UNIVERSITY OF GHANA

THE IMPACT OF SEPTIC TANK EFFLUENT ON UNDERGROUND WATER QUALITY OF SOME COMMUNITIES IN THE GA WEST DISTRICT, GHANA

BY

FRIMPONG BRIGHT

(10395904)

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DECLARATION

I testify that this research work was carried out entirely by me in the Environmental Science Programme, Faculty of Science, University of Ghana. This thesis has never been presented, either in parts or in whole, for the award of a degree in this university or any other institution. All cited works and assistance have been fully acknowledged.

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FRIMPONG BRIGHT   DATE

(STUDENT)

………………………………..   ……………………………….

PROF. F. K. NYAME   DATE
(PRINCIPAL SUPERVISOR)

………………………………..   ………………………………..

DR. OPOKU PABI   DATE

(CO-SUPERVISOR)

ABSTRACT

Investigations were conducted to assess the quality of borehole water and wells in relation to distance from septic tanks in residential households in Ga West District, Ghana. The geographical locations of the boreholes, hand dug wells and the nearest septic tanks were determined using global positioning satellite (GPS). Water quality analyses of some physico-chemical and bacteriological variables were carried out on water samples collected from boreholes and wells using processes outlined in the standard methods for the examination of water and wastewater and the examination of water for pollution control (WHO). Water sampled from boreholes showed the following variations in physico-chemical and bacteriological paramaters with distance from their nearest septic tanks over a three month period; conductivity; 2035-2830µS/cm (0-15m), 2500-3872µS/cm (16-30m), 870-1020µS/cm (>30m); Cl^-; 315-345mg/l (0-15m), 460.5-520mg/l (16-30m), 63.7-95.1mg/l (>30m); NO_3-N; 6.9-23.4mg/l (0-15m), 13.4-25.6mg/l (16-30), 5.1-7.3mg/l (>30m); FC;40-80cfu/100ml (0-15m), 0-20cfu/100ml (16-30m), 0-10cfu (>30m).The results of the hand-dug wells include: conductivity; 3125-6243µS/cm (0-15m), 1050-4568 µS/cm (16-30m), 428-965µS/cm (>30m); Cl^-;193.8-1401.5mg/l (0-15m), 665.7-1235mg/l (16-30m), 95.1-72.6mg/l (>30m); NO_3-N; 6.9-13mg/l (0-15m), 13.4-25.6mg/l (16-30), 4.6-7.6mg/l (>30m); FC; 30-210cfu/100ml (0-15m), 20-120cfu/100ml (16-30m), 0-10cfu/100ml (>30m)

The study revealed that, the concentrations of the physico-chemical and bacteriological parameters such as conductivity, total dissolved solids, sulphate, nitrate, phosphate, chloride, faecal coliform and total coliform in water samples at distances between 0-30m from the nearest septic tank for both boreholes and wells exceeded the WHO permissible limit for drinking water and other domestic needs as compared to the concentrations in the water samples at control distances (>30m). Sodium, potassium, total suspended solids, nitrite and ammonia concentrations were below the WHO guideline permissible limit. The high faecal coliform and total coliform and detection of *Escherichia-coli* in most sampled water is an indication of possible influence by septic sewage from the septic tank close to them. The views of the respondents on relevant issues of water and sanitation in the District were also sought through the administration of questionnaire. The social survey revealed that about 64% of the respondents were not aware of the possible impacts of their septic tank sewage system in relation to distance to their water source. Besides, all the wells and boreholes sampled had a septic tank within the distance 11 to 41m close to them. This study accentuates the need for the district assembly to set standards for the sitting of wells and boreholes from septic tanks considering all possible sources of contamination. Owners of the wells and boreholes should also treat the ground water before use.

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CHAPTER ONE

GENERAL INTRODUCTION

1.1 Background

One of the most significant determinants of the quality of life is water. Water is indeed essential for life, yet millions of people around the world face water problem. Potable water is indeed an essential ingredient for good health and the socio-economic development of man ((Annan, 2005)

As population grows and urbanization increases, more water is required and greater demand is made on ground and surface water.Ground water has an excellent microbiological and physico-chemical quality; however there are several anthropogenic activities that can pollute groundwater resources. Groundwater pollution has been attributed to the process of industrialization and urbanization that has progressively developed over time without any regard for environmental consequences which eventually results in the deterioration of physical, chemical and biological properties of water (Isikwe *et al*, 2011).

The word septic comes from the Greek ‘septikos’ which means to make ‘putrid or causing putrification. This involves the decomposition of organic matter resulting in the formation of foul smelling products. Septic tanks are designed to collect human wastewater, settle out the solids and anaerobically digest them leaching the effluent into the ground (Uduom *et al*, 2002).

One significant challenge in groundwater use in urban environment is the generation of high volume of waste and high densities of septic tanks serviced by soakage pit drainage whose leachate may serve as potential contaminant to aquifers. Septic tanks are very often not properly designed or sometimes sited too close to source of water supply therefore increasing the probability of a direct connection between the septic system and the water supply (USEPA, 2009).

About 10-20% of septic system fails annually and many people do not realize the potential for septic tanks to contribute to groundwater contamination and the epidemiological effect that may be caused by this process. The failure of septic tank systems can increase the risk of contaminants entering the drinking water source. Faecal coliforms, nitrate, phosphate, sulphates, chlorides, sodium, and other indicators of septic plumes are responsible for such diseases such as shigellosis, typhoid fever, gastroenteritis, diarrhea, infant cyanosis among others (NRC, 1998).

The rate of urbanization in the Ga West District of the Greater Accra Region is alarming and hence putting much pressure on water resources leading to acute shortages (GWDA, 2012). In response to the incessantly acute shortage and erratic water supply experienced in the district, many households resort to privately constructed shallow boreholes and hand dug wells located within the confines of their homes or nearby areas to access water for domestic use. Unfortunately, however, these homes also tend to host septic tanks and drainage that channel various forms of human and waste water directly into the ground. Such discharges therefore have the potential to directly and rapidly contaminate local groundwater sources without much time for natural attenuation by soils and rocks. The study area has a population of approximately 217,091(GSS, 2010), out of this, the total number of people in the municipality at present with safe water supply is 50,750 representing 20.8%.This translates that 79.2% are without access to good drinking water. The 79.2% either use borehole and hand dug wells as drinking water source and domestic water needs or at best buy water from sachet water producers and water tankers (GWDA, 2012).

Over the past several decades, researches repeatedly have shown that septic tanks contribute significantly to degraded groundwater quality in shallow aquifers in urban areas. It is generally accepted that the health of a community depends on the adequate supply of wholesome water. Ignorance of the parameters that determine the wholesomeness of water for human consumption implies that consumers may be exposed to a variety of water borne diseases, in some cases unknowingly, because water is a principal vehicle for transmitting diseases. Indeed, improvement in hygiene and sanitation are contingent upon the availability of good water quality.

The World Health Organization (WHO) has since 1993 set quality guidelines for drinking water and recommended that contaminants of every drinking water should fall within acceptable limit set by it. To safeguard the health of people and to reduce to the barest minimum the consumption of low quality water, it is necessary that the quality of water should be monitored with the view to finding solutions to health problems associated with its use.

The need to determine if septic tanks are a source of contamination to local water supply is therefore very important to the hundreds of thousands of inhabitants in the study area that use groundwater as drinking water source and other domestic needs and septic tanks as onsite sewage disposal within the confines of their homes.

This research work is therefore conceived to investigate the presence or otherwise the concentrations of some physical, chemical and bacteriological parameters in hand dug wells and boreholes in relation to distance to septic tanks sampled from three communities in Ga West Municipality. This will help to ascertain whether they are within the acceptable standard for human consumption set by WHO and or recommend appropriate measures accordingly.

1.2 Problem statement and Justification

Ghana has its fair share of problems from the water sector and in order to achieve the Millennium Development Goals(MDG) targets (2004–2015), data collected by Community Water and Sanitation Agency (CWSA) and Ghana Water Company Limited (GWCL) as part of their strategic investment plans estimate that, every year an average of 596,000 people need to gain access to an improved water supply.

In an effort to provide safe drinking water to the rural and urban dwellers, the government of Ghana in conjunction with development partners, Non Governmental Organization (NGO’s), Community Based Organization (CBO’s) and some individuals have exploited the groundwater reserves since groundwater is perceived to be cleaner and therefore do not need further chemical treatment before consumption. However, several activities such as fertilizer application, agro-chemicals, abandoned or inactive mine site, soak-away septic tanks, landfills, among others are possible natural and anthropogenic contaminants sources that often compromise the quality of water. Septic systems are a significant source of ground water contamination leading to waterborne disease outbreaks and other adverse health effects. In 2012 for instance, the Municipal Health Directorate reported that, out patient records from the municipal hospital indicated a total of 1,349 typhoid fever, 4,964 diarrhea, 63 cases of bilharzia (GWMHD, 2012). About 75% of the population in the study area use septic tanks as onsite sewage treatment system and the most assessed source of water in the municipality is ground water in a form of borehole or hand dug wells. (GWDA, 2012).

In the Ga West District of Ghana, inadequate supply of pipe borne water is a major concern and factors that have contributed to this include, rapid population growth and urbanization, rapid spatial development, increase in residential dwelling among others. This therefore put much pressure on utilities including water resources leading to acute shortages. As a result, many households resort to privately constructed shallow boreholes and hand dug wells close to areas where they reside or located within the confines of their homes for their sources of water. Unfortunately, however, these homes also tend to host septic tanks as drainage system that channel various forms of human and waste water directly into the ground. The major drawback of these sources of water supply relative to conventional water supply is that while tap water is readily subjected to routine evaluation of key water parameters to determine suitability before pumping into circulation, ground water is not.

There are several factors that can influence the potential of septic tank to contaminate ground water resources. These include: distance of the septic tank to the water source, septic tank density, topography or slope of the land, soil characteristics or hydraulic conductivity, depth of the well/ borehole among others. Some studies have been done to assess the quality of groundwater in urban and peri-urban communities (Nkansah et al., 2010; Osiakwan, 2002). However, not much has been done to investigate or assess groundwater quality in relation to localized or point sources of pollution such as septic tanks that are constructed near boreholes or wells that serve as major sources of water for many domestic activities including drinking in peri-urban areas. This current situation makes distance a very important factor to investigate in order to better understand the current state of the concentrations of the contaminants of the water source and subsequently assist in the future management of the water resources to improve public health.

The World Health Organization (WHO) recommends that boreholes should be located at least 30m from septic tanks (Chukwurch, 2001). Septic tank effluent typically contains elevated concentrations of chloride, sulphate, nitrate, faecal coliforms and total organic carbon (Canter and Knox, 1985).

1.3 Objectives of the Study

1.3.1 *Broad Objective*

The aim of the study is to contribute to the improvement, sustainable utilization and consumption of wholesome water and subsequently improve public health in Ga west District of Ghana.

1.3.2 *Specific objectives*

The specific objectives of the study include the following:

- Ascertain the ground water quality in relation to distance from soak –away septic tank.

- To determine the levels of some physico-chemical and microbiological parameters present and compare them with World Health Organization (WHO) water guideline standard.
- To identify any anthropogenic activities which may serve as potential contaminants to the ground water quality.
- Assessment of knowledge and perception of the studied communities on the impacts of septic tanks on ground water quality.

1.4 Hypothesis of the study

- Null hypothesis (Ho): There is no significant impact of septic tank effluent in relation to distance on ground water quality in the study zones.
- Alternative hypothesis (H_1): There is significant impact of septic tank effluent in relation to distance on ground water quality in the study zones.

1.5 Significance of Research

The research is necessary to provide adequate data and information on the level of physico-chemical and microbiological properties of ground water in relation to distance to septic tanks sampled in some communities in Ga West District which serves as the major source of available water for drinking and other domestic purposes. The study will help ascertain the quality of hand dug wells and borehole water supply sources consumed in the study area.

The findings of this research will provide additional guidelines regarding the need to continuously monitor ground water quality within the district. The study will also assist in the development and implementation of appropriate guideline to help in the effective design, siting and management of septic tanks in Ghana.

CHAPTER TWO

ORGANIZATION OF LITERATURE

2.1 Introduction

Globally, 1.1 billion people rely on unsafe drinking water sources from lakes, rivers and open wells. The majority of these are domiciled in Asia (20%) and sub-Saharan Africa (42%). Furthermore, 2.4 billion people lack adequate sanitation worldwide (WHO/UNICEF, 2000).

In developing countries, thousands of children under five years die every day due to the consumption of contaminated water. Lack of safe drinking water supply, basic sanitation and hygienic practices is associated with high morbidity and mortality from excreta related diseases (WHO, 2004).

Considerable amount of work has been reported on the impacts of septic disposal systems such as septic tanks and pit latrine. The most common and wide spread threat associated with water is contamination which is either directly or indirectly by sewage and other wastes from human or animal excrement. If such contamination is recent, and if among the contributors, there are carriers of communicable enteric diseases, some of the living casual agents may be present. The consumption of the contaminated water or its use in the preparation of certain foods may result in infection.

World Health Organization study group defined sanitation as “the means of collecting and disposing of excreta and liquid wastes in a hygienic way so as not to endanger the health of individuals and the community as a whole” (WHO,1993). Hygienic disposal of human wastes that does not endanger health should be the underlying objective of all sanitation programmes (Pickford *et al*, 1992).

In an attempt to dispose of human excreta, on-site and off-site sanitation systems have been recognized. The on-plot sanitation systems dispose off human excreta with or without treatment on the residents' housing plot. These may include pit latrines and septic tanks with drainage fields and the off-site systems move the excreta off the plot for treatment and disposal. The former is commonly considered an appropriate option for sanitation in developing countries, even in densely populated urban areas. On-plot sanitation systems will remain a popular form of low-cost sanitation for the foreseeable future, as conventional off-site options are usually much more expensive.

On-plot sanitation systems even though proved to be cost effective naturally raise a significant concern about the pollution of groundwater. Research over the years has shown that bacteria can be transported some distance through the ground by liquid leachate from a pit latrine or septic tank, and could thus contaminate local drinking water supplies drawn from groundwater.

2.2 How water gets into the ground

Whenever it rains, some of the water flows on the land surface into rivers, lakes and streams, some evaporates into the atmosphere whiles a majority seeps into the ground like a glass of water poured on a pile of sand (Clark *et al*, 1993). The water that eventually get into the soil is utilized by plant and soil organism whiles the water not used moves deeper into spaces in the ground. This water then moves downwards through cracks in the soil and fractures in rocks until it is intercepted by an impermeable layer of clay or rock. The water then accumulates on this layer filling up all available spaces until saturation. The top of the impermeable layer become the water table whiles the accumulated water becomes the ground water.

2.3 History of Borehole and well construction in Ghana

Groundwater development in Ghana can be traced from the 19th Century where communities entirely depended on hand dug wells for their potable source of water supply. The colonial administration from 1920-1945 initiated a national hand dug well program under the patronage of Rural Water Division a wing of the Gold Coast Survey Department (Osiakwan, 2002). The construction of boreholes in Ghana began in the 1940's. This was to increase the water supply to rural and urban communities. Since then it is believed that thousands of hand-dug wells and boreholes have been constructed both by local and foreign donors. The Ghana Water Company Limited by the year 2000 had constructed 25,000 boreholes all over the country. Through the help of the German government, another 3,000 boreholes have been drilled in southern Ghana between 1978 and 1983 (Issah, 2000). The World Vision International (WVI) between 1985 to June 2000 had drilled 1,523 boreholes throughout the country (WVI, 2000). The government of Ghana through collaboration with bodies like Community Water and Sanitation Agency, Catholic Relief Agency, World Vision International and many other NGO's currently drill hundreds of boreholes annually throughout the country. This has made boreholes and well water indispensable in most Ghanaian communities.

2.4 Borehole/Well contamination process

Ground water users would have gotten water all year round if the water level in the aquifers that supplied their wells and boreholes always remain the same. Unfortunately, seasonal variations in rainfall and occasional drought can affect the volume of the ground water. If the rate at which well water is pumped is faster than the rate at which the aquifer is recharged then the level of the groundwater can be lowered (Roger, 1982). Underground water can also be lowered if other bore holes or wells near it draw more water than the aquifer is recharged.

The term groundwater is usually reserved for the subsurface water that occurs beneath the water table in soils and geologic formation that are fully saturated (Chanda, 1999). Ground water plays a vital role in the development of arid and semi-arid zones. It is believed to be clean and free from pollution than surface water. However, it is susceptible to pollution and once polluted restoration is difficult and long term measures are needed. Ground water may contain some natural impurities or contaminants, even without human activity or disturbance. Natural contaminants can come from many conditions in the watershed or in the ground. Water moving through underground rocks and soils may attack geological materials and pick up magnesium, calcium and chlorides among others. Some ground water naturally contains dissolved elements such as arsenic, boron, selenium or radon, a gas formed by the natural breakdown of radioactive uranium in soil. These natural contaminants have significant health implications and may become a health hazard when they are present in high concentrations. Ground water may also be polluted by anthropogenic activities including improper use of fertilizers, animal manure, herbicides, insecticides and pesticides. (Arya *et al*, 2012).

Poorly built septic tanks and sewage systems for household wastewater, leaking or abandoned underground storage tanks, piping storm-waters, drains that discharge chemicals to ground water and improper disposal or storage of waste chemical spills at local industrial sites all contribute to the pollution of ground water.

2.5 Basic Groundwater Hydrology

Soil can dispose of water and human wastes very effectively and organic material for plants and other organisms can be effectively attenuated before reaching the saturated zones beneath the water table. The original parent material of soil is the solid rock from the Earth's outer skin weathered and eroded by wind. Soil depths and composition are therefore variable and may be directly related or bear no relation to the underlying weathered rocks. Most water in the soil comes from rainfall. Water seeps through the pore space by gravity and surface tension and its pathways are smoothed by a thin film of hygroscopic water on each of the soil particles. The hygroscopic moisture is held tightly by electrostatic forces and is not readily moved by other forces, including plant roots (Shaw, 1994). These forces are measured as the moisture potential or soil tension. The soil is saturated when the moisture tension is equal to zero. In the unsaturated, or aeration zone, the voids in the soil are filled with varying amounts of air and water vapour. The aeration zone is a complex mixture of solid particles, liquids and gases.

The area below the aeration zone lies the saturated capillary zone, a layer of saturated soil where all the pore space is occupied by water. In this zone, the water is at less than atmospheric pressure and is held by capillary forces between soil particles. The water table is defined as the surface over which the pressure equals atmospheric pressure. In the saturated or groundwater zone below the water table, the water pressure exceeds atmospheric pressure. The extent of the capillary zone depends on the composition of the soil and the packing of the soil particles, and can range from a few centimeters in a coarse sandy soil to a few metres in a clay soil.

2.6 The Risk that Septic Tanks Pose to Water Quality

On-site systems such as septic tanks are widely used in urban areas for the disposal of sewage and domestic waste (Dudley and May, 2007). This has implications for water quality as such systems are inevitably not well maintained and less regulated than large treatment plants, whilst they are also often located near relatively undisturbed, clean and environmentally sensitive watercourses.

Arnade (1999) conducted a study on the seasonal correlation of hand dug wells contamination and septic tank distances in Palm Bay, Florida to determine if season has a significant effect on the correlation between these parameters and the proximity of wells to septic tanks. The results revealed that ground water samples collected at all distances from septic tank during the rainy season contained twice as many as faecal coliforms and higher concentrations of nitrates, phosphates and chlorides compared to samples collected during the dry season. The results show a statistically significant correlation between increasing faecal coliform, nitrate, phosphate and chloride concentration and decreasing distance between wells and septic tanks.

Valenzuela *et al*. (2009) suggested that the most important factors affecting well vulnerability to bacterial contamination were those related to the well itself, construction and site management whilst its usage and maintenance is also crucial. However the concentration of microbiological contamination indicators organism observed in groundwater are a function of the contamination source active at that moment.

Adetunji *et al*. (2011) conducted a study on the impact of septic tank distances to wells in Agbowo community in Nigeria. Forty (40) wells were assessed for total aerobic bacteria counts (TABC) and total coliforms counts (TCC). The results indicated that all the wells sampled had high TABC and TCC which exceeded the international standard of 0 per 100ml of portable water. The TABC increased with a decrease in distance between the wells and the septic tanks though not significant ($P<0.05$). Verstraeten *et al*. (2005) used several tracers including nitrogen and boron isotopes and observed that sand point domestic wells within 30 m of a septic system and less than 14 m deep in a shallow aquifer were the most vulnerable to contamination from septic effluent.

The issue of septic tank pollution needs to be addressed in order to maintain healthy ecosystems, protect public health and to meet legal requirements (Dudley and May, 2007). Septic tank leachate has the potential to inhibit watercourses meeting a 'good' environmental status by 2015 as defined by the Water Framework Directive (EU, 2000). Aside septic tanks, other factors such as the environment where the well is sited, the level of hygiene of the well in terms of the use of receptacles for withdrawing the water and the population of people the well serves as well as its surroundings could be considered as other possible sources of contamination.

2.7 Domestic sources of ground water contamination

A major cause of ground water contamination is effluent (outflow) from septic tanks and cesspools. Misuse of these systems for disposal of anything other than domestic or sanitary waste can pose a substantial threat to ground water. Residential wastewater systems can be a source of many categories of contaminants including bacteria, viruses and nitrates from human waste and organic compounds (Harman et al, 1996). Injection wells used for domestic wastewater disposal (septic systems, cesspool drainage wells for storm water runoff, ground water recharge wells) are of particular concern to ground water quality if located close to and up gradient of drinking water wells. Improper storing or disposal of household chemicals such as paints, synthetic detergents, solvents, oils, medicines, disinfectants, pool chemicals, pesticides, batteries, gasoline and diesel fuel can lead to ground water contamination when stored in garages or basements with floor drains, spills and flooding may introduce such contaminants into the ground. Similarly, waste dumped or buried in the ground can contaminate the soil and leach into the ground (Mainstone *et al*, 2002)

As urban areas grow, there is an increase in rain water runoff caused by the additions of paved surfaces. Some municipalities use storm water drainage wells to dispose off this additional runoff particularly if the area is not served by storm sewers. Storm water drainage wells that communities use to control water during storm events pose a threat to ground water particularly areas with a high water table. Fertilizers, herbicides, insecticides, fungicides and pesticides applied to the lawn and garden contain hazardous chemicals that can travel through the soil and contaminate the ground water (Manivaskam, 2005). In the garage, items that are improperly used, stored or disposed off may potentially contaminate ground water especially if there is a drain to the ground in the floor of the garage. Sources include batteries that contain lead, cadmium or mercury. Paints containing lead and barium, gasoline and oils containing compounds, barium from diesel fuel combustion (Morgenstern, 2005)

Water used in the home and entering a septic system or sewer system may contain detergents from dishwashing and laundry, organic compounds from garbage, disposal bacteria, nitrates, and sulphate from sewage, greases and oils. Cleaning agents, aerosol sprays, coolants and solvent are potential sources of pollution.

2.8 Water, Sanitation and Health in Developing Countries

The availability of water in adequate quantity and quality is imperative for sustainable development. Worldwide, significant imbalance exists with regards to sustainable development particularly from a water and sanitation perspective. Water is a critical component of public health, and failure to supply safe water will place a heavy burden on the entire population. Although the 21stcentury has witnessed wealth and advanced development, it has not been realized everywhere. Billions of people are still striving to access the most basic human needs which are food, shelter, safe drinking water and adequate sanitation.

Waterborne diseases have a great burden on both public health and economy. Globally, 4 billion cases of diarrhea occur annually out of which around 2 million people die. In developing countries, nearly 80% of all diseases are linked to water and sanitation. Children bear the greatest health burden related to poor water and sanitation.

According to the World Health Organization, 47 percent of the world's population will be living in areas of high water stress by 2030 representing two-thirds of the world's population. Approximately 5.5 billion people will also live in areas facing moderate to severe water stress by the year 2025. 884 million people still rely on drinking water from unimproved sources such as ponds, streams, irrigation canals and unprotected dug wells. The WHO also reported that one in eight people worldwide lack safe water and less than 20% of the world's drainage basins exhibit nearly pristine water quality. Eighty-four percent(84%) of the world population without an improved drinking water source lives in rural areas and l.2 million tons of human wastes are disposed of in water courses every day (WHO, 2008).

The WHO report on sanitation confirms that**,** 2.6 billion population in the world do not have access to adequate sanitation and this is nearly two fifths of the world's population and 1.2 billion people representing 18 percent of the world's population defecate in the open. Sanitation coverage in developing countries represent (49%) which is only half that of the developed world (98%), two in five people do not have the security and dignity of a hygienic latrine or toilet, 64% of the people who gained access to improved sanitation during the period 1990-2008 live in urban areas and More than 80% of sewage in developing countries is discharged untreated in rivers, lakes and coastal areas (WHO, 2008).

