d.f.                   28
e.s.e.             0.0354

*** Standard errors of differences of means ***

Table            TREATMENT
rep.                    8
d.f.                   28
s.e.d.             0.0500

*** Least significant differences of means (5% level) ***

Table            TREATMENT
rep.                    8
d.f.                   28
l.s.d.             0.1025


***** Stratum standard errors and coefficients of variation *****

Variate: Copper

   d.f.          s.e.         cv%
     28        0.1000       154.9

  49  "One-way ANOVA (no Blocking)."
  50  BLOCK "No Blocking"
  51  TREATMENTS TREATMENT
  52  COVARIATE "No Covariate"
  53  ANOVA [PRINT=aovtable,information,means,%cv; FPROB=yes;
PSE=diff,lsd,means; LSDLEVEL=5]\

54   Iron

54.....................................................................
.....

***** Analysis of variance *****

Variate: Iron

Source of variation     d.f.       s.s.       m.s.    v.r.  F pr.
```

```
TREATMENT                  3     0.2032     0.0677    0.23  0.876
Residual                  28     8.3101     0.2968
Total                     31     8.5133


* MESSAGE: the following units have large residuals.

*units* 7           1.346   s.e. 0.510
*units* 15          1.204   s.e. 0.510
*units* 23          1.262   s.e. 0.510


***** Tables of means *****

Variate: Iron

Grand mean  0.783

 TREATMENT        1        2        3        4
             0.804    0.876    0.797    0.656


*** Standard errors of means ***

Table            TREATMENT
rep.                     8
d.f.                    28
e.s.e.              0.1926

*** Standard errors of differences of means ***

Table            TREATMENT
rep.                     8
d.f.                    28
s.e.d.              0.2724

*** Least significant differences of means (5% level) ***

Table            TREATMENT
rep.                     8
d.f.                    28
l.s.d.              0.5580


***** Stratum standard errors and coefficients of variation *****

Variate: Iron

   d.f.          s.e.         cv%
     28        0.5448        69.5

  55  "One-way ANOVA (no Blocking)."
  56  BLOCK "No Blocking"
  57  TREATMENTS TREATMENT
  58  COVARIATE "No Covariate"
  59  ANOVA [PRINT=aovtable,information,means,%cv; FPROB=yes;
PSE=diff,lsd,means; LSDLEVEL=5]\

 60   Manganese
```

```
60.....................................................................
.....

***** Analysis of variance *****

Variate: Manganese


Source of variation     d.f.       s.s.       m.s.    v.r.  F pr.
TREATMENT                  3    0.31097    0.10366    2.72  0.063
Residual                  28    1.06603    0.03807
Total                     31    1.37700


* MESSAGE: the following units have large residuals.

*units* 2           0.553   s.e. 0.183
*units* 13          0.427   s.e. 0.183


***** Tables of means *****

Variate: Manganese

Grand mean  0.252

 TREATMENT        1        2        3        4
             0.360    0.313    0.233    0.100


*** Standard errors of means ***

Table            TREATMENT
rep.                     8
d.f.                    28
e.s.e.              0.0690

*** Standard errors of differences of means ***

Table            TREATMENT
rep.                     8
d.f.                    28
s.e.d.              0.0976

*** Least significant differences of means (5% level) ***

Table            TREATMENT
rep.                     8
d.f.                    28
l.s.d.              0.1998


***** Stratum standard errors and coefficients of variation *****

Variate: Manganese

   d.f.          s.e.         cv%
     28        0.1951        77.6
```

```
  61  "One-way ANOVA (no Blocking)."
  62  BLOCK "No Blocking"
  63  TREATMENTS TREATMENT
  64  COVARIATE "No Covariate"
  65  ANOVA [PRINT=aovtable,information,means,%cv; FPROB=yes;
PSE=diff,lsd,means; LSDLEVEL=5]\
  66   Zinc
```

66.....

***** Analysis of variance *****

Variate: Zinc

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
TREATMENT	3	0.06561	0.02187	1.91	0.150
Residual	28	0.31997	0.01143		
Total	31	0.38559			

* MESSAGE: the following units have large residuals.

units 11 0.424 s.e. 0.100

***** Tables of means *****

Variate: Zinc

Grand mean 0.081

TREATMENT	1	2	3	4
	0.105	0.136	0.066	0.015

*** Standard errors of means ***

Table	TREATMENT
rep.	8
d.f.	28
e.s.e.	0.0378

*** Standard errors of differences of means ***

Table	TREATMENT
rep.	8
d.f.	28
s.e.d.	0.0535

*** Least significant differences of means (5% level) ***

Table	TREATMENT
rep.	8
d.f.	28
l.s.d.	0.1095

***** Stratum standard errors and coefficients of variation *****

Variate: Zinc

d.f.	s.e.	cv%
28	0.1069	132.6