Approximately 1.8 million people die every year from diarrhea diseases of which 90% are children under age 5, predominantly in developing countries. Nearly half the people in the developing world are suffering from one or more of the main diseases associated with dirty water and inadequate sanitation such as diarrhea, guinea worm, trachoma and schistosomiasis. Diarrhea kills more young children than AIDS, malaria, and measles combined (WHO, 2008).

About 10% of the total burden of disease worldwide is attributable to unsafe water, sanitation, and hygiene whilst approximately 443 million school days each year are missed due to water-related illnesses. Furthermore; there is inadequate progress in sanitation services and wastewater treatment. Access to sanitation services is disproportionate in the developing countries whereby services in some countries do not adequately reach the poor and the rural areas. The estimates of the World Health Organization (WHO) and the Water Supply and Sanitation Collaborative Council indicate that 25 percent of the developing country urban dwellers lack access to sanitation services with a much higher percentage for the rural populations of developing countries reaching up to 82 percent (Clark *et al*, 1995). Thus, in order to achieve the Millennium Development Goals (MDGs) there is a need to approximately double the sanitation investments (UN, 2009).

2.9 Factors promoting water pollution from septic tank systems

The risk that a septic tank poses to nearby water courses will depend on a number of factors related to the environment, the construction and maintenance of the system. Understanding these factors is essential to allow new systems to be constructed in a manner that will reduce their pollution risk, whilst also allowing management to be concentrated in vulnerable areas. These factors include the following: Distance to surface and ground water, soil type, maintenance of the system, the system age, septic tank density, slope or topography of the land and the depth of the underground water (Morgenstern, 2005).

2.9.1 *Distance to surface water and ground water.*

Septic tanks in close proximity to underground water channels, ditches and watercourses pose a greater risk than those further away (May *et al*, 2010), although there is controversy in literature surrounding minimum setback distances because a variety of other factors will influence the potential of the septic tank to pollute the watercourse. Canter and Knox (1985) suggest a minimum distance of 30m from open watercourses is suitable, a study in Ireland also concluded that systems should not be constructed within 400m of any surface watercourse (Clark *et al*, 1995). The World Health Organization recommends that boreholes should be located at least 30m away from septic tanks (Chukwurch, 2001). Different approach was applied by Kinsley and Joy (2005) who assigned any system within the one-hundred year floodplain boundary as high risk, and any system outside it as no risk. The risk of flood water inundation washing sewage into the watercourse was also recognized by Canter and Knox (1985). They propose that systems should not be located in areas liable to seasonal flooding.

2.9.2 *Soil Type*

Septic tank systems rely on the surrounding soil to filter and attenuate pollutants (Morgenstern, 2005). Soil is therefore the last line of defense between the sewage discharge and watercourse (May *et al*, 2010). Therefore, it is important that systems are located on suitable soil types. Ideally, systems should be located on well drained sandy loams, with good infiltration. Furthermore, they should be at least 90cm above the highest water table level to prevent surface break-out (Canter and Knox, 1985). Various techniques have been employed to rank the risk associated with soil types, with Kinsley and Joy (2005) estimating hydraulic conductivity from superficial geology maps while May *et al*.(2010) used the hydrology of soil types dataset in the UK.

2.9.3 *Maintenance*

In contrast to mainstream sewage treatment works, the maintenance and operation of septic tanks is unregulated and left to the discretion of the landowner, although it is recommended they are ‘de-sludged’ every 1 – 2 years (May *et al*, 2010). However, tanks are often not emptied and ‘de-sludged’ regularly, which is known to be a key determining factor on surrounding water quality. There is strong evidence to suggest that the problem of malfunctioning septic tank systems is widespread. A US census data estimated that over 10% of septic tanks had either backed up into homes or lead to sewage emerging at the ground surface (Morgenstern, 2005).

2.9.4 *System Age*

Although the basic design of septic tank systems has changed very little since Victorian times, construction techniques and materials have improved in recent years, moving from brick chambers to fibre-glass units (May *et al*, 2010). Older systems are much more susceptible to failure. Morgenstern (2005) suggested that systems more than 20 years old pose a high risk. This is broadly in agreement with Kinsley and Joy (2005) who suggest the average operating life of a septic tank system is 25 years. These facts could prove significant as it is estimated that approximately half of the septic tank systems in the USA were constructed over 30 years ago and have been found to impact significantly on underground water quality (Morgenstern, 2005).

2.9.5 *Slope/Topography*

Slope is a major control on hydrology as it affects percolation and through flow rates and pathways. Most domestic wells are intentionally located up gradient from the household septic tank, and at a specified minimum distance or depth to minimize potential groundwater-quality problems. Canter and Knox (1985) suggest that septic systems should not be constructed on slopes with a gradient greater than 20%, and preferably not greater than 5%. It is also noted that larger drainage fields will be required on steeper slopes and it is suggested that systems should not be located at the base of slopes.

2.9.6 *Septic Tank Density*

A high density of septic tanks will exceed the capacity of the surroundings to absorb pollution effectively, increasing the risk of watercourse pollution. Canter and Knox (1985) recommend a maximum density of one septic tank per ha of land. Rather than septic tank density, some research work use population density as an indicator of pollution load to assess the risk of watercourse contamination. Kinsley and Joy, (2005) observed that areas where there is a low density of households on septic tank systems, ground water contamination from septic leachate would be difficult to detect, as plumes from septic tanks tend to be highly variable in length and shape related to differences in groundwater velocity, aquifer lithology and mineralogy and redox conditions. Tinker (1991); Robertson *et al*. (1998) observed that for seven septic-tank systems studied in Minnesota, the average plume length was 25 m, but ranged from 10 to more than 100 m depending on the chemical constituent evaluated. Plumes from small septic systems tend to be narrow (10–20 m) and shallow in sand aquifers (Robertson *et al*, 1991).

2.9.7 *The Depth of a well*

It is generally believed that the deeper you sink a borehole the better the water quality, but this is true to some extent however various research work have disputed this believe. Eni *et al.* (2013) conducted a study on the influence of aquifer depth on microbial parameters of borehole water in Calabar Metropolis, Nigeria. The results indicated that the deepest depth of 50m still showed a value of 6cfu/100ml and 4cfu/100ml for faecal coliforms and total coliforms in the dry season. Efe (2008) stated that the longer the polluted water travels through the soil formation the better (cleaner) it becomes. Iserman (1977) and Essien (1996) stated that shallow wells close to sites that are contaminated will invariably be contaminated with the contaminating substances if they are less than 15m deep. Onwuka *et al.* (2004) evaluated eighty samples in Enugu Southeastern Nigeria, for bacteriological quality, the results showed evidence of sewage contamination. The work recommended improved ways of managing domestic wastes like the use of central sewer system. Agbede and Akpen (2008) in their study on the bacteriological and physico-chemical qualities of ground water in Makurdi metropolis in

Nigeria floodplains found that all the ten wells studied were polluted with faecal bacteria; while the wells outside the floodplain were polluted with non-faecal bacteria

2.10 Infectious Diseases Transmission through Groundwater.

Microbial contamination of water is a major problem for human health, and has led to some major waterborne disease outbreaks. Both drinking and recreational water can be highly susceptible to microbial contaminants, with pathogens frequently observed in surface and groundwater (Nwachukwu, 2006)

Zoonotic pathogens can be transmitted between animals and humans or transmission from livestock to humans and potentially wildlife are of increasing concern. Almost three-quarters of the emerging infectious diseases are zoonotic. In recent decades, infectious pathogens from wild animals are becoming more problematic throughout the world. This not only impacts human health, but also agricultural production, wildlife based economies, and wildlife conservation. In the United States, *Giardia*, *Campylobacter*, *Cryptosporidium*, *Salmonella*, and *Escherichia coli* have been the most commonly identified zoonotic agents of waterborne disease outbreaks (Craun, 2004).

2.10.1 Exposure to Pathogenic Microorganisms

Recent outbreaks of *E.coli* O157:H7, *Campylobacter,* and *Cryptosporidium* have the risk of contaminated water supplies(Lee *et al*, 2002). In Milwaukee, Wisconsin, approximately 400,000 gastroenteritis cases were linked to the city's drinking water source, where the etiologic agent was *Cryptosporidium parvum* (Mackenzie *et al,* 1994). In Walkerton, Canada in 2000, waterborne *E. coli* O157:H7 and *Campylobactor jejuni* caused more than 2,000 gastrointestinal disease cases, with seven deaths (Tebbut, 1983).

An outbreak of *E. coli* 0157:H7 occurred among attendees at the Washington country in Fair, New York, USA and was known to be caused by drinking water from contaminated shallow well that had no chlorination (Lee *et al*, 2002). This outbreak resulted in the hospitalization of approximately 65 people and 11 children developed haemolytic syndrome whilst two people died.

In 1974 an outbreak of acute gastrointestinal illness at Richmond Heights in Florida, USA was traced to a hand dug well that was contaminated with sewage from a nearby septic tank (Weissman *et al*, 1976). The outbreak recorded approximately 1200 cases from a population of 6500 and the main pathogenic agent was linked to *Shigella sonnei*.

Pokhel and Viraraghavan (2004) in a review of diarrhea disease in Nepal in relation to water and sanitation cited areas in South Asia where contamination of groundwater supplies has lead to disease outbreak. A study of local populations in Kanpur, India recorded an overall incidence of water borne diseases of which 80 per 1000 population were affected (Mackenzie *et al,* 1994). The communities in the study areas took water from shallow ground water sources. The analysis of the results revealed that 70 percent of the wells were contaminated with faecal contaminants. The greatest proportion of the water borne disease investigated was found to be gastroenteritis and dysentery.

Water plays essential roles in supporting human life. In the developed world, water related diseases are rare, due essentially to the presence of efficient water supply and waste water disposal systems (Nwachukwu, 2006). However, in the developing world perhaps a lot of people are without safe water supply and adequate sanitation (Tebbut, 1983). As a result, the toll of water-related diseases in these areas is frightening. There is also limited data on groundwater related outbreaks making it very difficult for local health surveillance systems to identify the causal factors. Tebbut (1983) observed that in developing countries, the use of poorly protected groundwater sources has been linked to acute diarrhea disease.

2.11 Indicators of contaminated wells/boreholes

2.11.1 *Nitrates*

Nitrate is a chemical compound of one part nitrogen and three parts oxygen that is designated by the symbol "NO_3^-". It is the most common form of nitrogen found in water. In water, nitrate has no taste or smell and can only be detected through a chemical test. The Maximum Acceptable Concentration (MAC) for nitrate in drinking water according to WHO drinking-water quality, set up in 1993 is 50 mg/l of total nitrogen. For laboratory tests reported as nitrate-nitrogen (NO_3^- -N), the permissible amount of nitrogen present in nitrate is 10 mg/l.

There are many sources of nitrogen (both natural and anthropogenic) that could potentially lead to the pollution of the groundwater with nitrates; the anthropogenic sources are really the ones that most often cause the nitrate to rise to a dangerous level. Waste materials are one of the anthropogenic sources of nitrate contamination of groundwater. Many local sources of potential nitrate contamination of groundwater exist such as sites used for disposal of human and animal sewage, industrial wastes related to food processing, munitions, and some polyresin facilities and sites where handling and accidental spills of nitrogenous materials may accumulate (Iserman, 1977). Septic tanks are also another significant contributor of anthropogenic source nitrogen. Groundwater contamination is usually related to the density of septic systems. In densely populated areas, septic systems can represent a major local source of nitrate to the groundwater.

However in less populated areas septic systems don't really pose much of a threat to groundwater contamination.

❖ *Nitrate in groundwater system*

According Wakida (2008) the rapid growth of urban population in developing countries leads to unplanned settlements where limited pit latrines or septic tanks are the only options available for sewage disposal. Urban sources of nitrate-N may have a high impact on groundwater quality because of the high concentration of potential sources in a smaller area than agricultural land (Wakida, 2008). The mobility of N with respect to groundwater is related to chemical properties that affect the ease of transport with water and adsorption to soil particles. Nitrate (NO_3) is the most mobile form of N because of its high solubility and negative charge (Baird, 1999)

Ammonia is produced by the breakdown of organic sources of nitrogen; being a major constituent of proteins and nucleic acids. Municipal wastewaters contain large amounts of organic wastes, so the wastewater will have a high ammonia concentration. Ammonia is toxic to aquatic life at high concentrations, and the nitrification process requires oxygen (ammonia contributes to the BOD of the wastewater) so it will use up the oxygen needed by other organisms (Baird).

The rates of nitrification reaction are highly dependent on a number of environmental factors. These include the substrate and oxygen concentration, temperature, pH, and the presence of toxic or inhibiting substances (Comly, 1987). One striking aspect of environmental nitrogen chemistry is the coexistence of reduced compounds (ammonia N oxidation state = -3) and fully oxidized species (e.g., nitrate N oxidation state =+5). This results from chemical and biochemical processing that occurs in both aerobic and anaerobic environments.

Bacteria play an important role as catalysts in almost all nitrogen transformations in nature. The two important overall reactions are denitrification and nitrification. Denitrification stimulates the reduction of nitrate to N_2 (g) by bacteria, through a complicated pathway involving intermediates like nitrite. It should be noted that denitrification is not a reversible reaction. During nitrification, bacteria oxidize amines from organic matter to nitrite and nitrate (Baird, 1999)

- *The environmental health concerns of nitrate*

Though nitrate is considered relatively non-toxic, a high nitrate concentration in drinking water is an environmental health concern because it can harm infants by reducing the ability of blood to transport oxygen. In babies, especially those under six months old, methemoglobinaemia, commonly called “blue-baby syndrome,” can result from oxygen deprivation caused by drinking water high in nitrate (Baird, 1999). It can also occur in adults with methemoglobinaemia reductase enzyme defiency. Methemoglobin is probably formed in the intestinal tract of an infant when bacteria convert the nitrate ion to nitrite ion (Comly, 1987). One nitrite molecule then reacts with two molecules of hemoglobin to form methemoglobin. In acid mediums, such as the stomach, the reaction occurs quite rapidly. This altered form of blood protein prevents the blood cells from absorbing oxygen which leads to slow suffocation of the infant which may lead to death (Gustafson, 1993).

Excess nitrate in drinking water has also been linked with stomach cancer although epidemiological investigations have failed to establish any positive link (Baird, 1999). The suspicion arise from the fact that ingested nitrate can be converted to nitrite in the stomach. The nitrite could react with amines in the stomach to produce nitrosamines which are known to produce cancer in animals (Baird, 1999).

Hantzsche and Finnemore (1992) drilled several wells in three different unsewered developments and reported mean nitrate concentrations of 9600 to 13900 ug/L. Concentrations in individual wells ranged from less than 3000 ug/L to 65000 ug/L. Gustafson(1993) sampled several domestic wells in a deep sand and gravel aquifer and found concentrations between 5000 and 11000 ug/L. Harman *et al*. (1996) installed multilevel wells along two hydrologic transects in two separate unsewered subdivisions with lot sizes ranging from 0.5 to 0.7 acres. Concentrations of nitrates ranged from 5000 to 15000 ug/L, with average concentrations of 6000 to 8000 ug/L. Nitrates can be used as a crude indicator of faecal pollution where microbiological data are unavailable.

2.11.2 *Chlorides*

Chloride is one of the major anions found in water and is generally combined with calcium, magnesium or sodium. Since almost all chloride salts are highly soluble in water, the chloride content ranges from 10 to 100 mg/l. Sea water contains over 30,000mg/L as NaCl. Chloride is associated with the corrosion of piping systems. The corrosion rate and the iron dissolved into the water from piping increases as the NaCl content of the water is increased. The suggested maximum contaminant level (SMCL) for chloride is 250mg/l which is due strictly to the objectionable salty taste produced in drinking water (USEPA, 1994). Department of Natural Health and welfare, Canada

(1978) reported that chloride in surface and ground water may result from both natural and anthropogenic sources such as run off containing salts, the use of mineral fertilizers, septic tank effluent, industrial leachate, intensive irrigation drainage and sea water intrusion in areas close to the sea. Chloride is not harmful to humans at low concentrations but its effects depend on the associated cations present in the water such as calcium, sodium, potassium and magnesium. In a research conducted on ground water from open wells in the vicinity of a cement factory at Akporkloe in south eastern Ghana, the amount of chloride ions found in the water samples were between 87.97 and 5142.1 mg/l with a mean of 1348.18 mg/l which was five times higher than the WHO permissible safe limit of 250 mg/l. The higher levels were attributed to the natural geochemistry of the area (Addo *et al*, 2012).

2.11.3 *Sulphates*

Sulphates occur in almost all natural waters. Most sulphate compounds originate from the oxidation of sulphate ores, the presence of the shale and the existence of industrial waste. Sulphate is one of the major nutrients dissolved in rain. As water moves through the soil and rock formations that contain sulphate minerals, some of the sulphate dissolves in the water into the groundwater (Chanda,1999). Minerals that contain sulphate include magnesium sulphate (Epsom salt), sodium sulphate and calcium sulphate (gypsum). A high concentration of sulphate in drinking water causes a laxative effect when combined with calcium and magnesium, the two most common components of water hardness (Chapman,1996). Sulphate levels also exceeding 250mg/l is also known to cause ailments like Catharsis and dehydration. Some reducing bacteria can also attack and reduce sulphates in water producing hydrogen sulphide gas which is an acidic gas that can therefore make groundwater mildly acidic. Sulphate does not have a health-based guideline value, however, the WHO recommends that values higher than 250mg/l should be reported to "the health authorities" due to problems of the gastro-intestinal tract (WHO, 2003). Sulphate ion is precipitated in an acetic acid medium with barium chloride to form barium sulphate.

2.11.4 *Phosphates*

Phosphorus is one of the key elements necessary for the growth of plants and animals. Phosphorus in elemental form is very toxic and is subjected to bioaccumulation. Phosphates exist in three forms thus Orthophosphate, metaphosphates (polyphosphates) and organically bounded phosphate. Each compound contains phosphorus in a different chemical formula. Ortho forms are produced by natural processes and are found in sewage. Poly forms are used for treating boilers and in detergents but in water, they change into ortho forms (Dudley et al, 2007).

Organic phosphates are important in nature. Their occurrence may result from the breakdown of organic pesticides which contains phosphates. They exist in solution as particles, loose fragments or in the bodies of aquatic organisms. Rainfall can cause varying amounts of phosphates to wash from farm soils into nearby waterways. Phosphate stimulates the growth of plankton and aquatic plants which provides food for fishes. Phosphate also leaches into groundwater. It may not be toxic to people or animals unless they are present in very high levels. Digestive problems could occur from extremely high levels of phosphates (USGS, 1970).

Brown (1980) report that most phosphorus goes into the septic tank in organic forms, but that orthophosphate accounts for about 80% of the total phosphorus in the tank effluent.

Phosphate precipitates in the unsaturated zone or is adsorbed in the aquifer close to the drainfield. In old systems, the attenuation capacity within unsaturated zone diminishes and phosphate can reach ground water and move down-gradient in the septic plume. Robertson *et al.*(1998) observed phosphate migration exceeding 10 meters in six of ten plumes investigated. In contrast, Harman (1996) observed phosphate concentrations of less than 1000 ug/L within ten meters of the drainfield for a 44-year old system servicing an elementary school. Movement of phosphate rarely exceeds 5 meters; even in very old systems (Wilhelm *et al*, 1994).

Phosphate may be a concern in poorly buffered systems if the pH within the plume drops below 6. Dudley and May (2007) suggested that septic tanks are a significant and underestimated source of phosphorus pollution to rural UK watercourses. Phosphorus may be present in septic tank systems due to phosphorus-rich human excrement or phosphate based detergents and cleaning products (Pieterse *et al*, 2003), therefore making septic tank leachate a potential nutrient input to freshwater ecosystems. The effects of eutrophication are highly detrimental to water quality and the aquatic ecosystem as it changes the competitive balance between species (Mainstone and Parr, 2002) and because the process is also often severely limiting, the potential uses for the water is affected (Chapman, 1996). Undesirable toxic algal growth often occurs during the growing season, when high water temperatures, abundant light levels and long residence times promoting algal blooms that are of a human health concern (Jarvie *et al*, 2006).

2.12 Some physico-chemical parameters which serve as indicators of water quality.

2.12.1 *Total dissolved solids*

Total dissolved solids is the sum of all the materials dissolved in the water, it has many different mineral sources. Total dissolved solids (TDS) consist of mainly carbonates, bicarbonates, chlorides, sulphates, phosphates, nitrates, calcium, magnesium, sodium, potassium, iron, manganese and a few others. They do not include gases, colloids or sediments. The total dissolved solids can be estimated by measuring the specific conductance of the water.

dissolved solids in natural water range from less than 10mg/l for rain water to more than brine well-125000 and dead sea-250,000. The total dissolved solids can be determined by using an electric probe which also measures temperature and conductivity (APHA, 1998)

2.12.2 *pH*

The pH of a solution is the measure of how acidic or basic that solution is or the concentration of hydrogen ions in a solution. Natural water often have a pH of 4-9 and most are slightly basic as a result of bicarbonate and carbonates of the alkali and alkaline earth metals(Langmuir,1997). The determination of pH involves the activity of hydrogen ions by potentiometric measurement using a standard hydrogen electrode and a reference electrode. The measurement of pH is influenced by temperature in two ways. Mechanical effects caused by changes in the properties of the electrode and chemical effects caused by equilibrium changes. In the former, the nerstian slope increases with increasing temperature and takes a lot of time to attain thermal stability. This can cause a long term drift in the pH. Due to the effect of chemical equilibrium on pH; standard pH buffers have a specific pH at specified temperatures (APHA, 1998).

2.12.3 *Electrical Conductivity*

Conductivity is defined as the ability of a solution to carry electric current. This is normally dependant on the presence of mobile ions, their concentration, mobility, valency, relative concentration and temperature of measurement (Akeredolu, 1991). Compounds which dissociates easily in solution are good conductors whiles those which do not dissociate easily are poor conductors. In a laboratory determination, conductivity is measured in microsemen per centimeter (µS/cm) or in decisemens per centimeter (dS/cm). In the Laboratory conductivity measurements are used to establish degree of mineralization, to assess the effect of the total concentration of ions on chemical equilibria, physiological effects on living things and the rate of corrosion. When conductivity is multiplied by a factor, total dissolved solids of water can be determined. This factor may vary from 0.055 to 0.9 depending on the soluble component of the water and on the temperature of measurement (Agbede, 2008).

2.12.4 *Total Alkalinity*

Alkalinity is defined as the ability of water to neutralize an acid, and is determined by titration against a known standard acid (usually 0.02N sulfuric acid). Alkalinity has traditionally been reported in terms of mg/L as calcium carbonate. This is somewhat a confusing nomenclature since the chemical species responsible for virtually all the alkalinity of natural waters is the bicarbonate ion (Agbede, 2008). The optimal amount of alkalinity for given water is a function of several factors including pH, hardness and the concentration of dissolved oxygen and carbon dioxide that may be present. As a general rule 30 to 100 mg/l calcium carbonate is desirable although up to 500 mg/L may be acceptable. Alkalinity is apparently unrelated to public health but is very important in pH control. Alum, gaseous chlorine and other chemicals are occasionally used in water treatment to acts as acids and therefore tend to depress pH. Many waters are deficient in natural alkalinity and must be supplemented with lime (CaO) or some other chemicals to maintain the pH in the desirable range to usually 6.5 to 8.5.Alkalinity values can change significantly from groundwater between samples taken at the wellhead and samples taken from other spots(Akeredolu,1991).

2.12.5 *Turbidity*

Turbidity is the term given to anything that is suspended in a water supply. It is most common in surface waters and usually non-existent in ground water except in shallow wells and springs after heavy rains. Turbidity gives the water a cloudy appearance or shows as dirty sediments. Undisclosed materials such as sand, clay, silt or suspended irons contribute to turbidity. Turbidity can cause the staining of sinks and fixtures as well as the discolouring of fabrics (ANZECC, 2000). Usually turbidity is measured in NTU (nephelometric turbidity units). Drinking water have turbidity level of 0 to 1 NTU. Turbidity can also be measured in ppm (parts per million) and its size is measured in microns. Turbidity can be particles in the water consisting of finely divided solids larger than molecules, but visible to the naked eye, ranging from 0.001 to 0.150mm (1 to 150 microns). Typically turbidity can be reduced to 75 microns with a cyclone separator then reduced down to 20 microns with standard back washable filter, however flow rates of 5gpm/sq. ft are recommended maximum. Turbidity can be reduced to 10 microns with a multimedia filter while providing flow rate of 15 gpm/sq. ft cartridge filter of various sizes are also available down into the submicron range (USEPA, 1994).

Turbidity is caused by suspended matter such as clay, silts, finely divided organic and inorganic matter, soluble coloured organic compounds and plankton and other microscopic organisms. Turbidity expresses the optical property that causes light to be scattered and absorbed rather than transmitted in a straight line through the sample. Correlation of turbidity with weight concentration of suspended matter is difficult because the size, shape and refractive index of the particle also affect the light scattering properties of the suspension (ANZECC, 2000).

2.12.6 *Sodium*

Sodium levels in drinking water that are less than 20mg/l are considered safe for most people (WHO, 1998). In the sea coast area however, elevated levels of sodium and chlorides occur naturally due to the proximity to sea water. Substantially higher levels of sodium and chloride may also be due to contamination by activities of man including the use of road de-icing salts, discharges from water softeners, human or animal waste disposal, Leachate from landfills and many other activities. At present there are health standards for sodium and chloride in drinking water. A review by EPA in the mid-1980’s showed that elevated levels of sodium in drinking water did not cause high blood pressure or heart disease, rather only that sodium should be avoided by those who already had such medical conditions. It is important to note that sodium is an essential nutrient. The food and nutrition board of National Research Council recommends that healthy adults need to consume at least 500mg of sodium per day and that sodium intake be limited to no more than 2400mg/day. The food and drug administration publication states that most American adults tend to eat between 4000 and 6000 mg of sodium per day (USEPA, 1994)

CHAPTER THREE

MATERIALS AND METHODS

3.1 Physical and Natural Environment

3.1.1 *Description of study area*

The Ga West Municipality is currently one of the seven districts in the Greater Accra Region with its capital being Amasaman. Ofankor, Medie, Adjen Kotoku and Pokuase are some of the major towns found in the municipality. The municipality lies within latitude 50º 48^{1}North, 5º 29^{1} North and longitudes 0º 8^{1} west and 0º 30^{1} west respectively and occupies a land area of 284.01sq km. The municipality is zoned into six zonal councils namely Pokuase; Mayera, Ofankor, Ayikai Doblo, Kotoku and Amasaman.

The population for Ga West Municipality for the year 2010 was 217,091 with a growth rate of 3.4%. Female population represents 49% of the total population whilst male population was 51% (Ghana statistical service, 2010). The municipality remains predominantly peri- urban and urban with a population growth rate of 3.4% in the year 2010. The population is mainly concentrated along the peri-urban areas of the municipality particularly on the border with the Accra Metropolitan Assembly and Ga East District Assembly. The 2000 population figure also showed a density which was much higher than the national density though lower than that of Greater Accra Region (with 895.5 persons per sq. km). This implies great pressure on resources including water (GWDA, 2012).

3.1.2 *Climate and vegetation*

The Ga West municipal lies in the coastal savanna agro-ecological zone. The relief is generally undulating at less than 76m (250ft) above sea level except for the areas around the Akuapem and Weija hills and only the alluvial areas surrounding the coastal lagoon could strictly be called flat. The rainfall pattern is bi-modal with an annual mean varying between 790mm on the coast to about 1270mm in the extreme north. The annual average temperature ranges between 25.1℃ in August and 28.4℃ in February and March. February and April are the hottest months. Humidity is generally high during the year (GWDA, 2012).

3.1.3. *Geology and Soil*

The land area is underlain by shallow rocky soils and is extensively developed on the steep slopes of the Akwapim range and the Weija hills as well as the basic gneiss inselbergs. On the Akwapim range the soils are mainly pale and sandy with brushy quartzite occurring to the surface in most places. These soils are rich in sandstone and limestone that are good source of material for the construction industry. The red earths are usually developed in old and thoroughly weathered parent materials. They are typically loamy in texture near the surface becoming more clay below. The red soils are porous and well drained and also provide ample moisture storage at depth for deep-rooting plants. Nutrients supplies are concentrated in the humus top-soil. (GWDA, 2012).

3.1.4 *Topography and Drainage*

The land area consists of gentle slopes interspersed with plains in most parts and generally undulating at less than 76m above sea levels. The slopes are mostly formed over the clay soils of the Dahomeyan gneiss with alluvial areas surrounding the coastal lagoons generally flat. The Akuapem range and the Weija hills rise steeply above the western edge. The crest of the Akuapem range lies generally at 300m southwards. This line of hills continues through to the Weija hills with the highest point reaching 192m near Weija. There are three major rivers in the district namely: the Densu, Nsaki and Ponpon river. The largest of the three is the Densu which drains down from the Eastern Region through the western portions of the district to Weija where it enters the sea. It is the main source of water supply to over half the entire population of the Accra Metropolis. Other water bodies mostly tributaries of the Densu are the Adaiso, Doblo, Ntafafa and the Ponpon river (GWDA, 2012)

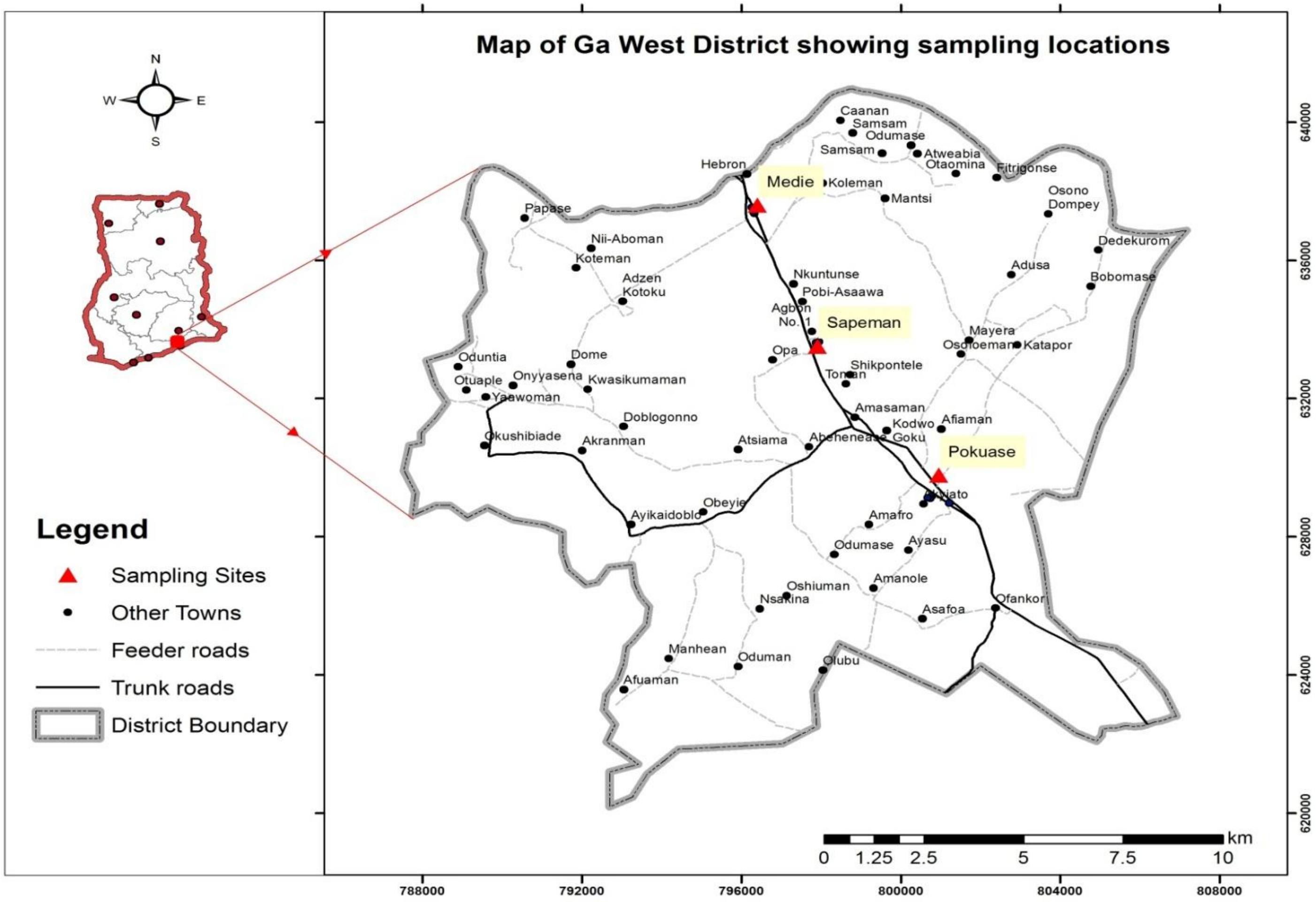

Figure 3. 1: Map of Ga West District showing sampling Locations.

3.2 Research Design

The sample design for the research involved both cluster sampling and purposive sampling. For administrative purposes, the Ga West District has been divided into six zonal councils, namely ofankor, Pokuase, Mayera, Amasaman, Ayikai Doblo and Kotoku Zonal Councils. All the communities in the six zonal councils that benefited from underground water facilities within the district were visited. The Six zonal councils were further divided into three clusters. A well water, borehole water and septic tank use questionnaire was distributed in households and communities using snowball sampling techniques and it involved asking whether the household use septic tank, what type of septic tank, the age of the septic tank, the number of people in the household, the age of the well, borehole water or well location, the distance of borehole to the septic tank. Based on the response and the analysis of the questionnaire, eleven (11) sampling locations were identified comprising of five boreholes and six hand-dug wells with distance from the nearest septic tank being the determining factor in three randomly selected communities namely; Medie, Sapeiman, and Pokuase. These communities were selected from each of the three clustered zonal councils because septic tank usage and groundwater use are high (GWDA, 2012). Site evaluation was observed at each selected sampling site in order to minimize any other anthropogenic extraneous factors such as animal pens, intensive backyard farming and refuse dump that could impact on the water quality.

The wells and boreholes to septic tank distances were categorized into three, 0-15m, 16-30m and >30m (control). The distances were chosen because the World Health Organization recommends that septic tank should be at least 30m away from a underground water source (WHO, 2004).The wells and boreholes under investigation were coded as PWI, PW2, PW3, PW4, MW1, MW2, MW3, MW4, SWI, SW2, and SW3 where P, M and S are Pokuase, Medie and Sapeiman respectively. The table below illustrates the sites and distances from which water samples were taken.

Table 3. 1: Sampled boreholes/wells sampling sites and distance groupings

Distance of septic tank from wells/boreholes(m)		0-15m	16-30m	>30m(control)
category	BH	MW1, MW3	SW3	PW2, SW2
	HDW	PW1, SW1	PW3,MW2,PW4	MW4

BH: Borehole; HDW: Hand dug well Source: Fieldwork, 2014

The position of the control was determined in order to minimize the influence of the nearest septic tank or other topographical features that could influence any of the other characteristics under investigation. At this position there was no evidence of intensive farming or animal pens that could influence results.

The geographical locations of the boreholes, hand dug wells and septic tanks were determined using global positioning satellite (GPS) device (Model, GARMIN etrex 20) and distances of boreholes/wells to septic tank were also determined using a GPS and a tape meter (model, ZJF-100m). Data was taken at four weeks interval within a period of three months (February-April).

Even though seasonal variation has an effect on ground water pollution, it was a limitation to this study

Table 3. 2: Sampled boreholes/wells codes and nearest septic tanks distances

Sampling point	Code/ID	Actual distance(m)
Pokuase 1A	PWI	12
Pokuase 1B		12
Pokuase 2A	PW2	41
Pokuase 2B		41
Pokuase 3A	PW3	23
Pokuase 3B		23
Pokuase 4A	PW4	18
Pokuase 4B		18
Medie 1A	MWI	13
Medie 1B		13
Medie 2A	MW2	17
Medie 2B		17
Medie 3A	MW3	11
Medie 3B		11
Medie 4A	MW4	34
Medie 4B		34
Sapeiman 1A	SWI	36
Sapeiman 1B		36
Sapeiman 2A	SW2	12
Sapeiman 2B		12
Sapeiman 3A	SW3	22
Sapeiman 3B		22

‘’A’’ indicates borehole and well sampled Source: Field work, 2014.

“B” indicates nearest septic tank to borehole or well sampled.

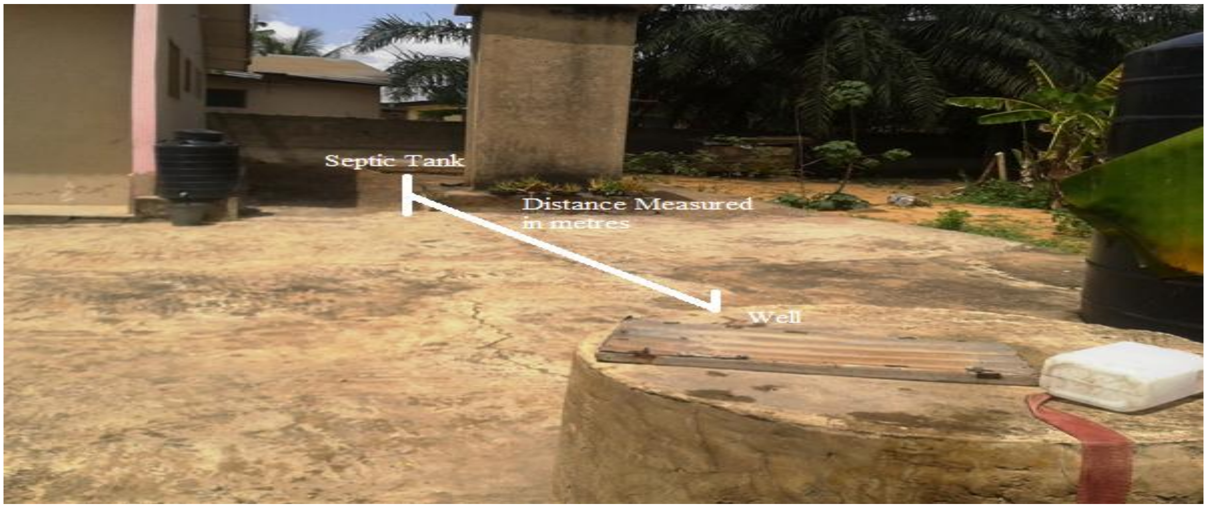

Plate 3. 1: Picture showing septic tank distance to well in a sampled residential household.

Source: Fieldwork, 2014.

3.3 Sampling design for Socio- economic survey

The data collection techniques that was used in this study involved a combination of cluster sampling, stratified sampling, purposive and incidental sampling technique. These techniques were considered based on the objectives of the study and the questions were structured accordingly using both precoded and open ended. In the cluster sampling, the households were divided into four clusters from a reference position on the field namely; West cluster, East cluster, South cluster and North cluster. The population was then identified and selected from each cluster using purposive sampling techniques based on availability of water facility at homestead and presence of septic tank as onsite sewage system. In the stratified sampling the population was stratified, thus divided into groups such as youth groups, middle aged and elderly. This was to avoid bias in interviewing a population of a certain age groupings. In the incidental sampling technique, the samples were picked by accident where there was no prior decision. In this technique any person within the various strata was interviewed.

3.3.1 *Administration of questionnaire*

Questionnaire was the main research tool that was used to collect data on issues of sanitation, water supply and waste management. The opinions and comments of a total number of 60 respondents in the study area were sought using a structured questionnaire. The interviews were conducted in the sampling residential houses of the study and other households within the community.

Information that were sought include sources of water for domestic purposes, protection of the water source, relative distances between sanitary structures and domestic water sources, awareness of potential water contamination from septic tank, and the knowledge of any common water related diseases that affects the community.

3.4 Sampling procedures

For water assessment regarding the suitability of water for human consumption and other domestic purposes, carefully sampling and sample handling procedures are required. Strict measures were adhered to in order to avoid any external influences that could affect the loss of integrity of the sample during sampling, handling, transportation and preservation.

Polyethylene sample containers of 500ml capacity with stopper were used for collecting the water samples. The containers were pretreated by washing with acetone to get rid of organic substances such as grease and fat residues. Each bottle was then washed with detergents and finally rinsed with de-ionized water. The sample containers used for sampling water for phosphate analysis was washed with phosphate free detergents. The sampling containers were then soaked in 1.0M nitric acid solution for 24hours.The containers were finally rinsed three times with distilled water before transporting them to the sampling site.

At the sampling site the sampling bottles were rinsed thoroughly with the water of the source from where the sample was to be collected and the rinsed water was discarded away from the area being sampled. A clean water sampler was introduced into the well/borehole with the help of a rope and the water was fetched out. The water sample was collected into a pretreated clean plastic bucket for in-situ measurements as the chemistry of water is sensitive to environmental changes.

In the BOD and DO sampling, two bottles, one plain and the other darker (amber bottle) to prevent the possibility of photosynthetic production of oxygen were used for sampling. The plain bottle was used for dissolved oxygen sampling and the amber bottles were used for BOD sampling. The bottles were filled with water to overflow in order to avoid any air bubbles from getting trapped to interfere with the sample. The dissolved oxygen sample was fixed on site with 2ml each of Winkler 1(Manganous chloride) and Winkler 2(alkaline-iodide-azide reagent).The samples were collected in three replications.

Physico-chemical parameters measured are pH, temperature, conductivity, salinity, turbidity, total suspended solids, total dissolved solids, nitrogen-nitrate, nitrogen-nitrite, nitrogen ammonia, total alkalinity, chloride, sulphate, phosphate- phosphorus, biological oxygen demand (BOD), dissolved oxygen (DO), sodium and potassium. Bacteriological parameters determined were total coliform (TC) and faecal coliform (FC) - *E. coli*. The sample containers were filled leaving no air space to prevent air from entering. Each container was clearly marked with the name, address of the sampling station, sample description and the date of sampling. Samples that were not analyzed immediately at the sampling site were preserved in an ice chest at a controlled temperature and finally transported to the laboratory and stored in a refrigerator below 4°C.

3.5 Sample Analysis

All the water analysis were determined using appropriate certified and acceptable international procedures outlined in the standard methods for the examination of water and waste water (APHA, 1998). The physical parameters such as pH, conductivity, temperature, salinity and turbidity were measured in -situ using HACH model multi-probe meter (Model YSI 63).The turbidity was measured using turbidimeter (Model HACH 2100P) NTU and total dissolved solids (TDS) were measured with a portable digital TDS meter (Model HI 99301). The salinity was measured using a hand- held refractometer.

The sodium and potassium ions were analyzed employing Flame emission photometric methods whilst chloride was analyzed using Agentometric methods. The total alkalinity was determined titrimetically using potentiometric methods (APHA, 1996). The dissolved oxygen was measured with a DO meter and BOD was analyzed using titrimetric methods (Azide modification of Winkler method). The nitrogen-nitrate, nitrogen-nitrite, nitrogen -ammonia, phosphate -phosphorus, sulphate and total suspended solids were determined using HACH direct reading spectrophotometer. The total coliform (TC) and faecal coliform (FC) - *E. coli* were analyzed using membrane filtration technique (HACH, 1996, WHO, 1997) placed in a paqualab incubator. The growth media used was *E. coli*/coliform selective media for TC and FC. They were incubated at 35℃ for 48 hrs and 44℃ for 24 hrs for TC and FC respectively.

The physico-chemical parameters were carried out at the University of Ghana Ecological Laboratory located in the Department of Geography and Resource Development and the bacteriological analysis was analysed at Noguchi Memorial Institute for Medical Research of the University of Ghana.

3.5.1 Nitrogen -Nitrate (NO_3^-) Analysis.

The method used for the nitrate analysis was the Cadmium reduction method. The nitrate level in each sample was measured using Nitrate powdered pillows in a direct reading HACH spectrophotometer (Model DR. 2010). Ten (10) ml of the sample was measured into sample cell of the spectrophotometer. One Nitraver 5 nitrate reagent powder pillows was added to the sample. The mixture was then shaken vigorously for 1 minute. Five minutes was allowed for the solution to react. An orange colour of the mixture indicates the presence of nitrate. A blank was placed into the cell holder to calibrate it. The prepared sample was then placed into the cell holder to determine the nitrate- nitrogen concentration at 500 nm in mg/l (HACH, 1996).

3.5.2 Nitrogen- Nitrite (NO_2^-) Analysis

The nitrite level in each sample was measured using nitrite reagent powdered pillows in a direct reading HACH spectrophotometer (Model DR.2010). Ten (10) ml of the sample was measured into sample cell of the spectrophotometer. One Nitraver 3 nitrite reagent powder pillows was added to the sample. The mixture was then shaken vigorously to dissolve the powder. Twenty-minutes was allowed for the solution to react. A pink colour of the mixture indicates the presence of nitrite. A blank was placed into the cell holder to calibrate it (zeroing). The prepared sample was placed into the cell holder to determine the nitrite concentration at 507nm in mg/l (HACH, 1996).

3.5.3 Nitrogen -Ammonia (NH_3-N)

The method used for the ammonia- nitrogen analysis was the salicylate and spectrophotometric methods. The nitrogen ammonia level in each sample was measured using salicylate reagent powder pillows (reagent 1) and cyanurate reagent powder pillows (reagent 2) in a direct reading HACH spectrophotometer (Model DR. 2010). Ten milliliters of the sample was measured into sample cell of the spectrophotometer. One salicylate reagent powder pillows was added to the sample. The mixture was then shaken vigorously and three minutes reaction period was allowed for the solution to react. After the three minutes, one cyanurate reagent powder pillows was added to the sample and shaken to dissolve and a 15minute reaction period was allowed. A green colour of the mixture indicates the presence of ammonia. After the fifteen minutes, another cell was filled with 10ml of only the sample (blank).The blank sample was placed in the spectrophotometer to calibrate it. The prepared sample was then placed into the cell holder to determine the nitrogen ammonia concentration at 655 nm in mg/l (HACH, 1996).

3.5.4 Phosphate -Phosphorus (PO_4^{3-})

A 25ml of water (prepared sample) was placed in the sample cell. Phos ver 3 phosphate reagent powder pillow was added to the sample content and swirled immediately to mix. A two-minute reaction period was allowed. A blue coloration of the mixture indicates the presence of phosphate. A blank was placed into the cell holder to calibrate it. After reaction period, the prepared sample was placed into the cell holder and the level of phosphate-phosphorus was determined at 890nm. The spectrophotometer displayed the results in mg/l PO_4^{3-} (HACH, 1996).

3.5.5 Sulphate (SO_4^{2-}) Analysis

The level of sulphate in the sample was determined using turbidimetry and spectrophotometric method in a direct reading HACH spectrophotometer (Model DR. 2010). Ten milliliters of the sample was measured into a sample cell. One sulfa Ver 4 reagent powder pillows was added to the sample and swirl to dissolve. Five-minute reaction period was allowed. A blank was placed into the cell holder to calibrate it. After the reaction period the prepared sample was placed into the cell holder and the concentration of the sulphate was determined at 450nm. The sulphate ions in the sample react with barium in the sulfa Ver 4 reagent to form insoluble barium sulphate turbidity. The amount of turbidity form is proportional to the sulphate concentration in the sample (HACH, 1996).

3.5.6 Biochemical Oxygen Demand (BOD)

Biochemical oxygen demand (BOD) is a measure of organic matter contamination of water. It measures the amount of oxygen used by microorganisms in oxidizing or decomposing organic matter in water. This test is used to measure the amount of oxygen consumed by these organisms during a specified period of time usually five days at a temperature of 20°C.The BOD test was done by filling and hermetically sealed BOD bottle with the sample of water and incubating it at the specified temperature for five days. The Dissolved oxygen was measured initially and after incubation, the BOD was found by the difference between the initial and the final DO. The samples taking from the field for the BOD analysis were diluted. The dilution was done because BOD concentration in the water sampled was suspected to exceed the concentration of DO available in the water sample as initial measurements recorded very low values. Because the initial DO is determined immediately after the dilution is made, all oxygen uptake, including that occurring during the first 15 minutes was included in the BOD measurement. The dilution water was prepared by 1 ml each of phosphate buffer, Magnesium sulphate, calcium chloride and iron (III) chloride solution per litre of water (APHA, 1995).

Mathematically the BOD was computed as below;

where; $\mathrm{BOD}_5 \frac{\mathrm{mg}}{\mathrm{l}} = \frac{\mathrm{DI}-\mathrm{D2}}{\mathrm{P}}$

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

D2= DO of diluted sample incubated for 5 days at 20℃ mg/l

P= Decimal volumetric fraction of sample used.

3.5.7 Chloride Analysis

The chloride level in the water sample was determined using Agentometric method. 10ml of the water sample was pipette into a conical flask and 3 drops of 0.1M potassium chromate ($K_2Cr_20_4$) indicator was added and titrated with 0.1M silver nitrate ($AgNO_3$) to end point. The colour changes from yellow to light orange. The standard Molarity of the silver nitrate used was 0.0141M. (British Pharmacopoeia, 1993).

The chloride was computed mathematically as below;

$$\text{Chloride Concentration mg/l} = \frac{(\text{A} - \text{B}) \times \text{M} \times 35.5 \times 1000}{\text{ml Sample}}$$

Where;

A = ml titrant used for sample

B = ml titrant used for blank, M = Molarity of the silver nitrate.

3.5.8 Total Alkalinity

Alkalinity of water is defined as its capacity to neutralize acid. Carbonates, bicarbonates and hydroxides content contribute to this capacity. The total alkalinity was determined using potentiometric method. A PH electrode was inserted into a 50ml water sample and was then titrated against 0.02M Hydrochloric acid. Titration continued till a PH of 4.5 which is equivalent to the methyl orange endpoint. The volume of the acid used in the titration was recorded and alkalinity calculated as follows:

$$\text{Alkalinity as CaC}0_3\ /\text{mg/L} = \frac{\text{A} \times \text{N} \times 1000}{\text{ml Sample}}$$

Where; A= ml of standard acid, N= Liter of acid used (AWWA, 1998).

3.5.9 Sodium and Potassium ions

Sodium (Na) and Potassium (K) ions were analyzed by the Flame emission photometric method using Gallenkamp digital flame analyzer. Samples were digested and filtered into a 100ml volumetric flask. The sample was aspirated and the valves read out from digital display.

Sample whose concentrations were higher than that of the standard were diluted and results multiplied by the dilution factor. Trace amount of K were determined at wavelength of 768µm and Na was determined at a wavelength of 589µm.The intensity of light at these wavelength is approximately proportional to the concentration of K and Na respectively in the sample.

3.6 Bacteriological Analysis

Glass bottles with metal cap were used to collect the water sample. The bottles were sterilized before used and the mouth was covered with aluminum foil to avoid contamination during sampling. After collection the samples were stored on ice to avoid the multiplication of the bacteria.

The total and faecal coliform bacteria present in the water sample were determined using Membrane filtration (MF) technique (HACH, 1996; WHO, 1997). The membrane filter with 0.45µm pore size was sterilized and used to filter 100ml of water mixed with 10ml of the sampled water. The results that was obtained from the colony counting were then multiplied by 10 to obtain the actual count per 100ml.The membrane filter was lifted from the system with a sterilized forceps after filtration and carefully placed on the sterile media in petri dish. *Escherichia coli/* coliform selective media was used as the growth medium for the culture of the faecal and total coliforms.

Using the pour plate method, 2ml of sterilized *E. coli*/ coliform selective media was poured on an absorptive pad placed in a petri dish. The petri dish were covered and incubated at 37 °C for total coliform and 44°C for faecal coliforms for 24hrs. After the 24 hours the petri dishes were removed from the incubator and the colonies were counted using a colony counting chamber (Gallenkamp, UK) and recorded in coliform forming units per 100ml (CFU/100ml).

3.8 Quality assurance

Proper quality assurance procedures and precautions were taken to ensure the reliability of the results. The samples were carefully handled to avoid any external influences that could interfere with the integrity of the sample and hence contaminate it. Triplicate determination of the samples were made and the data was presented as means. Glasswares were properly cleaned, and reagents were of analytical grades. Deionized water was used throughout the study. For the spectrophotometric analysis, reagent blank determinations were used to correct the instrument readings. For validation of the analytical procedure, repeated analysis of the samples against internationally certified/standard reference material (SRM-1570) of National Institute of Standard and Technology, USA were used. With the exception of temperature, multi probe meters were calibrated together using the same standard and procedures .Electrical conductivity was calibrated against 0.005, 0.05 and 0.5M standard potassium chloride solution; pH was calibrated with standard buffer at pH of 4 and 9.2. The dissolved oxygen (DO) was calibrated against zero solution of sodium sulphate. Temperature was checked against standard mercury thermometer for consistency.

3.7 Data Analysis

Raw data collected for physico-chemical, bacteriological and socio-economic survey were done using microsoft spreadsheet version 2007. Statistical Product for Service Solutions (SPSS) software version 20.0 was used to generate the means, maximum and minimum ranges for the various parameters and frequencies used in the data for both the social survey and the water quality. One–way Analysis of variance (ANOVA) was used to test for the significant difference between the septic tank distances to water source groupings. A correlation analysis was also carried out to establish the degree of relationship between the physico-chemical and microbiological counts and the distances between the septic tanks and wells/boreholes.

CHAPTER FOUR

RESULTS OF THE STUDY

4.1 Physical Parameters

4.1.1 Temperature

The mean water temperature ranged from a minimum of 28.2℃ at site MW2 (well) with distance between 16-30m and a maximum of 31.8℃ at site PW2 (borehole) with distance greater than 30m (control) (Fig 4.1). Analysis of variance at 95% confidence interval did not reveal any statistically significant differences (P>0.05) in temperature in relation to distances over the study period. However, the distances between 0-15m recorded the highest mean values. The values for the individual sites and distances are presented in appendix A1.

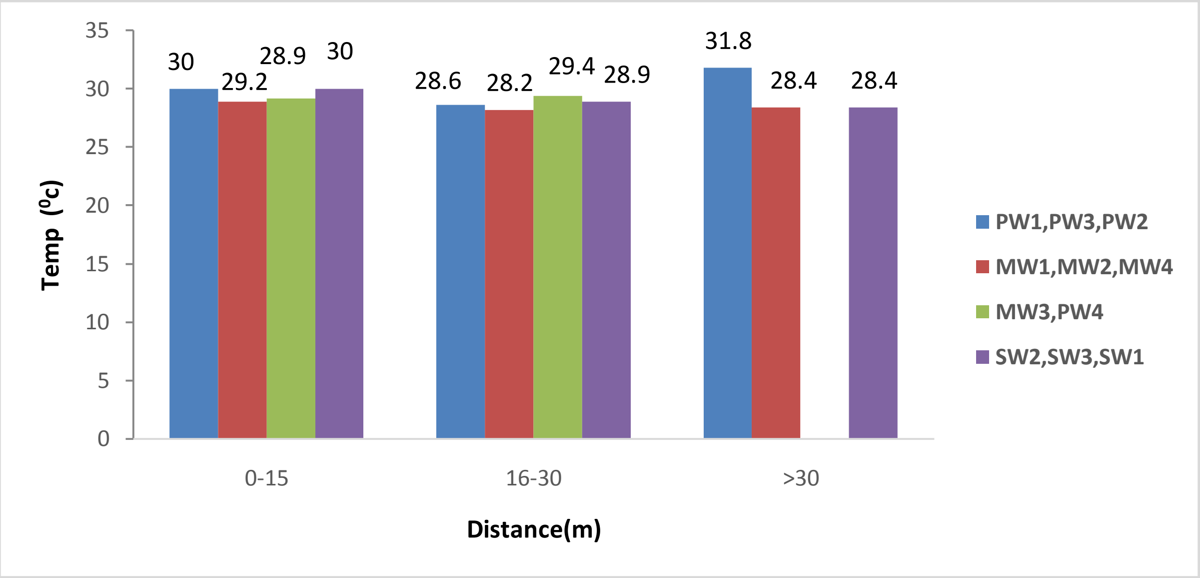

Figure 4. 1: Mean temperature in relation to distance from septic tank in the Ga West District.

4.1.2 pH

Figure 4.2 is graphical illustration of the mean pH values of the water sample for the various sites and their distance categories. The values for the individual sites with the distances are presented in Appendix A2.The mean pH values ranged from a minimum of 6.3 at site SW3 (well) between the distance 16-30m and a maximum of 7.2 at site PW1 (well) between the distance 0-15m. Analysis of variance at 95% confidence interval did not show any statistically significant differences (P>0.05) in pH in relation to distances over the study period). However, the highest mean pH was recorded at distances between 0-15m and lowest at distances greater than 30m (control).

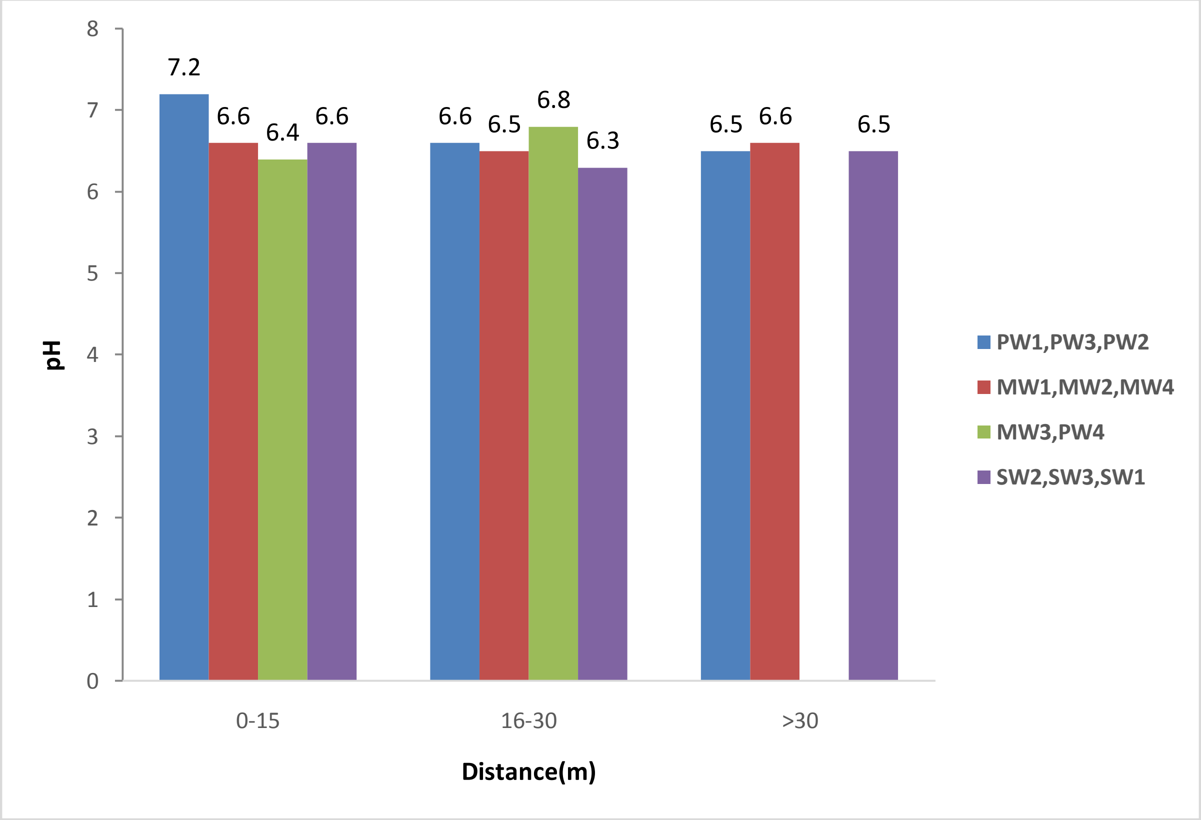

Figure 4. 2: Mean pH in relation to distance from septic tank in the Ga west District.

4.1.3 Electrical conductivity (EC)

The mean conductivity of the water sample ranged from a minimum of 675.3µS/cm at site SW1 (borehole) at distance greater than 30m (control) to a maximum of 5393.7µS/cm at site PW4 (well) at distance between 16-30m. The mean conductivity values and their distance is illustrated in (Fig 4.3) below. The conductivity recorded during the sampling period differ significantly ($P<0.05$). When the Least significant difference (LSD) was used to compare the means, there were no differences in conductivity in relation to distance between 0-15m and 16-30m but were however different from the control. Absolute values recorded for the entire study period are presented in Appendix A3.

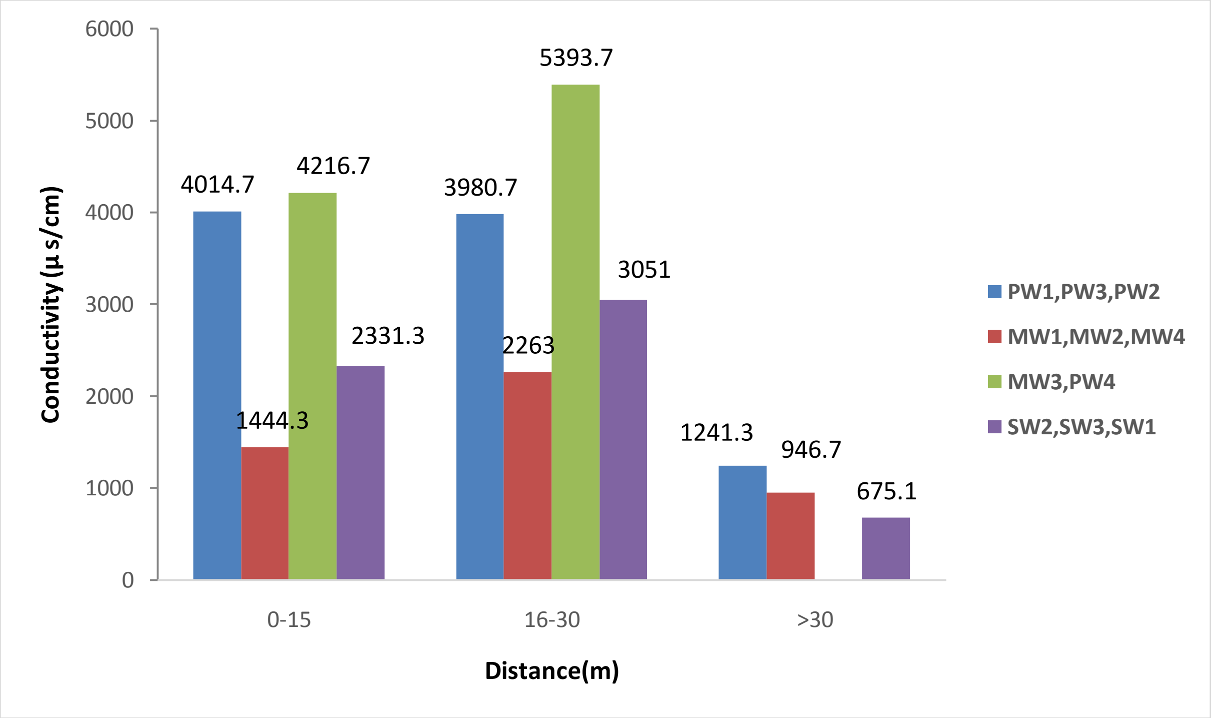

Figure 4. 3: Mean conductivity in relation to distance from septic tank in the Ga west District.

4.1.4 Total Dissolved Solids (TDS)

The mean values for total dissolved solids for the water sampled with distances are illustrated in Fig 4.4. The mean TDS ranged from a minimum of 439.4mg/l at site SW1 (borehole) at distance greater than 30m (control) to a maximum of 2929.9mg/l at site PW4 (well) at distance between 16-30m. Analysis of variance at 95% confidence interval revealed a statistically significant differences ((P<0.05) in TDS in relation to distances over the study period. When the LSD was used to compare the means, there were no differences between the distances 0-15m and 16-30m but were however, different from the control.

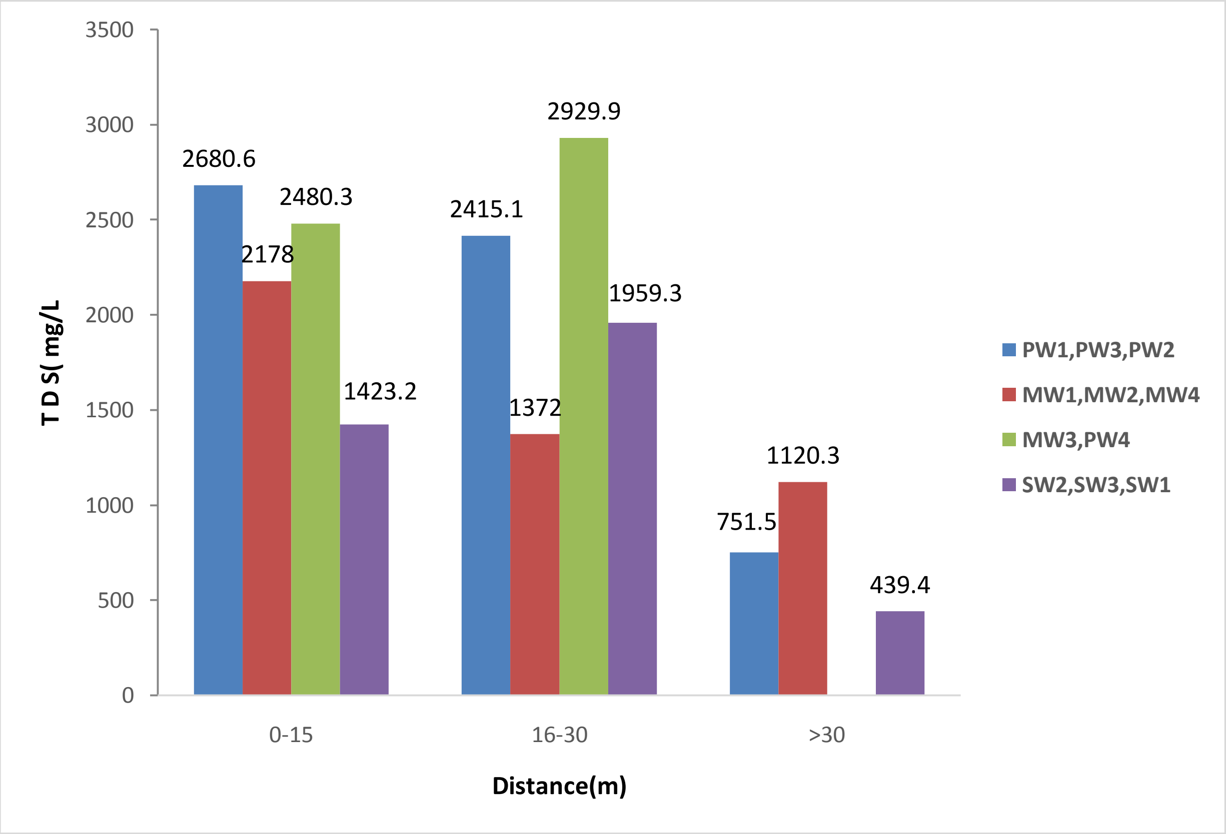

Figure 4. 4: Mean total dissolved solids in relation to distance from septic tank in the Ga west District.

4.1.5. Turbidity

Turbidity was generally very high at distances between 16-30m. The turbidity of the sample water ranged from a minimum of 1.7NTU (Nephlometic turbidity units) at site PW2 (borehole) with distance greater than 30m (control) to a maximum of 6NTU at site SW3 (well) with distance between 16-30m (Fig 4.5). Analysis of variance revealed a statically significant difference (P<0.05) between the distances. When the LSD was used to compare the means, there were no differences between the distances 0-15m and 16-30m but were, however, different from the control (>30m).

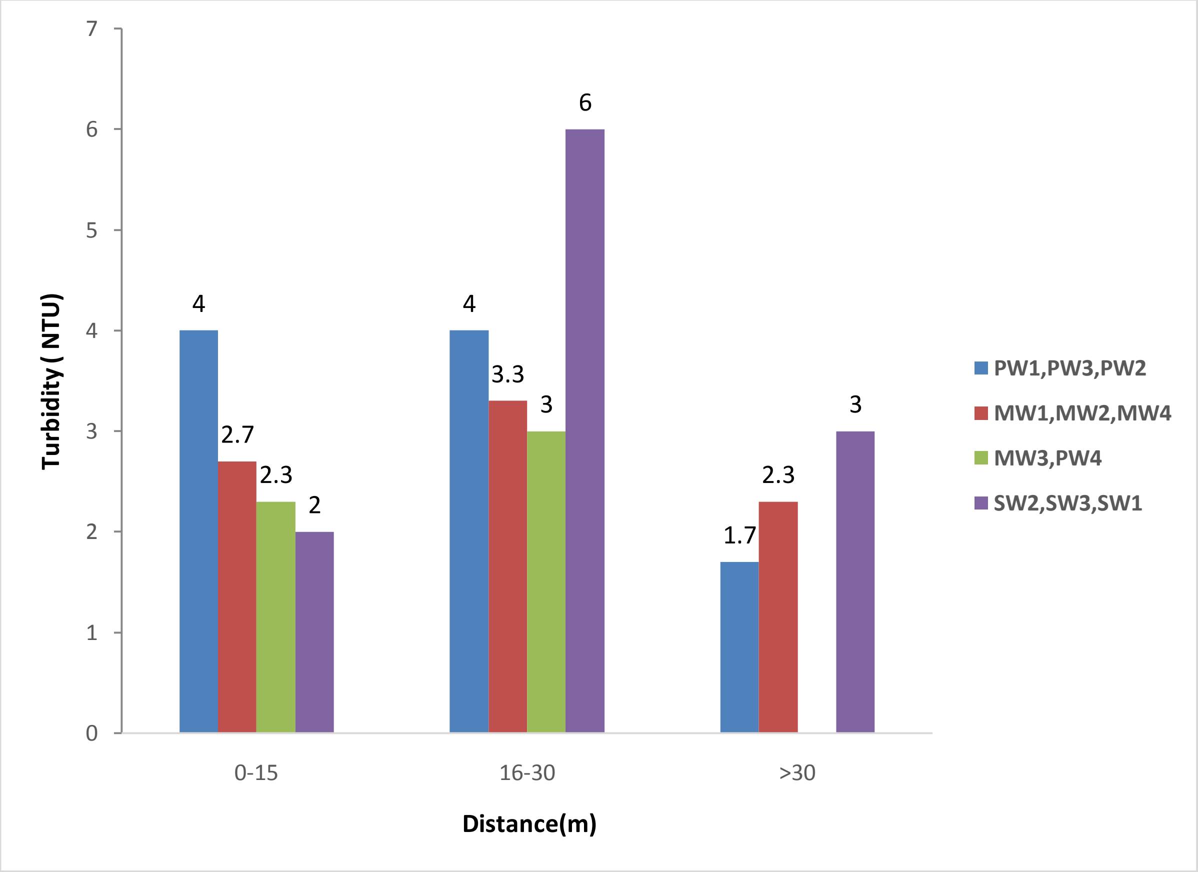

Figure 4. 5: Mean turbidity in relation to distance from septic tank in the Ga west District.

4.1.6 Total Suspended Solids

The mean total suspended solids in the water sample ranged from a minimum of 11.3mg/l at site MW3 (borehole) at a distance between 0-15m to a maximum of 33.7mg/l at site SW3 (well) at distance between 16-30m (Fig.4.6). Analysis of variance at 95% confidence interval revealed a statistically significant differences (P>0.05) in TSS in relation to distances over the study period (Appendix B). When the LSD was used to compare the means, there were no differences between the distances 0-15m and 16-30m but were however, different from the control. The values for the individual sites and distances are presented in appendix A6.

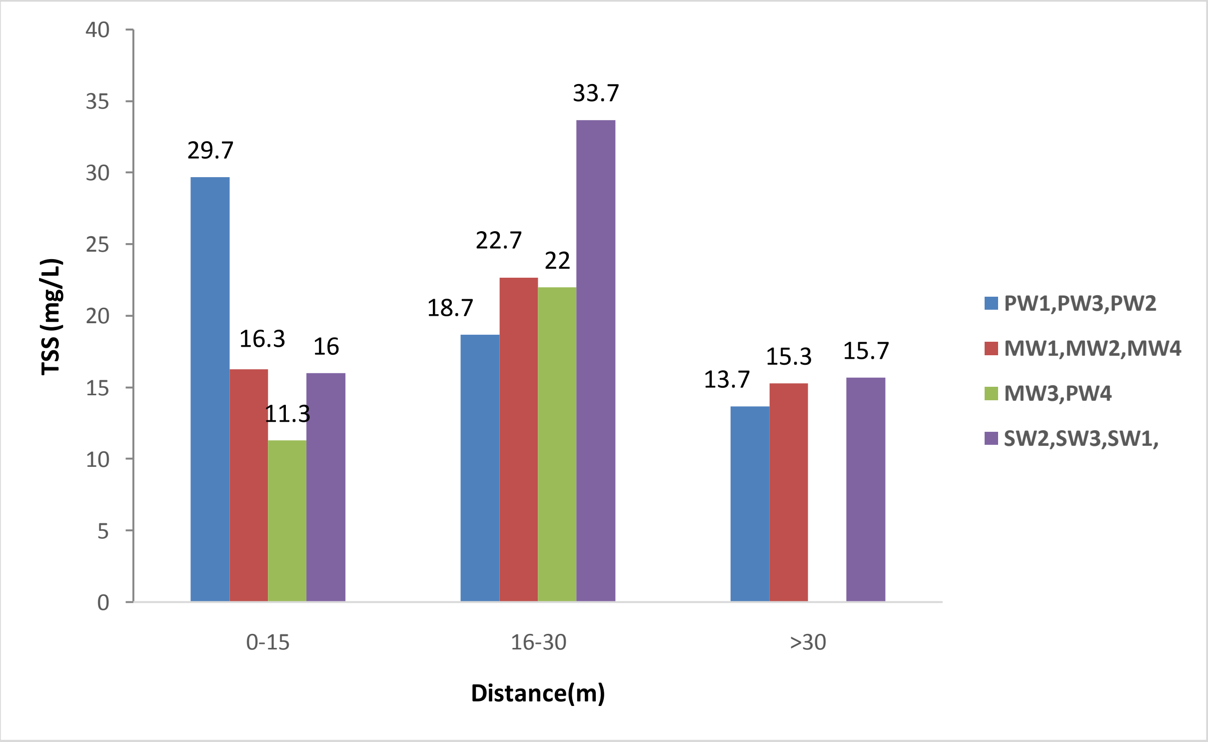

Figure 4. 6: Mean total suspended solids in relation to distance from septic tank in the Ga west District.

4.2. Chemical Parameters

4.2.1 Dissolved Oxygen (DO)

Figure 4.7 shows graphical illustration of the mean dissolved oxygen of the water sample for the various sites at various distances. The mean dissolved oxygen ranged from a minimum of 4mg/l at site MW1 (borehole) and SW3 (well) placed at distances 0-15m and 16-30m respectively and a maximum of 6.8mg/l at site PW2 (borehole) at distance greater than 30m (control).The values for the individual sites and distances are presented in Appendix A7. Analysis of variance at 95% confidence interval did not show any statistically significant differences (P>0.05) in dissolved oxygen in relation to distances over the study period (Appendix B).

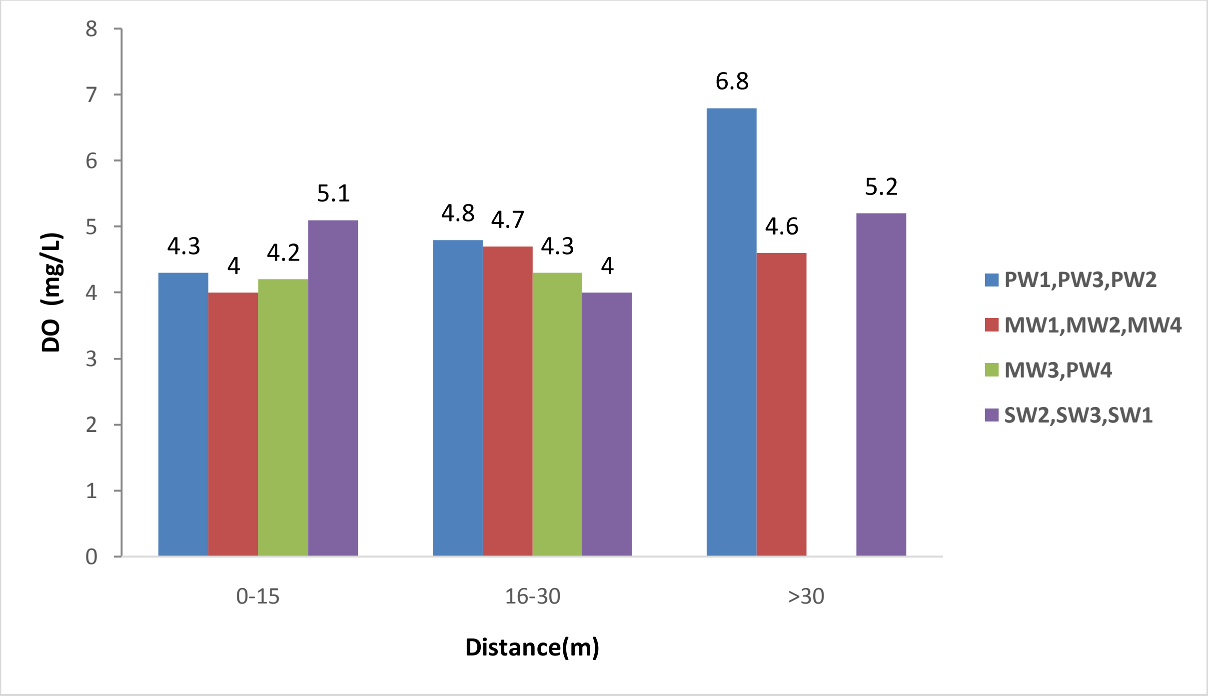

Figure 4. 7: Mean dissolved oxygen in relation to distance from septic tank in the Ga west District.

4.2.2 Biological Oxygen Demand (BOD)

Figure 4.7 shows graphical illustration of the mean biological oxygen demand of the water sample for the various sites at various distances. The mean values ranged from a minimum of 0.7mg/l at site MW4 (well) at distance greater than 30m (control) to a maximum of 3.3mg/l at site PW4 (well) at distance between 16-30m.The values for the individual sites and distances are presented in Appendix A9.Analysis of variance at 95% confidence interval did not show any statistically significant differences (P>0.05) in biological oxygen demand in relation to distances over the study period (Appendix B).

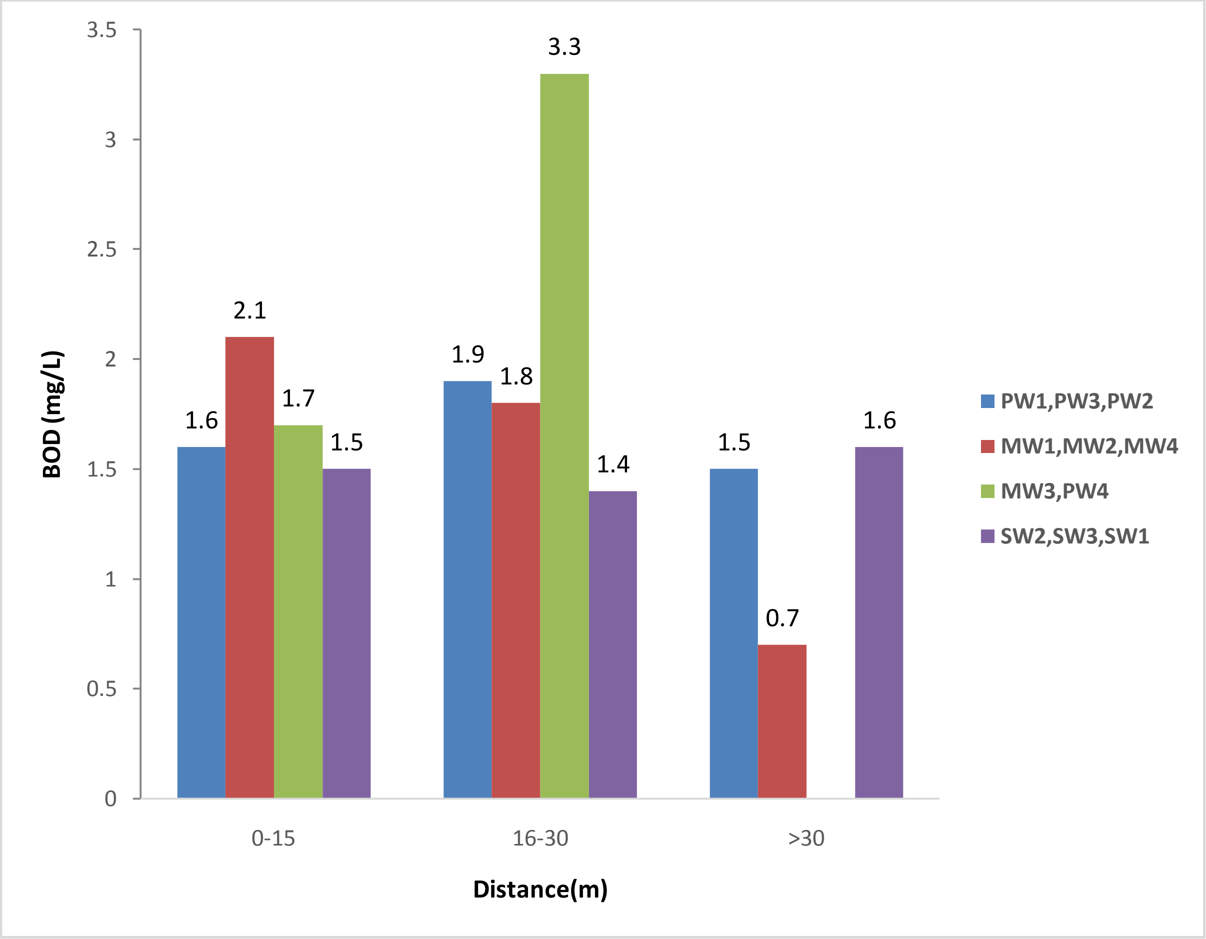

Figure 4. 8: Mean biological oxygen demand in relation to distance from septic tank in the Ga west District.

4.2.3 Nitrogen- Nitrate (NO_3^- -N)

The mean nitrogen- nitrate values ranged from a minimum of 2.2mg/l at site MW2 (well) at distance between 16-30m to a maximum of 19.6mg/l at site SW3 (well) at distance between 16-30m (Fig 4.9). Analysis of variance at 95% confidence interval revealed a statistically significant differences ($P<0.05$) in nitrogen- nitrate in relation to distances over the study period (Appendix B). The mean values recorded for the entire study period are presented in Appendix A9. When the LSD was used to compare the means, there were differences between the distances 0-15m, 16-30m and the control. The values for the individual sites and distances are presented in appendix A8. The nitrate levels were in the decreasing order of ranking; 0-15m >16-30m> control (>30m).

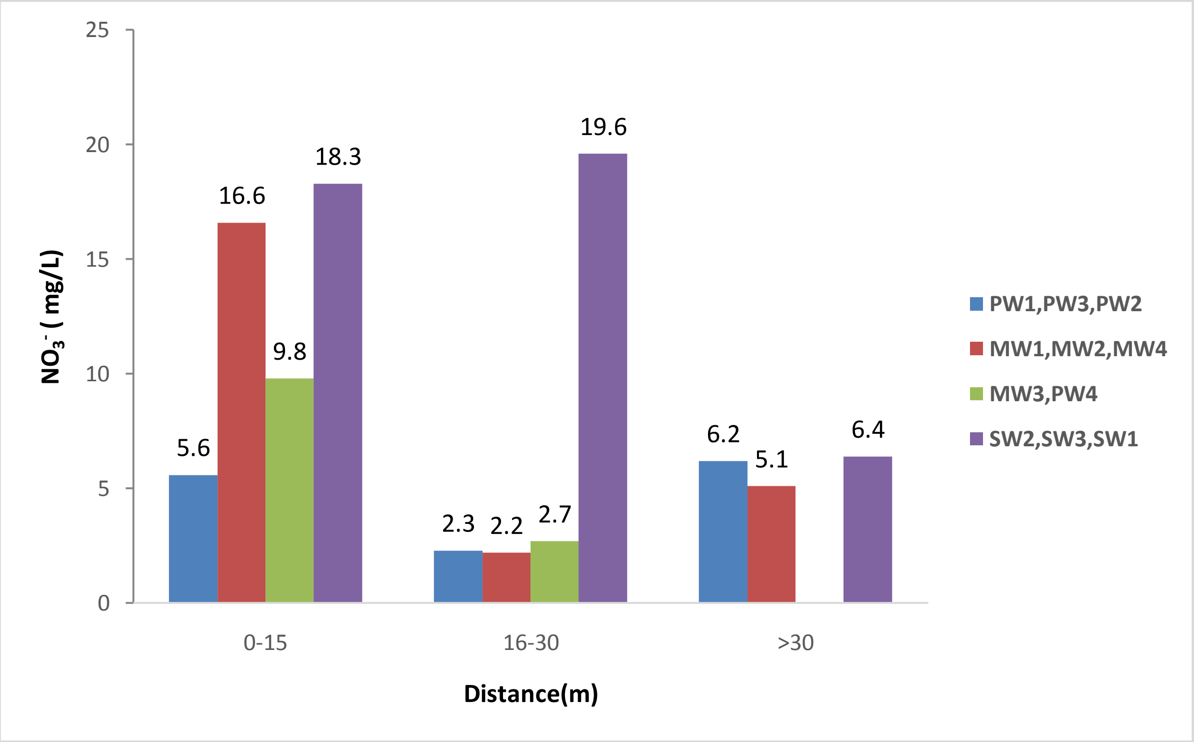

Figure 4. 9: Mean nitrogen nitrate in relation to distance from septic tank in the Ga west District.

4.2.4 Nitrogen- Nitrite (NO_2^- -N)

Figure 4.10 shows graphical illustration of the mean nitrogen-nitrite values of the water sample for the various sites at various distances. The mean values ranged from a minimum of 0.01mg/l to a maximum of 0.198mg/l .The values for the individual sites and distances are presented in Appendix A10. Analysis of variance at 95% confidence interval did not show any statistically significant differences (P>0.05) in nitrogen-nitrite in relation to distances over the study period (Appendix B).

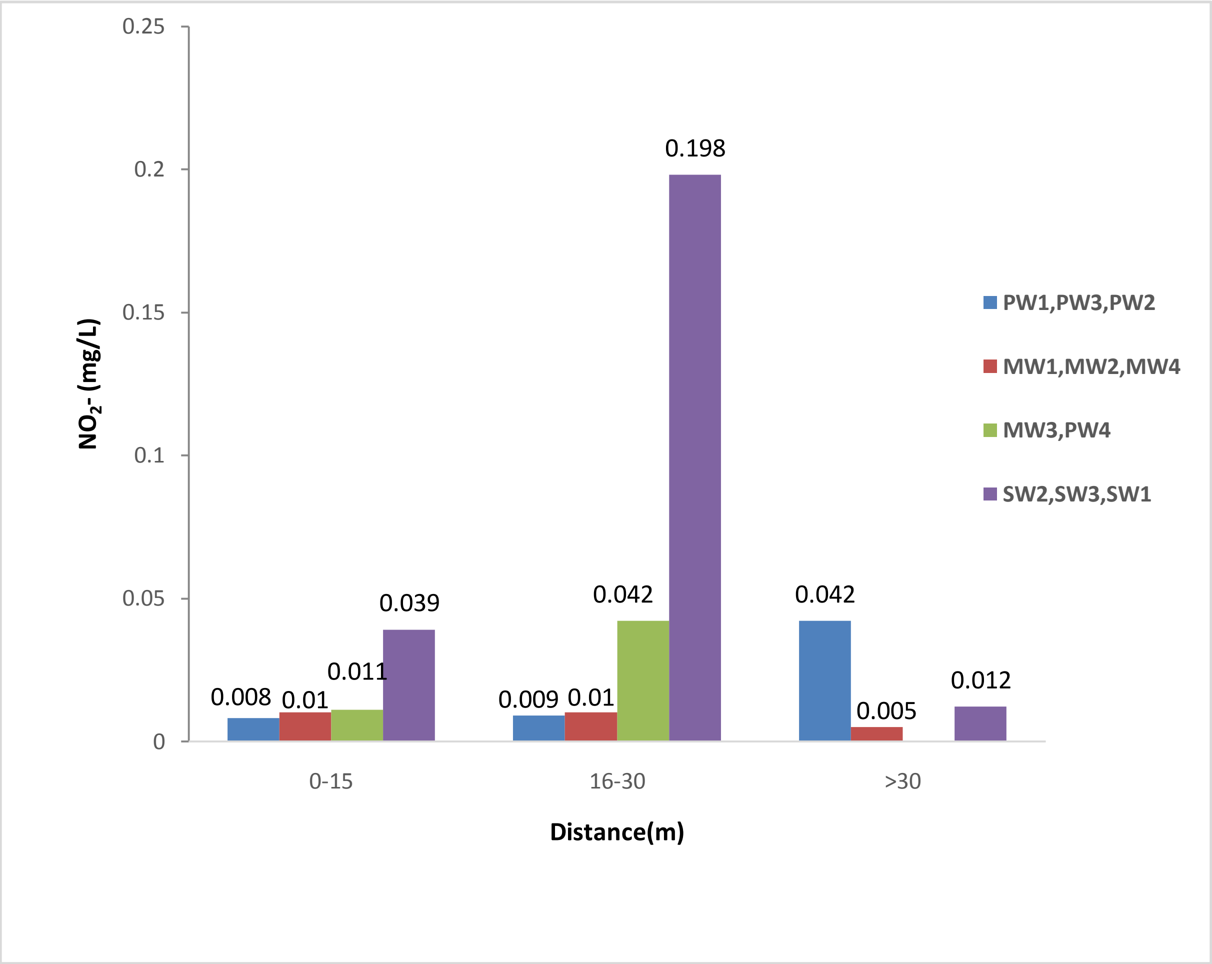

Figure 4. 10: Mean nitrogen-nitrite in relation to distance from septic tank in the Ga west District.

4.2.5 Nitrogen- Ammonia (NH_3-N)

The nitrogen ammonia levels were relatively high at distances between 0-15m and lowest at distances greater than 30m (control).The mean values ranged from a minimum value of 0.01mg/l to a maximum of 0.16mg/l (Fig 4.11). Analysis of variance at 95% confidence interval did not show any statistically significant differences (P>0.05) in nitrogen-ammonia in relation to distances over the study period. However the distances between 0-15m recorded the highest mean values whilst the control (>30m) recorded the lowest mean values. The individual values recorded for the entire study period are presented in Appendix A13.

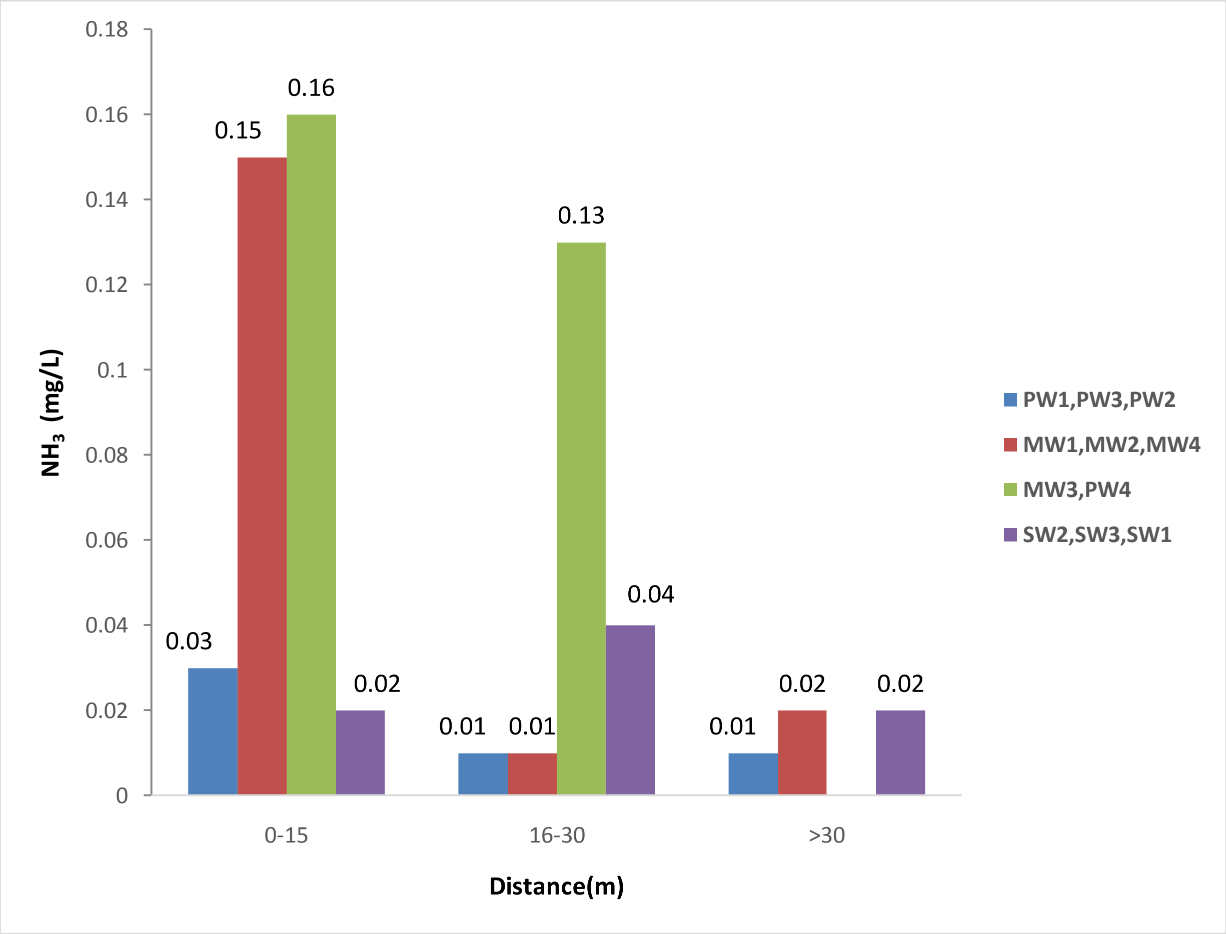

Figure 4. 11: Mean nitrogen-ammonia in relation to distance from septic tank in the Ga west District.

4.2.6 Phosphate-Phosphorus (PO_4^{3-})

The mean phosphate-phosphorus values in the water sample ranged from a minimum of 0.23mg/l at site SW1 (borehole) at distance 36m (control) away from the nearest septic tank to a maximum of 1.1mg/l at site PW1 (well) at distance of 12m away from the nearest septic tank (Figure 4.12). Analysis of variance at 95% confidence interval revealed a statistically significant differences ($P<0.05$) in phosphate-phosphorus in relation to distances over the study period (Appendix B).The individual values recorded for the entire study period are presented in Appendix A14. When the LSD was used to compare the means, there were differences between the distances 0-15m, 16-30m and the control (>30m). The mean concentrations followed the decreasing order of ranking; 0-15m> 16-30m> control (>30m).

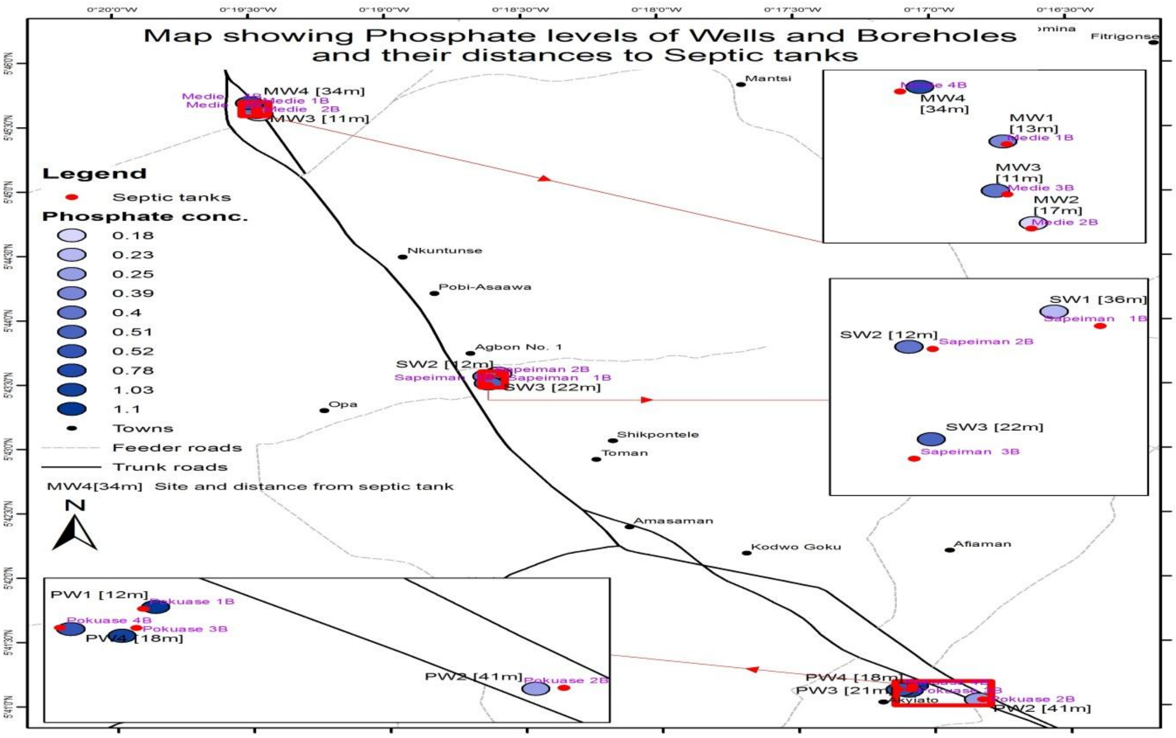

Figure 4. 12: Map showing mean phosphate-phosphorus in relation to distance from septic tank in the Ga west District.

4.2.7 Sulphate (SO_4^{2-})

Figure 4.13 shows a map illustration of the mean sulphate values of the water sample for the various sites and actual distances. The mean values ranged from a minimum of 17.7mg/l at site PW2 (borehole) at control distance 41m away from the nearest septic tank to a maximum of 491.7mg/l at site PW4 (well) at distance of 18m from the nearest septic tank. The values for the individual sites and distances are presented in Appendix A12. Analysis of variance at 95% confidence interval revealed a statistically significant (P<0.05) differences in sulphate in relation to distances over the study period (Appendix B). When the LSD was used to compare the means, there were no differences between the distances 0-15m and 16-30m but were however, different from the control.

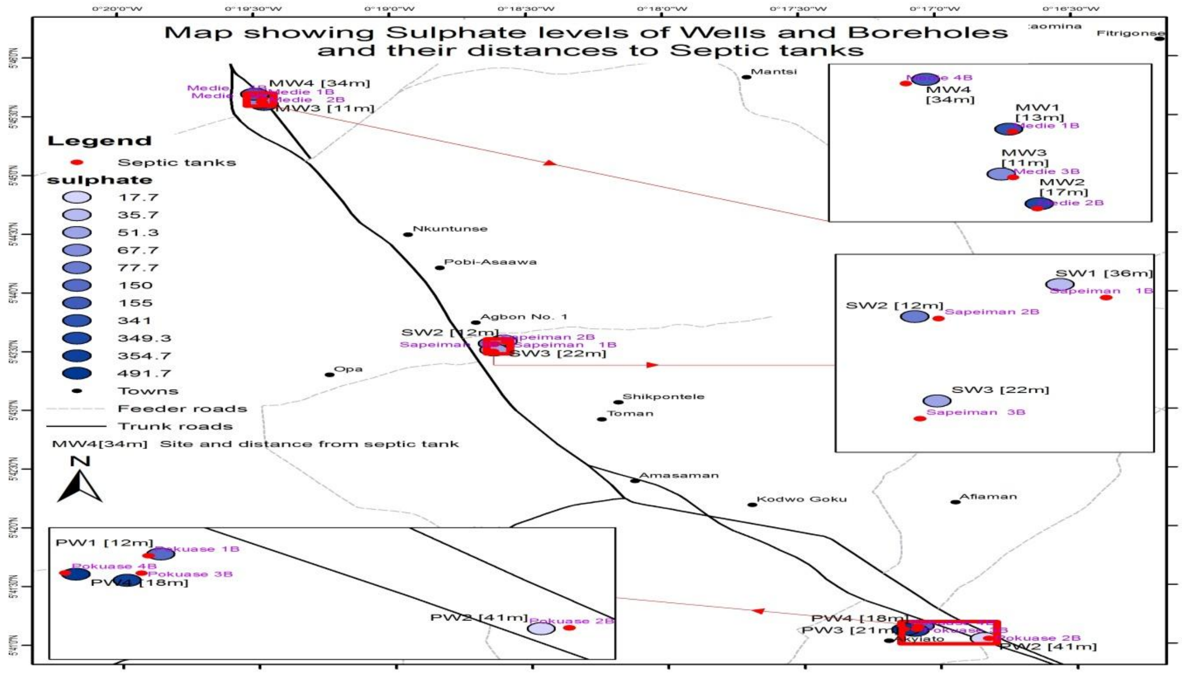

Figure 4. 13: Map showing mean sulphate in relation to distance from septic tank in the Ga west District.

4.2.8 Chlorides (Cl^-)

Figure 4.14 shows a map illustration of the mean chloride values of the water sample for the various sites and actual distances. The mean values ranged from a minimum of 72.6mg/l at site SW1 (borehole) at control distance 36m away from the neatest septic tank to a maximum of 1336.5mg/l at site PW4 (well) at distance 18m away from the nearest septic tank. The values for the individual sites and distances are presented in Appendix A11. Analysis of variance at 95% confidence interval revealed a highly statistically significant differences ($P<0.05$) in chloride in relation to distances over the study period (Appendix B).When the LSD was used to compare the means, there were differences between the distances 0-15m, 16-30m and the control. The mean concentrations followed the decreasing order of ranking; 0-15m>16-30m >control (>30m).

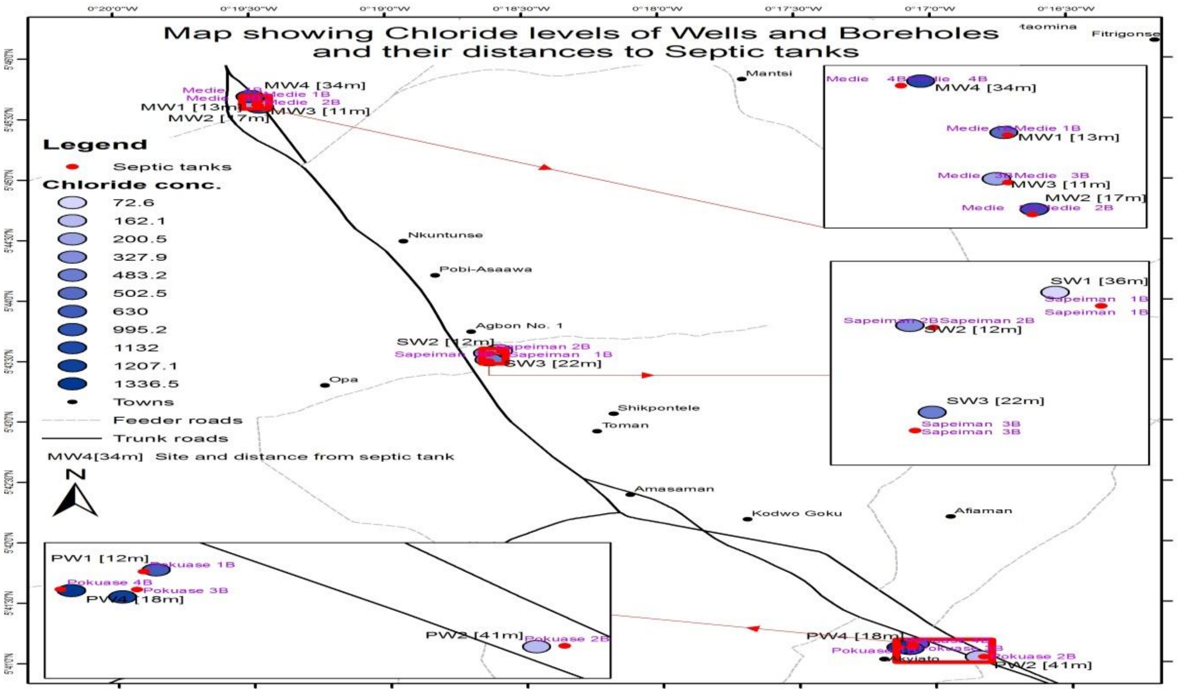

Figure 4. 14: Map showing mean chloride in relation to distance from septic tank in the Ga west District.

4.2.9 Salinity

The mean salinity of the water sample in the study area ranged from a minimum of 0.3ppt at site PW2 (borehole) at distance greater than 30m (control) to a maximum of 2.3ppt at site PW4 (well) at distance 0-15m and 16-30m (Figure 4.15). Analysis of variance at 95% confidence interval revealed a statistically significant differences(P<0.05) in salinity in relation to distances over the study period (Appendix B).When the LSD was used to compare the means, there were no differences between the distances 0-15m and 16-30m but were, however, different from the control. The values for the individual sites and distances are presented in Appendix A16.

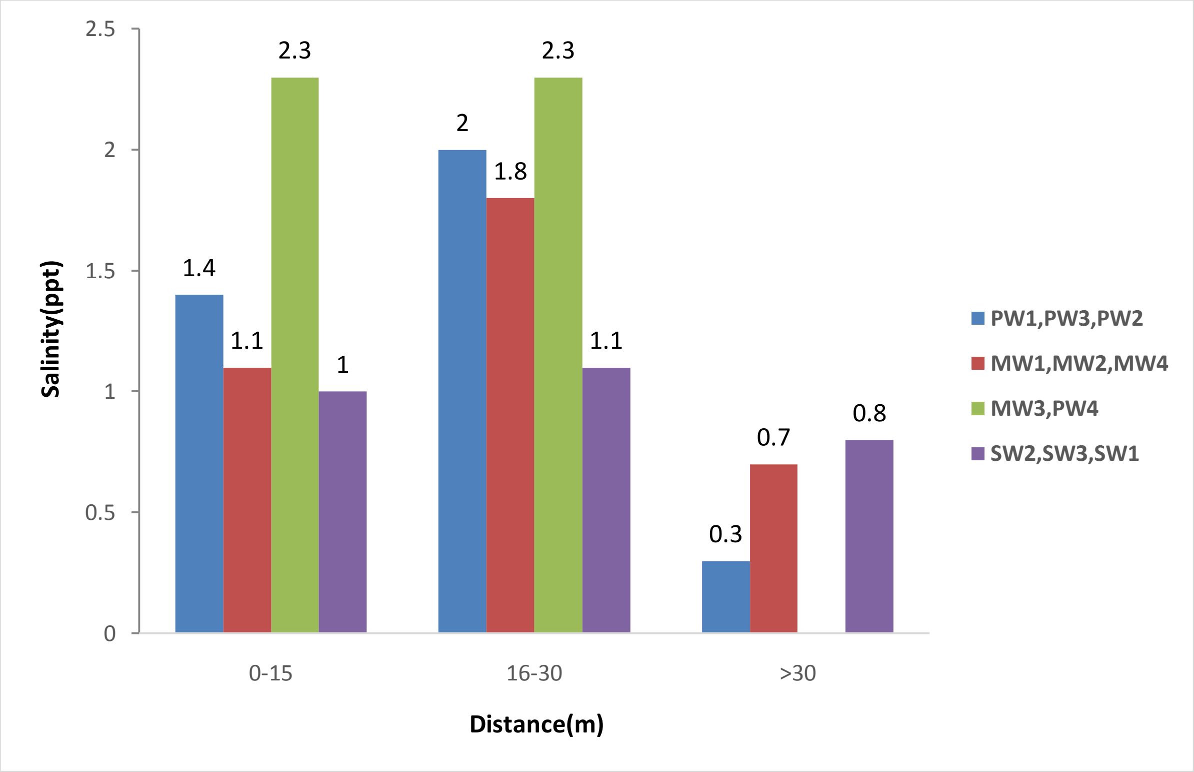

Figure 4. 15: Mean salinity in relation to distance from septic tank in the Ga west District.

4.2.10 Total Alkalinity

The total alkalinity did not show any statistically significant differences (P>0.05) in relation to distance for all the sampling sites during the sampling period. The mean values ranged from a minimum of 22mg/l at site PW2 (boreholes) at control distance (>30m) to a maximum of 399mg/l at site MW2 (well) at distance between 16-30m (Figure 4.16). The values for the individual sites and distances are presented in Appendix A17.

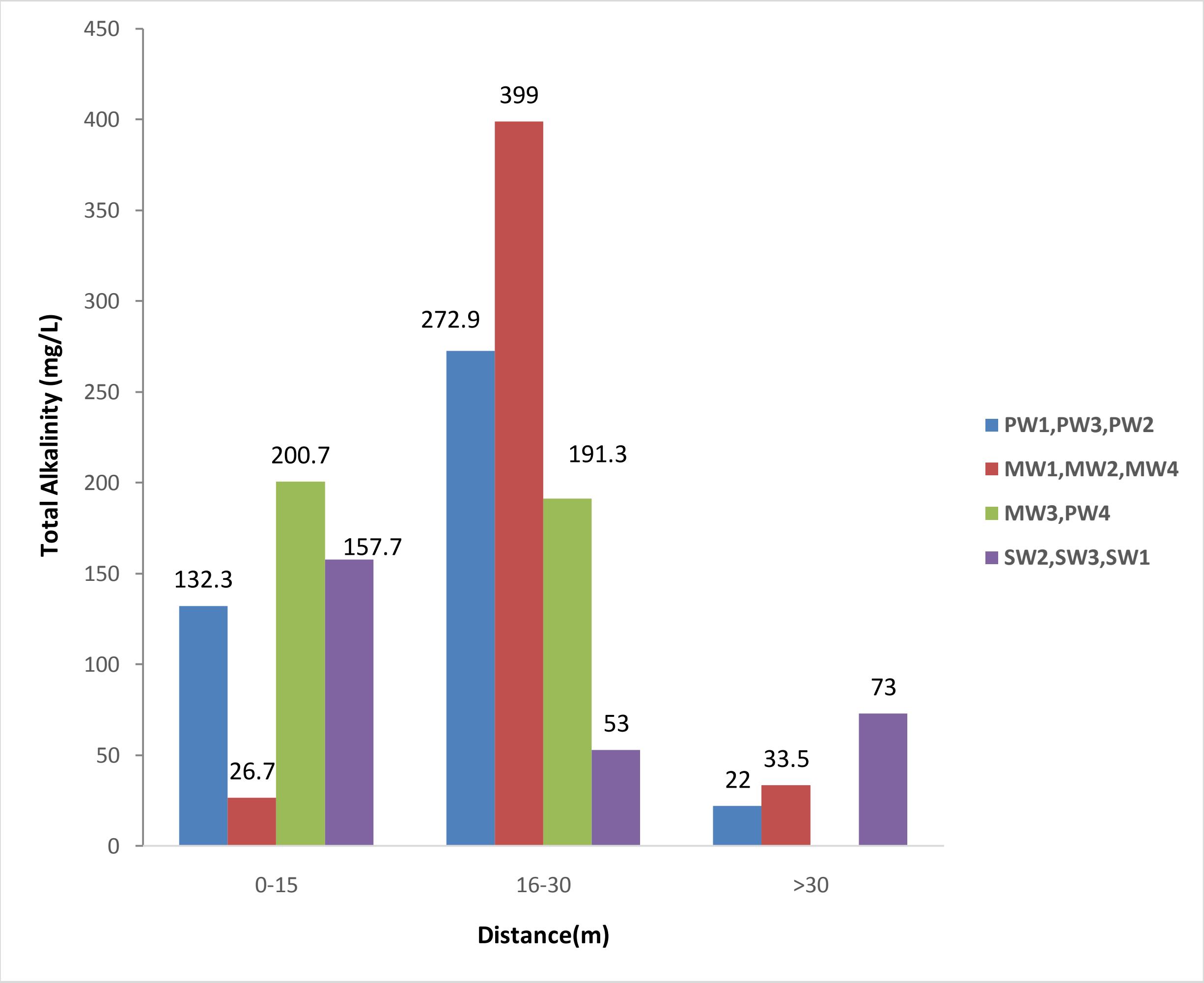

Figure 4. 16: Mean total alkalinity in relation to distance from septic tank in the Ga west District.

4.2.11 Sodium

Figure 4.17 shows graphical illustration of the mean sodium values of the water sample for the various sites at various distances. The mean values ranged from a minimum of 6.3mg/l at site SW1 (boreholes) at control distance (>30m) to a maximum of 43.1mg/l at site MW1 (borehole) at distance between 0-15m.The values for the individual sites and distances are presented in Appendix A15. Analysis of variance at 95% confidence interval revealed a statistically significant ($P<0.05$) differences in sodium in relation to distances over the study period (Appendix B). When the LSD was used to compare the means, there were differences between the distances 0-15m, 16-30m and the control.

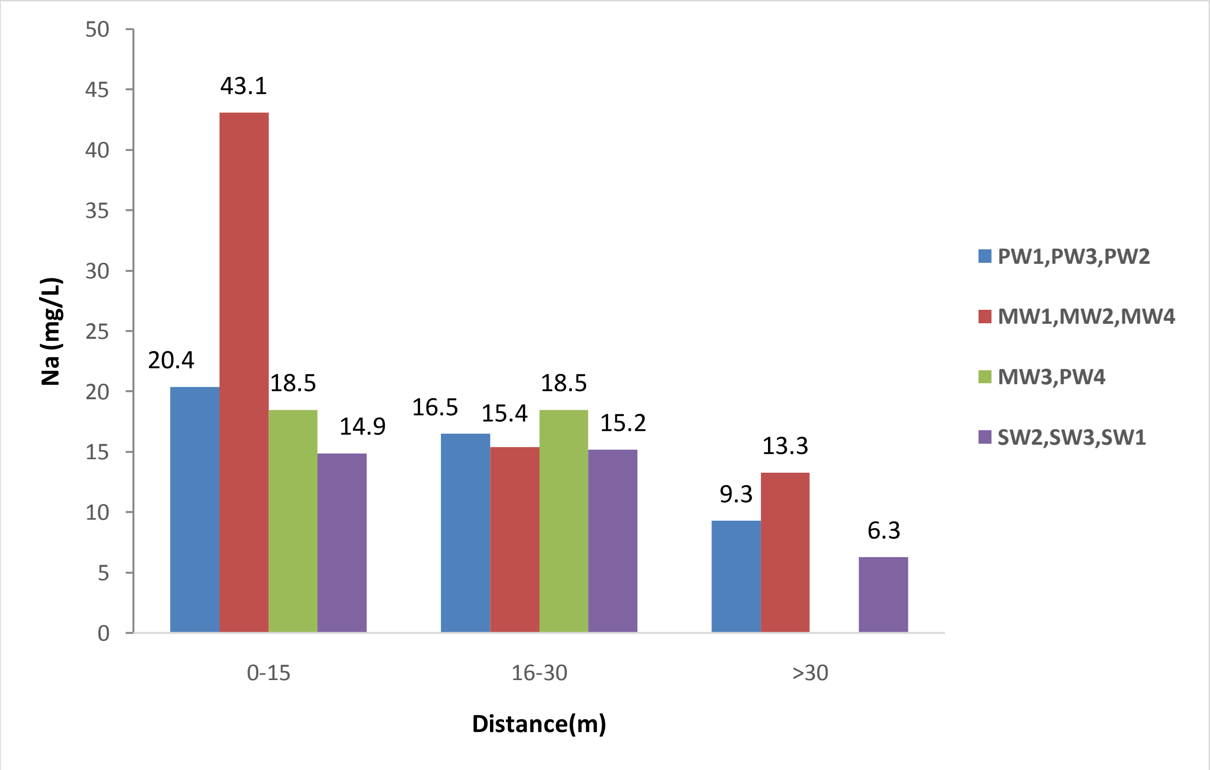

Figure 4. 17: Mean sodium in relation to distance from septic tank in the Ga west District.

4.2.12 Potassium

Figure 4.18 shows a map illustration of the mean potassium values of the water sample for the various sites at various distances. The mean values ranged from a minimum of 2.4mg/l at site PW4 (well) with distance 16-30m to a maximum of 48.9mg/l at site MW1 (borehole) at distance between 0-15m.The values for the individual sites and distances are presented in Appendix A18. Analysis of variance at 95% confidence interval revealed a highly statistically significant differences in potassium in relation to distance over the period (P<0.05)(Appendix B).When the LSD was used to compare the means, there were differences between the distances 0-15m, 16-30m and the control.

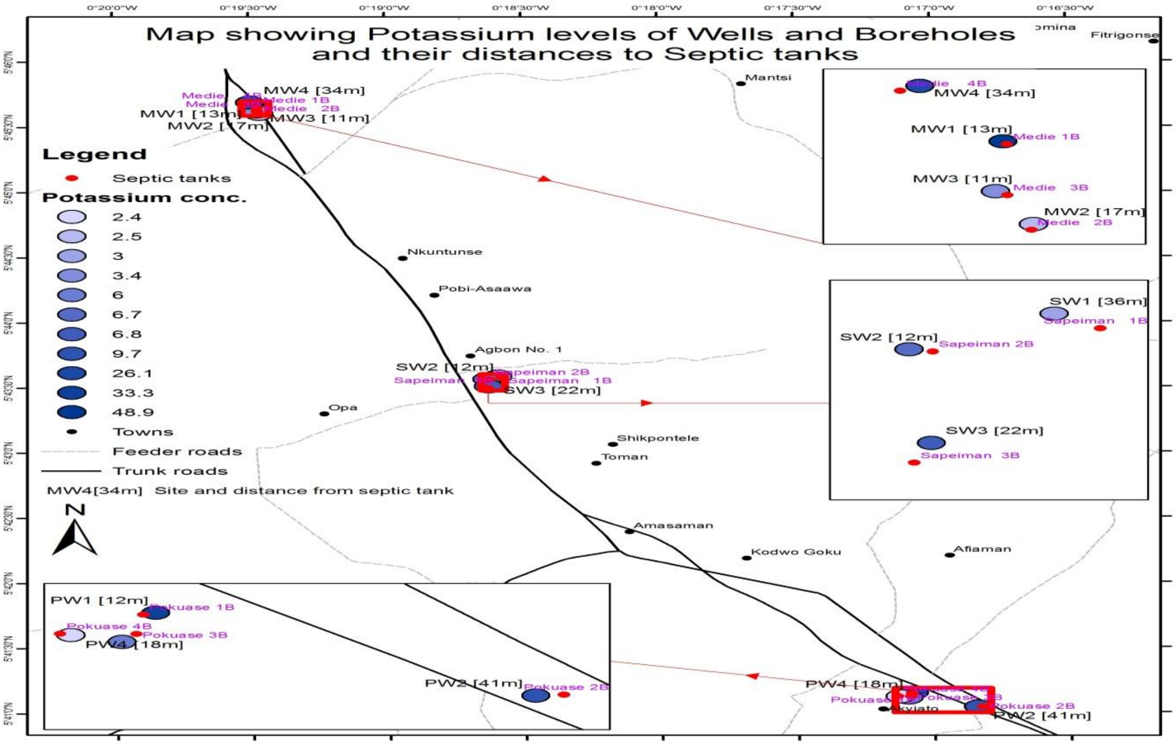

Figure 4. 18: Map showing mean potassium in relation to distance from septic tank in the Ga west District.

4.3 Bacteriological Parameters

4.3.1. *Total Coliform (TC)*

Figure 4.19 shows a map illustration of the mean total coliform/100ml of the water sample for the various sites at various distances. The mean values ranged from a minimum of 53cfu/100ml at site SW1 (borehole) at control distance (>30m) to a maximum of 463cfu/100ml at site PW1 (well) at distance between 0-15m.The values for the individual sites and distances are presented in Appendix A19. Analysis of variance at 95% confidence interval did not show any statistically significant (P>0.05) differences in total coliform population in relation to distances over the study period. Though not significant the mean total coliform population were generally higher at distances 0-15m and lowest at control distance (>30m).

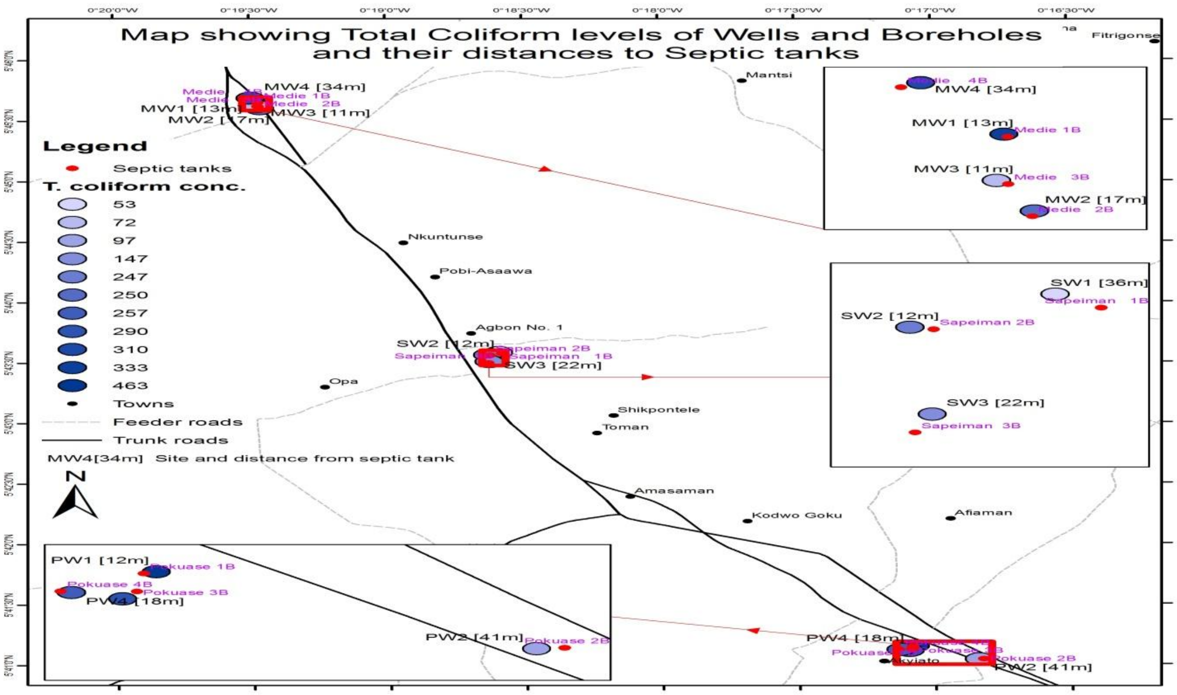

Figure 4. 19: Map showing mean total coliform in relation to distance from septic tank in the Ga west District.

4.3.2 *Faecal Coliform (FC)*

Figure 4.20 shows a map illustration of the mean faecal coliform per 100ml of the water sample for the various sites at various distances. The mean values ranged from a minimum of 0cfu/100ml at distances greater than 30m to a maximum of 143cfu/100ml at distance between 0-15m.The values for the individual sites and distances are presented in Appendix A20. Analysis of variance at 95% confidence interval did not show any statistically significant (P>0.05) differences in faecal coliform population in relation to distances over the study period. However, the mean total faecal coliform population were generally higher at distances 0-15m and lowest at distances greater than 30m (Control).

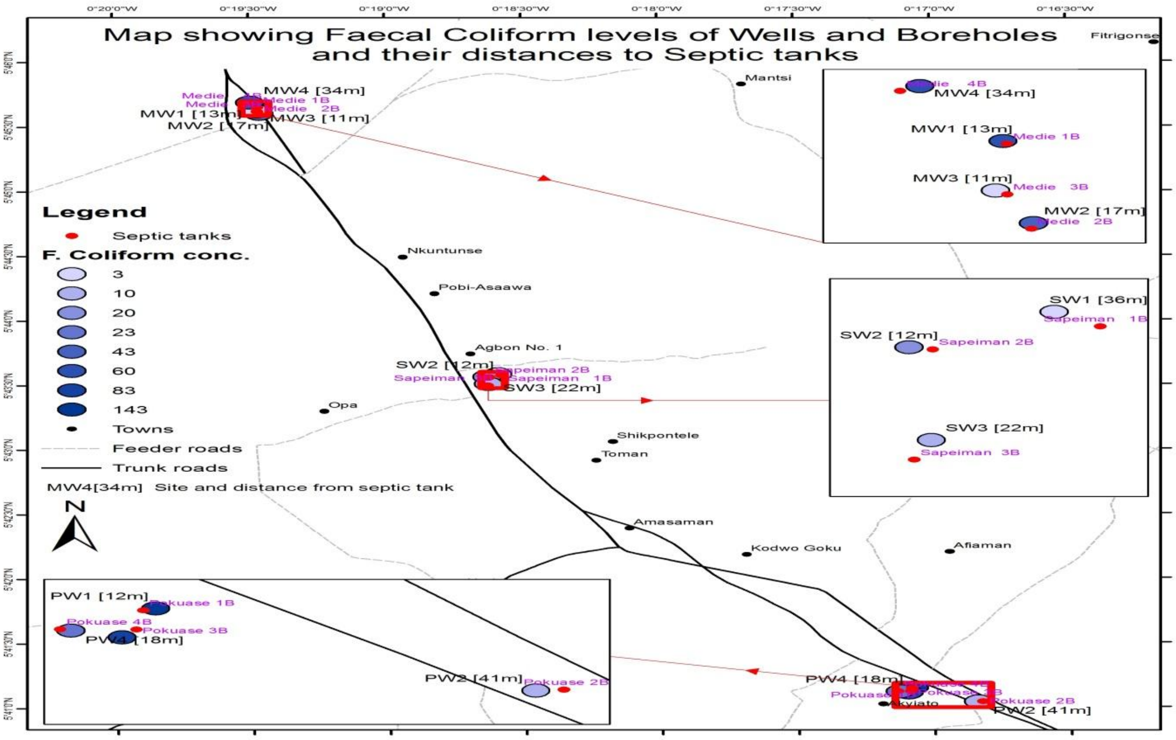

Figure 4. 20: Map showing mean faecal coliform in relation to distance from septic tank in the Ga west District.

4.4 Correlation between the physico-chemical parameters of well/borehole water sample

To investigate the association, the direction and strength of the physico-chemical parameters of the water sample in the study area in the Ga West district, Pearson's product moment correlation coefficient was used. Considerable numbers of significant positive correlation were observed between the following physico-chemical variables; Cl^- and conductivity ($r=0.726$, $P<0.05$), Cl^- and pH($r=0.683$, $P<0.05$), Cl^- and salinity ($r=0.784$, $P < 0.01$), Cl^- and Na ($r=0.809$, $P<0.01$), Cl^- and SO_4^{2-}($r=0.896$, $P<0.01$), Cl- and TDS ($r =0.727$,$P<0.05$), pH and Alkalinity ($r=0.790$, $P<0.01$)(Table 4.4).

The strong positive correlation between chloride and these physico-chemical variables is of significant health concern as research have shown that an increase in chloride and conductivity in water will lead to corrosion of metals that may leach it content into the water. If the pipe that distributes the water to the household is made of iron, then one may have high metal ions dissolved in solution rendering the water unwholesome for human consumption. The highly significant positive correlation between sodium ions and chloride ions is also of public health concern as high concentration of sodium ions in water will give objectionable salty taste to the water rendering it not suitable for human consumption. Table 4.4 below shows the significant strong positive correlation matrix between the physico-chemical parameters of the water sample. The entire correlation matrix however is shown in Appendix C.

Table 4. 1: Pearson's product-moment correlation coefficient between the studied parameters of well/borehole water.

VAR	Cl^-	EC	pH	TDS	Na	SO_4^{2-}	Sal
Cl-	1	0.726*	0.683*	0.727*	0.809**	0.896**	0.784*
EC		1	0.234	0.936**	0.735*	0.550	0.449
pH			1	0.086	0.544	0.762**	0.790*
TDS				1	0.737**	0.551	0.448
Na					1	0.877**	0.491
SO_4^{2-}						1	0.755**
Sal							1

*. Correlation is significant at the 0.05 level (2-tailed). **. Correlation is significant at the 0.01 level (2-tailed). Sal: salinity; EC: Electrical conductivity; TDS: Total dissolved solids;

4.5 Social Survey

4.5.1 Background of respondent

This section involves the analysis of the questionnaire administered to some individuals within residential houses in the selected communities in the study area. A total of 60 respondents from three communities namely; Pokuase (44%), Medie (33%) and Sapeiman (23%) were interviewed. With respect to sex of the individuals, 27 individuals representing 45% were males whilst 33 individuals representing 55% were females.

Figure 4.21 below shows the community in which the respondent resides.

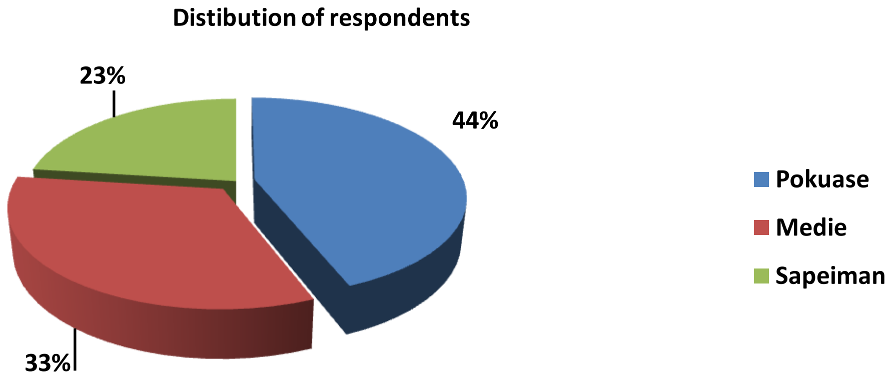

Figure 4. 21: Distribution of respondents in the study area of the Ga West District.

Source: Fieldwork, 2014.

Table 4.1 below also indicates the ages of the respondents in the study area. Twenty-seven(27%) of the respondent were below 20 years, 37%, 30% and 4% were between the ages of 20-29, 30-39 and 40-49 respectively whilst only 2% were 50years and above at the time of the interview.

Table 4. 2. Age of respondent in the study area of Ga West District.

Age Group (Years)	percentage (%)
below 20yrs	27.0
20-29yrs	37.0
30-39yrs	30.0
40-49yrs	4.0
50 and above	2.0
Total	100.0

Similarly, Sixteen percent (16%) of the respondent were students whilst 44% engage in various trading activities with 25% and 15% engaging in farming and public service work respectively. The figure below shows the occupation of the respondents in the study area.

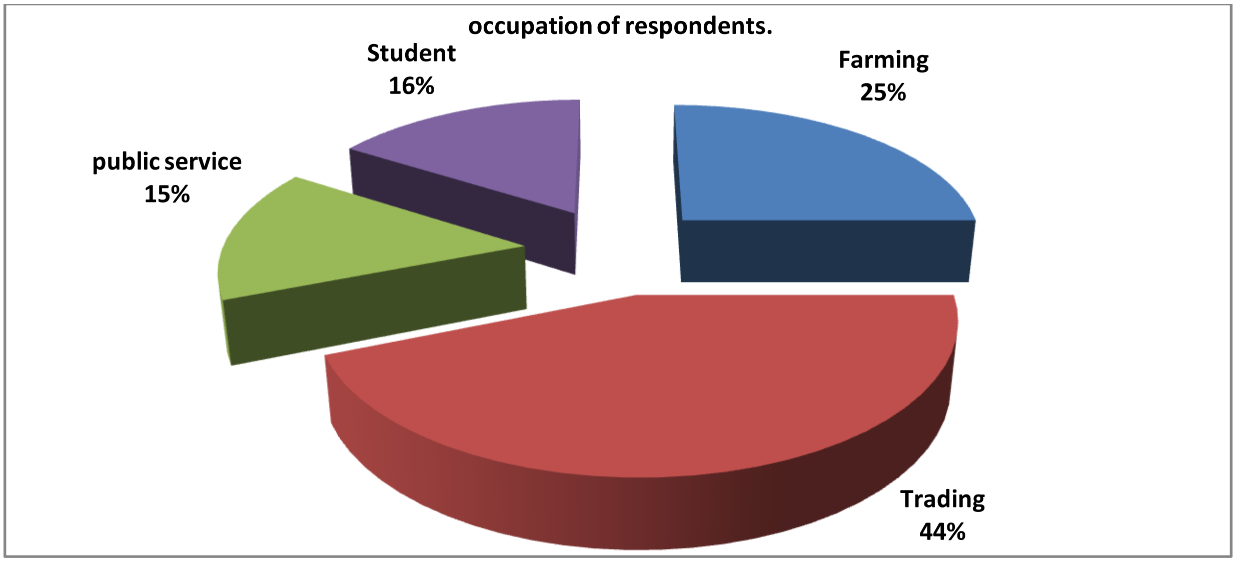

Figure 4. 22: Occupation of respondents in the study area of the Ga west District.

As part of the social appraisal, the educational levels of the respondents were sought as it plays a significant role in comprehensive understanding of issues relating to sanitation. Fifty-eight percent (58%) of the population had had SSS/6th form education whilst 27% had tertiary education indicating greater percentage of respondent who may have better understanding of sanitation and water related issues. However, the survey proves otherwise as when they were asked whether septic tank effluent in their own view can impact their wells or boreholes, only 36% answered in the affirmative whilst 64% had no idea about the possible impacts. Figure 4.23 below illustrates the educational level of the respondents in the study area.

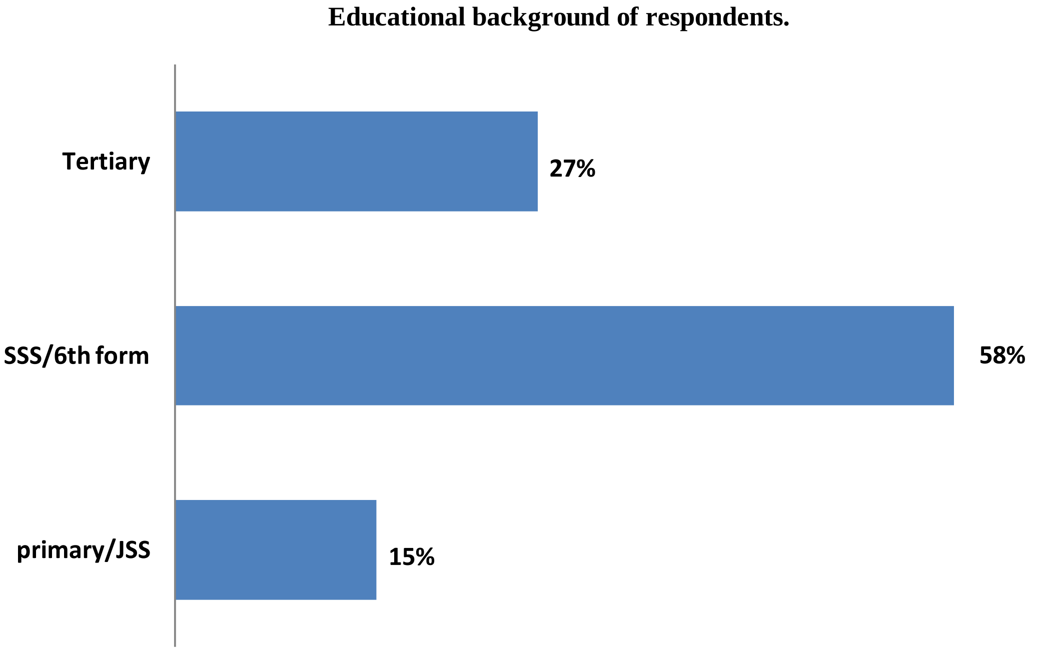

Figure 4. 23: Educational level of respondents in the study area of Ga West District.

Source: Fieldwork, 2014.

The respondents also noted health problems that are associated with the improper disposal of human excreta. These included; cholera, diarrhoea, typhoid fever, dysentery and buruli ulcer.

Almost all of the respondents interviewed were aware of at least one disease that were associated with improper disposal of septic sewage. Twenty-seven (27%) of the respondents indicated that diarrhea was a common disease contracted by improper disposal of human excreta whilst 25% indicated cholera. Typhoid fever and diarrhea (6%); Typhoid fever, diarrhea and cholera (13%); diarrhea and cholera (13%); Typhoid fever, cholera and dysentery (9%); Guinea worm, typhoid fever, cholera and dysentery (7%).Table 4.2 illustrates the respondents views on water borne diseases associated with improper disposal of human waste.

Table 4. 3: Views on diseases associated with human excreta in Ga West District.

waterborne disease	percentage (%)
Diarrhea	27.0
Cholera	25.0
Typhoid Fever and diarrhea	6.0
Typhoid Fever, diarrhoea, cholera	13.0
Diarrhoea and cholera	13.0
Typhoid fever, cholera and dysentery	9.0
Guinea Worm, typhoid fever, cholera, diarrhoea	7.0
Total	100.0

4.5.2 Water quality and Assessment

The main source of water in the study area includes pipe borne, wells, streams, boreholes and rivers (GWDA, 2012). Those in the rural environment mostly depend on wells and rivers whilst those in the urban depends on wells ,boreholes and pipeborne water for their domestic water requirement. However due to incessant supply of treated pipe borne water to most residents in the study area, majority of the residents rely on shallow wells and boreholes as the social survey indicated that 42% had boreholes and 58% had hand dug wells.

About 67% of the respondents had septic tanks within the confines of their homes that also host either a borehole or well. The survey revealed that 55% of this septic tanks were "soak aways" that leaches its effluent underground whilst 45% were "soak in" that is collected and emptied regularly when it is full. Fifteen percent (15%) of the septic tanks had their ages below 1 year as this were newly constructed residential apartments whilst 20% and 42% had their ages ranging from 1-10years and 11-20years respectively at the time the interview were sought. Twenty-three (23%) however, had their ages exceeding 20 years. The figure below illustrates the ages of the septic tanks.

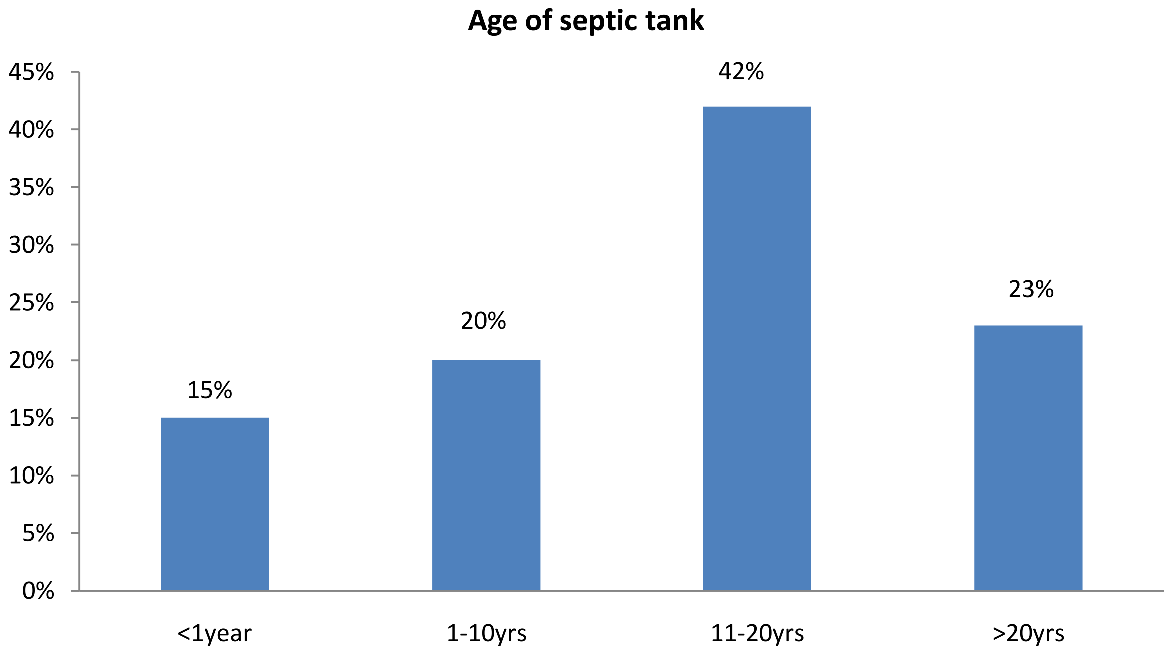

Figure 4. 24: Views of respondents on the age of septic tank in Ga West District.

Source: Fieldwork, 2014.

On the issue of septic tank distance to borehole or well, 26%, 20%,12% and 15% indicated that the distance between their borehole and septic tanks were 0-30m, 31- 60m, 61-90 and greater than 100m respectively. Twenty- seven (27%) however, did not know the distance between their septic tank and water source. Actual field measurement however proved otherwise as distances measured were between 11m -41m. The table below shows the respondents view on the distance between septic tank and their water source.

Table 4. 4: Perceptions of well/borehole owners on septic tank distance to their water source.

Sampling Code	Perceptive Distance (m)	Actual Distance Measured (m)
PWI	30.0- 50.0	12.0
PW2	80.0 -100	41.0
PW3	50.0 -60.0	23.0
PW4	40.0 -70.0	18.0
MW1	20.0 -30.0	13.0
MW2	30.0-40.0	17.0
MW3	50.0- 70.0	11.0
MW4	20.0-30.0	34.0
SW1	45.0-70	36.0
SW2	30.0- 60.0	12.0
SW3	40.0-50.0	22.0

Source: Fieldwork, 2014.

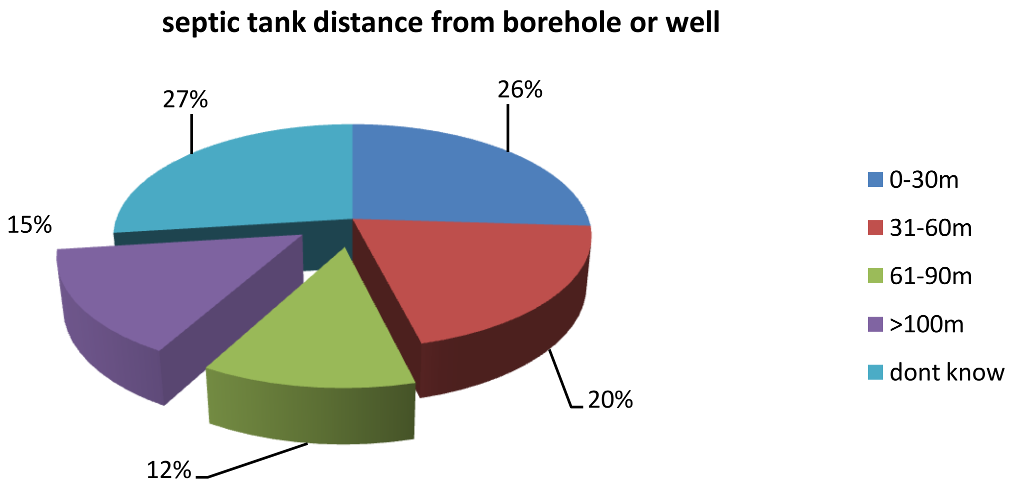

Figure 4. 25: Views of respondents on septic tank distance from borehole and well in the Ga West District.

Similarly information gathered indicated that the respondents use the borehole or well water for various purposes such as cooking, bathing, washing and drinking. About 90% of the respondents use the water for bathing, cooking and washing whilst 10% use for drinking. The respondents however noted that, the water was not used for drinking purposes because it was saline as 75%, 15% and 10% indicated that it was saline, clear and turbid respectively. One hundred percent (100%) of the respondents also admitted that the district assembly does not inspect their water source probably due to the fact that it is privately owned and how it should be managed and kept was left to the well and boreholes owners discretion. As a result, there were no rules and guidelines as to how boreholes or wells should be constructed, site evaluated to determine its suitability and maintenance in order to ensure its safety from anthropogenic impacts.

The views of respondents on how they dispose off refuse from their households were also sought as improper refuse disposal could impact on their boreholes and wells. The results revealed that 90% of the respondents contracts waste management companies such as Zoomlion and Asedu waste management to dispose off their waste. Ten percent (10%) however, practice burning as a means of disposing off their refuse. The various receptacles used in fetching the water could also be a potential source of contaminant to the water source.

CHAPTER FIVE

DISCUSSION

5.1 pH and Temperature

With the exception of site MW3 (borehole) placed at distance between 0-15m and PW4(well) placed at 16-30m that recorded a range of 6.4 to 7.2 pH units respectively, all the other water samples fell within the WHO range for portable water of 6.5-8.5. The results obtained indicated neutral to alkaline conditions and it is not surprising since Amoako *et al.* (2011) reported that the bedrock of the area is rich in limestone and sandstone which contains higher levels of carbonate and bicarbonates ions and since this ions have very high buffering capacity and can resist acidity, they may have accounted for the high pH levels recorded for the period. The mildly acidic pH levels recorded in site MW3 and PW4 however may be due to the dissolution of carbon dioxide from the atmosphere during water withdrawal or the presence of high level of organic matter within the soil zones whose oxidation releases carbon dioxide that reacts with water to produce a weak carbonic acid (Langmuir, 1997). Nkansah *et al.* (2010) reported that pH values lower than 6.5 are considered too acidic for human consumption and can cause significant health problems such as acidosis and adverse effects on digestive and lymphatic system. A drop in pH could also be harmful since metals are more soluble higher in low pH waters and thus could contain elevated levels of toxic metals posing a health hazard to consumers. Low pH can also cause damages to metal piping and staining of laundry. It was also observed from the study that pH correlates positively with chlorides, sulphate and salinity. This means an increase in alkaline conditions in the water will increase the salinity of the water rendering the water unusable for human consumption.

The water temperature did not show any significant variation in relation to distance. The natural background limit for WHO is between 22℃ to 27℃ (WHO, 1998). The temperature values obtained from sampled water for the entire study period were slightly above the natural background limit. Temperature is a critical factor of significant importance for aquatic ecosystem as it affects the water organism as well as the physico-chemical properties of water (Nkansah, 2010).The high temperature recorded could be due to some active microorganism activities in the water or possibly the different depth with which the samples were taken (Nkansah *et al*, 2010).

5.2 Conductivity, TDS, TSS, Turbidity

Electrical conductivity is the measure of the total dissolved ions in water. The conductivity of all the values recorded during the study period far exceeded the WHO regulatory limit of 250µS/cm. The high values indicated that the dissolve ions were too high for human consumption. Research have found that there is a positive correlation between conductivity and total dissolved solids (TDS) and the later may be obtained by multiplying conductivity by a factor between the ranges of 0.55-0.75 (Chapman, 1992).

Total dissolved solids is a measure of the total organic and inorganic substances dissolved in water (ANZECC, 2000).With the exception of site SW1 (borehole) and PW2 (borehole) at controlled distances that recorded 439.4mg/l and 751.5mg/l respectively, all the other sites between 0-15m and 16-30m far exceeded the WHO guideline limit of 1000mg/l. Total dissolved solids above 1000mg/l may be objectionable to consumers (WHO, 2004). The high levels of conductivity and TDS may be due to the natural geochemistry of the study area since the controlled sites at distances greater than 30m from the nearest septic tank also recorded slightly above the recommended limits. However, the significant increase in the concentration at distances between 0-15m and 16-30m could be due to some anthropogenic effects of which the source to indict could be the proximity of the wells to septic tank. These water samples are therefore not considered safe for consumption without adequate treatment because of its high dissolved salt content.

Total suspended solid relatively measure the visual observation of water sample. The TSS of the sampled water ranged from 13.7mg/l to 33.7mg/l indicating an excellent measure of the quality of the water for human consumption. The WHO value guideline dictates that, water must have a TSS value not exceeding 500mg/l for it to be considered safe (WHO, 2004). The values of TSS recorded for the entire study period was far below the recommended limit. This results is indeed not surprising and it confirms a similar report where TSS in ground water was found to be very low between 10mg/l to 45mg/l (Amoako *et al*, 2011).This low values may have arisen is as a result of the filtering capacity of the soil and earth materials that the water pass through before getting to the ground water acqifer as most suspended materials are effectively attenuated.

The WHO guideline for turbidity in drinking water is 5NTU (Nephelometic turbidity units). The turbidity ranged from 1.7NTU to 6NTU.With the exception of site SW3 (well) that recorded a mean turbidity value of 6NTU, all the other sites at various distances fell within the WHO permissible limit. Though the turbidity recorded is not alarming as far as this research is concern, the increase may have arisen from soil disturbance and resuspension within the well during water withdrawal as site SW3 was a sandpoint well.

5.3 Dissolved Oxygen (DO) and Biological Oxygen Demand (BOD)

The dissolved oxygen was generally low at sites placed at distances between 0-15m and 16-30m. The results of this research confirms a similar values reported for a well water in Western Niger Delta, Nigeria where the DO ranged from 3-7mg/l (Efe *et al*, 2005). The World Health Organization does not have a specific guideline for DO in drinking water, however, provisional health based guideline value of at least 7.5mg/l have been given for the purpose of public health protection (WHO, 1995). Almost all the samples recorded for the entire study period fell below the guideline value. The low DO recorded in the water samples may be due to high levels of oxidizable substances in the water sample such as sulphur and nitrogenous compounds which are oxidized to sulphate and nitrate respectively and also the decomposition of organic matter. The different depth with which the samples were taken could also influence the DO as dissolved oxygen decreases with depth. The high salinity levels and temperature recorded for the study could also not be rule out as high temperature encourages active microorganisms in water that consumes oxygen (Robertson, 1992). This low DO levels may encourage anaerobic respiration activities and could lead to bad odour in the water rendering it unwholesome for human consumption.

The BOD is a measure of organic matter contamination of water and therefore a good measure of the relative oxygen depleting effect of biodegradable pollutants in water. The World Health Organization recommends that, water considered to be safe for drinking should not have any material of organic origin (WHO, 2004). Though the BOD at the control sites were relatively lower compared to the sites with distances 0-15m and 16-30m, all the values exceeded the WHO permissible zero limit per 100ml rendering the water unsuitable for drinking purposes as it could pose health problem if not treated. The higher levels recorded may be due to the possibility of poor mixing of atmospheric oxygen into the water. There was a weak negative correlation between DO and BOD over the entire study period. The use of the water without treatment by well/ borehole owners may pose a health hazard.

5.4 Ions and Nutrients

5.4.1. Chloride, Sulphate and Phosphate- Phosphorus.

The WHO permissible limit for chloride in drinking water is 250mg/l (WHO, 2004). The mean chloride values in all the control sites fell within the WHO permissible limit, but the sites at distances 0-15m and 16-30m from the nearest septic tank recorded higher levels far above the permissible limits. It was observed from the study that the concentrations of chloride in water samples at distances between 0-15m and 16-30m were about four times higher than the WHO permissible limit of 250mg/l and also about three times higher than the control sites indicating that some anthropogenic influences might be at play with which the source to indict could be effluent from the septic tank close to them. Amoako *et al.* (2011) reported that higher levels of chloride in water may not have a health problem but its effects depend on the associated cation such as sodium, calcium, magnesium and potassium. The greatest effect is the objectionable salty taste if it combines with sodium ions forming sodium chloride in excess of 200mg/l (WHO, 2004). Most researchers have also found a positive correlation between sodium chloride salts in water and cardiovascular problems. The outcome of this research found chloride to have a significant strongly positive correlation with conductivity, TDS, pH, sodium, salinity and sulphate. This is of significant health concern as higher levels of this ions may pose a health problem to consumers. The Department of Natural Health and Welfare, Canada (1978) reported that chlorides in surface and ground water may result from both natural and anthropogenic sources such as run off containing salts, the use of mineral fertilizers, septic tank effluent, industrial leachate, intensive irrigation and sea water intrusion in areas close to the sea. The results obtained in this study agrees with a similar research work on ground water from wells from the vicinity of a cement factory in the Eastern region of Ghana where a mean chloride levels between 87.97mg/l to 5142.1mg/l were reported(Addo *et al*,2012).The higher levels were attributed to the natural geochemistry of the study area. The higher chloride levels obtained in this research work could be attributed to the natural geochemistry of the area. However, some anthropogenic factors could also not be ruled out as sites with distances between 0-15m and 16-30m recorded a mean value of 1336.5mg/l and 1132mg/l respectively which exceeded the recommended limits. In this research however, the source to indict will be the proximity of those wells to the septic tank since human wastes contain high levels of chloride salts.

Sulphate is also non toxic anion that is of significant health concern .The World Health Organization (WHO) recommends that concentrations of sulphate higher than 250mg/l should be reported to health authorities due to problem with catharsis, dehydration, gastrointestinal and digestive problems (WHO, 2005). Excess sulphate in water is also known to cause a laxative effect and also induce a bitter taste. About 60% of the water samples at sites between 0-15m and 16-30m had sulphate levels above the permissible limits. Manivaskam (2005) reported that sulphate occurs naturally in water as a result of leaching from rocks containing calcium sulphate (gypsum), sodium sulphate and magnesium sulphate (Epson salt). Increasing levels however may be attributed to anthropogenic effects with which the source to indict in this research may be due to the proximity of the wells to the nearest septic tank.

Phosphorus phosphate is a limiting nutrient for algae growth and a major cause of eutrophication in surface waters. This is a biological effects in which there is a successive increase in the concentration of plant nutrients and it therefore controls primary productivity of a water body(Karikari *et al*,2007).The presence of phosphate in water is a significant indicator of anthropogenic pollution. The phosphate level in the water sample ranged from 0.23mg/l to 1.1mg/l. The WHO does not have a specific regulation limit for phosphate concentration in water. Addo *et al.*(2011) also reported that phosphate concentration in most natural waters ranged from 0.005-0.020mg/l. Karikari *et al.*(2007) also reported that in pristine waters phosphate concentration may be as low as 0.001mg/l. The phosphate levels in the controlled samples were generally lower and fell within the ranges reported by Karikari *et al.*(2007) limit as compared to the sites with distances 0-15m whose phosphate level exceeded the permissible limit and the levels in most natural waters. Phosphate may not be toxic to humans unless they are present in very high levels where digestive problems could occur. Phosphorus in a form of orthophosphate may be present in septic tanks systems due to phosphorus rich human excrement or phosphate detergents and cleaning products (Pieterse *et al*, 2003).The source to indict the increasing levels may probable be to the proximity of septic tank to the water source.

5.4.2 *Nitrate-Nitrogen, Nitrite- Nitrogen, Ammonia-Nitrogen*

The nitrate levels recorded during the entire study period ranged from 2.2mg/l to 19.6mg/l. With the exception of site MW1 (borehole), SW2 (borehole) placed at 0-15m and at SW3 (well) placed at 16-30m that recorded a mean value of 16.6mg/l, 18.3mg/l and 19.6mg/l respectively, water samples from other sites fell within the WHO maximum contamination level (MCL) of 10mg/l. This research confirms a similar value reported by Arnade (1999) who also recorded a range between 4mg/l to 34mg/l in well water sampled at various distances to a septic tank. The presence of these nutrients in water is an in indication of faecal pollution. Baird(1999) reported that, high levels of nitrate in water are directly associated with Methemoglobaenimia or infant cyanosis, an acute condition which is most frequently found among bottle-fed infants less than three months of age. Nitrates have also been known to cause ailment like diarrhea and have also been suggested as a known carcinogen when it combines with amines to form nitrosamines by a number of researchers. Nitrates are conservative in shallow ground water hence its presence could be associated with anthropogenic factors such as animal waste, human waste and mineral fertilizers (Robertson and Cherry, 1995).The increasing levels of the outcome of this research may probably be due to the proximity of the wells to the nearest septic tank.

Nitrite-nitrogen is also a contaminant of significant health risk in water and hence need to be regulated in water. Nitrite in water is an indicator of biological pollution due to the presence of nitrogenous compounds (Addo *et al,* 2011).The World Health Organization has adopted 1 mg/l as the maximum contaminant level (MCL) for nitrite- nitrogen in water. The levels recorded during the entire study period was within the permissible limit and are not alarming to consumers of the water.

Ammonia is toxic to aquatic organisms but the toxicity however depends mainly on pH and temperature (Wilkels *et al,* 1998).The WHO guideline for ammonia in drinking water is 0.5mg/l (WHO, 1993).The ammonia levels in all the water samples during the entire study period was within the permissible limit. In an uncontaminated ground water, the value of ammonia is usually less than 0.1mg/l (Wilkels *et al,* 1995).

5.5 Total Alkalinity, Salinity and Sodium

Alkalinity of water is its capacity and ability to resist changes in acidity. Total alkalinity for portable drinking water according to WHO (2004) is 400mg/l. The concentrations in the water for the entire study period was within the WHO permissible limit. Alkalinity of 500mg/l is also accepted by the USEPA and Ghana water company (GWC). Alkalinity is apparently unrelated to public health but is very important in pH control. The major ionic species that contribute to alkalinity in water include carbonates, bicarbonates, hydroxides, phosphates, borate and organic acids. The low levels of alkalinity recorded for the entire study period may be attributed to the geology of the study area. The study area is characterized by sedimentary rocks comprising of limestone and sandstone which is very rich in carbonates and bicarbonates ions (Amoako *et al,* 2011).

Salinity is a measure of the total soluble or dissolved salt in water. It is normally a measure of the total dissolved solids or the electrical conductivity of the water. WHO recommends that water that is considered to be save for human consumption should not have salinity levels exceeding 200mg/l as it will induce a salty taste in the water (WHO, 2004). All the water samples analyzed for the entire study period exceeded the WHO permissible limit. This confirms result obtained from the social survey where 75% of the respondents confirmed that the water was saline and as such 85% according to the survey used the water for bathing, cooking and washing and not drinking due to its salty taste. The high salinity in the water samples may be attributed to the high levels of conductivity and total dissolved solids recorded over the study period which might have arisen as a result of the natural geology of the area and possibly the proximity of the wells and boreholes to septic tanks. The statistical analysis in this study also revealed a very high positive correlation between salinity and chloride ions.

Sodium is a highly soluble chemical element that is often naturally found in groundwater because most rocks and soils contain sodium compounds from which sodium is easily dissolved. The World Health Organization (WHO) recommends that sodium should not exceed 200mg/l (WHO, 1998). All The water samples for the entire study period fell within the WHO permissible limit of 200mg/l. The correlation matrix revealed a very strong positive correlation between sodium and chloride ions. This is of significant health concern since the cation and anion could combine to form sodium chloride salt which normally induces a salty taste in the water when the sodium ions exceed 200mg/l (WHO, 2003).

5.6 Faecal Coliform, Total Coliform.

For water to be considered safe for human consumption, coliform bacterial and *E. coli* in the water sample should be zero and the total heterotrophic bacteria (THB) count should not exceed 500 CFU/ml (WHO, 2004). Results from the study showed high levels of total and faecal coliforms population and the population decreases with increase in distance to the nearest septic tank. About 70% of the well and borehole sampled had their total and faecal coliform levels above the zero limit. The boreholes however, were least polluted as compared to the wells. It was evidently clear that the septic tank was imparting and extending their influence on the wells and boreholes under investigation. The high coliform counts could also be due to water withdrawal and unhygienic practices around the water points which could have caused the introduction of coliforms by the users (Pieterse *et al*, 2003). This high coliform counts therefore pose a significant health problem to the consumers of the water if the water is used without treatment. When respondents were asked during the social survey whether septic tank distance can influence their water source, about 63% answered no, indicating that a greater percentage of the interviewed population were not aware that septic tank could impact on their water source. This research outcome agrees with a similar one conducted by Umar (2008), in Asamankese in the Eastern Region of Ghana where he reported high faecal and total coliform counts in the well sampled. Ifabiyi (2008) also reported similar values. Akinbile and Yusoff (2011) recorded high values for total coliform counts in various groundwater wells in a study conducted in Ibadan, Nigeria.

The results of the study also confirms a similar research by Adetunji (2010) who investigated the impact of septic tank distances to wells in Agbowo community in Nigeria. Forty (40) wells were assessed for faecal coliform and total coliforms counts. The results indicated that all the wells sampled had high faecal and total coliform counts which exceeded the international standard of 0 per 100ml of portable water. Any water source used for drinking or cleaning purposes should not contain any organism of faecal origin (Akeredolu, 1991). The total and faecal coliform population increased with a decrease in distance between the wells and the septic tanks though not significant ($P<0.05$).This research outcome also agrees with the work of Nwachukwu and Otokunefor (2006) who also found a correlation between high bacterial load in borehole water supplies and discharges from septic tanks. Research over the years has shown that bacteria can be transported some distance through the ground by liquid leachate from a pit latrine or septic tank, and could thus contaminate local drinking water supplies drawn from groundwater and this may occur during the lateral movement of water beneath the ground.

CHAPTER SIX

CONCLUSION AND RECOMMENDATION

6.1 Conclusion

Physico-chemical and bacteriological characteristics of selected water sampling locations in residential apartment in the Ga west District were assessed to find out the potential quality of the water samples in relation to distance from septic tank effluent.

The concentrations of the physico-chemical parameters such as conductivity, total dissolved solids and major nutrient ions such as nitrate, phosphate, chlorides and sulphate in most of the water samples at distances between 0-30m far exceeded the WHO guideline and Ghana standard limit for drinking water and other domestic needs as compared to the control samples(>30m). The pH was generally excellent with the exception of site MW3 (borehole) and SW3 (well) between the distance 0-15 and 16-30m that recorded 6.3 and 6.4 respectively. The DO was also generally low throughout out the entire study period. The TSS, turbidity, BOD, ammonia, nitrite, potassium, sodium and total alkalinity however fell within the WHO permissible limit.

The bacteriological analysis also indicated high levels of microbiological pollution indicator organisms; total coliform and faecal coliform- *E. coli*. This therefore suggests that the water had been polluted with faecal material possibly from the septic sewage and at risk to contamination by disease causing pathogens. The entire study period recorded a high microbial load in most samples at distances between 0-15m and 16-30m but their population decreased with an increase in distance. The research revealed that the contaminant could influence up to about 30m of its radius, beyond which with the exception of oxygen decreases with an increase in distance. This is of significant health concern since about 90% of the households during actual field measurement had their septic tank to water source distances between 12m - 41m. Consumption of such water without adequate treatment will pose a health problem to the inhabitants of the study area since the septic tank may impact on the water source if it happens to be a "soak away" or if there is any possible leakages.

In the social survey however, it was revealed that over 64% of the inhabitants have septic tanks as onsite sewage disposal facility of which 55% were "soak aways". Results of this study are significant because, a large population of people in the study area mostly rely on septic tanks as onsite sewage disposal system and wells/boreholes as domestic water source. The consumers may be at risk of suffering from water borne illnesses and general ill health after consumption of the water without treatment. In addition, the problem of groundwater contamination through septic tank is not an isolated problem of the study area but rather a nationwide problem hence precautions should be taken by setting standards for sitting of wells and boreholes from septic tanks and treatment of well water before use. This current water quality situation therefore needs urgent intervention to ensure portable quality water for the people in the study area. The study therefore rejects the null hypothesis (Ho) that; There is no significant impact of septic tank effluent in relation to distance on ground water quality in the study zones and accept the alternative hypothesis (H_1); There is significant impact of septic tanks effluent in relation to distance on ground water quality in the study zones.

6.2 Recommendation

Based on the findings of the study, some effective measures were recommended. These suggestions will ensure efficient utilization and management of ground water and sanitary conditions in the study area.

- As the importance of safe guarding quality of water supply has become widely recognized, standards regarding septic tank placement should be reviewed by the district assembly if there be any at all. This can be achieved by imposing minimum lot size requirements larger than those which have been found to be associated with ground water contamination

- The district assemblies must impose a ban on “soak away” septic tanks and regularly inspect and monitor the water sources of the communities.

- The district assembly should educate the communities on the need to keep their surroundings clean most especially around the water sources.

- It is recommended that the hand dug wells and boreholes should be sited at least 30m away from the nearest septic tank and other potential contaminants like refuse dump within the confines of the residential facility.

- Hand-dug wells and boreholes were polluted by faecal mater and therefore the well and borehole owners should resort to treatment processes like boiling and effective chlorination before using the water for domestic purposes.

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LIST OF APPENDICES

APPENDIX A1: Temperature at the sampling site

	MONTH						
DISTANCES	**SITE**	**FEB**	**MAR**	**APR**	**MIN**	**MAX**	**MEAN**
0-15m	**PWI**	29.8	30.2	30	29.8	30.2	30
	MW1	28.5	28.6	29.5	28.5	29.5	28.9
	MW4	29.9	29.3	28.6	28.6	29.9	29.2
	SW2	28.8	28.9	29.2	28.8	29.2	30
MEAN							
16-30m	**PW3**	28.4	28.5	28.9	28.4	28.9	28.6
	MW2	28.5	28.4	27.8	27.8	28.5	28.2
	PW4	29.3	29.8	29.2	29.2	29.8	29.4
	SW3	29.1	29	28.5	28.5	29.1	28.9
MEAN							
>30m	**PW2**	30.6	34.2	30.5	30.5	34.2	31.8
	MW3	29	27.9	28.3	27.9	29	28.4
	SW1	28.4	28.2	28.6	28.2	28.6	28.4
MEAN							

APPENDIX A2: pH at the sampling site

	MONTH						
DISTANCES	**SITE**	**FEB**	**MAR**	**APR**	**MIN**	**MAX**	**MEAN**
0-15m	**PWI**	7.7	6.9	7.1	6.9	7.7	7.2
	MW1	6.9	6.4	6.6	6.4	6.9	6.6
	MW4	6.9	6.2	6	6	6.9	6.4
	SW2	7.1	6.5	6.1	6.1	7.1	6.6
16-30m	**PW3**	7.1	6.6	6.3	6.3	7.1	6.6
	MW2	6.9	6.3	6.2	6.2	6.9	6.5
	PW4	7.3	6.7	6.5	6.5	7.3	6.8
	SW3	6.8	6.2	6	6	6.8	6.3
MEAN							
>30m	**PW2**	6.8	6.4	6.2	6.2	6.8	6.5
	MW3	6.9	6.6	6.2	6.2	6.9	6.6
	SW1	6.9	6.1	6.4	6.1	6.9	6.5
MEAN							

APPENDIX A3: Conductivity(μS/cm) at the sampling site

	MONTH						
DISTANCES	**SITE**	**FEB**	**MAR**	**APR**	**MIN**	**MAX**	**MEAN**
0-15m	**PWI**	2550	5042	4452	2550	5042	4014.7
	MW1	4294	3019	2980	2980	4294	1444.3
	MW4	6243	3282	3125	3125	6243	4216.7
	SW2	2830	2129	2035	2035	2830	2331.3
MEAN							
16-30m	**PW3**	4794	3694	3454	3454	4794	3980.7
	MW2	4568	1171	1050	1050	4568	2263
	PW4	6237	5290	4654	4654	6237	5393.7
	SW3	3872	2781	2500	2500	3872	3051
MEAN							
>30m	**PW2**	1608	1118	998	998	1608	1241.3
	MW3	1020	950	870	870	1020	946.7
	SW1	965	633	428	428	965	675.3
MEAN							

APPENDIX A4: Total dissolved solids(mg/l) at the sampling site

	MONTH						
DISTANCE	**SITE**	**FEB**	**MAR**	**APR**	**MIN**	**MAX**	**MEAN**
0-15m	PWI	1415	3226.9	3400	1415	3400	2680.6
	MW1	2377	1932.2	2225	1932.2	2377	2178
	MW4	3431	2100	1910	1910	3431	2480.3
	SW2	1567	1362.6	1340	1340	1567	1423.2
MEAN							
16-30m	PW3	2636	2364.2	2245	2245	2636	2415.1
	MW2	2509	749.4	856	856	2509	1371.5
	PW4	3454	3385.6	3240	3240	3454	2929.9
	SW3	2148	1779.8	1950	1779.8	2148	1959.3
MEAN							
>30m	PW2	889	715.5	650	650	889	751.5
	MW3	1250	1061	1050	1050	1250	1120.3
	SW1	533	405.2	380	380	533	439.4
MEAN							

APPENDIX A5: Turbidity/NTU at the sampling site

	MONTH						
DISTANCES	**SITE**	**FEB**	**MAR**	**APR**	**MIN**	**MAX**	**MEAN**
0-15m	**PWI**	2	6	4	2	6	4
	MW1	1	3	4	1	4	2.7
	MW4	2	3	2	2	3	2.3
	SW2	2	1	3	1	3	2
MEAN							
16-30m	**PW3**	5	3	4	3	5	4
	MW2	3	2	5	2	5	3.3
	PW4	2	3	4	2	4	3
	SW3	6	7	5	5	6	6
MEAN							
>30m	**PW2**	2	1	2	1	2	1.7
	MW3	1	2	4	1	4	2.3
	SW1	3	4	2	2	4	3
MEAN							

APPENDIX A6: Total suspended solids(mg/l) at the sampling site

	MONTH						
DISTANCES	**SITE**	**FEB**	**MAR**	**APR**	**MIN**	**MAX**	**MEAN**
0-15m	**PWI**	16	31	42	16	42	29.7
	MW1	9	18	22	9	22	16.3
	MW4	14	9	11	9	14	11.3
	SW2	17	12	19	12	19	16
MEAN							
16-30m	**PW3**	22	16	18	16	22	18.7
	MW2	21	20	27	20	27	22.7
	PW4	21	17	28	17	28	22
	SW3	20	33	48	20	48	33.7
MEAN							
>30m	**PW2**	14	10	17	10	17	13.7
	MW3	10	18	18	10	18	15.3
	SW1	9	15	23	9	23	15.7
MEAN							

APPENDIX A7: Dissolved oxygen(mg/l) at the sampling site

	MONTH						
DISTANCES	SITE	**FEB**	**MAR**	**APR**	**MIN**	**MAX**	**MEAN**
0-15m	PWI	5.1	3.6	4.2	3.6	5.1	4.3
	MW1	3.8	3.8	4.5	3.8	4.5	4
	MW4	5.2	3.4	4	4	3.4	4.2
	SW2	5.3	4.8	5.3	4.8	5.3	5.1
MEAN							
16-30m	PW3	4.3	4.7	5.4	4.3	5.4	4.8
	MW2	3.6	4.8	5.7	3.6	5.7	4.7
	PW4	5.2	3.6	4.2	3.6	5.2	4.3
	SW3	4.6	3.4	4	3.4	4.6	4
MEAN							
>30m	PW2	6.3	6.8	7.4	6.3	7.4	6.8
	MW3	3.1	5	5.6	3.1	5.6	4.6
	SW1	3.7	3.2	3.9	3.2	3.9	3.6
MEAN							

APPENDIX A8: Nitrogen nitrate(mg/l) at the sampling site

	MONTH						
DISTANCES	**SITE**	**FEB**	**MAR**	**APR**	**MIN**	**MAX**	**MEAN**
0-15m	PWI	4.4	5.7	6.8	4.4	6.8	5.6
	MW1	12.4	16.9	20.4	12.4	20.4	16.6
	MW3	13	6.9	9.6	6.9	13	9.8
	SW2	13.2	18.4	23.4	13.2	23.4	18.3
MEAN							
16-30m	PW3	1.4	2.4	3.2	1.4	3.2	2.3
	MW2	1.1	2	3.5	1.1	3.5	2.2
	PW4	1.4	2.6	4.2	1.4	4.2	2.7
	SW3	13.4	19.9	25.6	13.4	25.6	19.6
MEAN							
>30m	PW2	5.1	6.4	7.3	5.1	7.3	6.2
	MW4	1.9	5.8	7.8	1.9	7.8	5.1
	SW1	4.6	7.1	7.6	4.6	7.6	6.4
MEAN							

APPENDIX A9: Biochemical oxygen demand(mg/l) at the sampling site

	MONTH						
DISTANCES	**SITE**	**FEB**	**MAR**	**APR**	**MIN**	**MAX**	**MEAN**
0-15m	**PWI**	1.1	1.6	2.1	1.1	2.1	1.6
	MW1	2.7	1.5	2.2	1.5	2.7	2.1
	MW3	0.7	1.8	2.5	0.7	2.5	1.7
	SW2	1.3	1.4	1.7	1.3	1.7	1.5
MEAN							
16-30m	**PW3**	2.5	1.3	1.8	1.3	2.5	1.9
	MW2	2.8	0.3	2.3	0.3	2.8	1.8
	PW4	4.5	2.3	3.2	2.3	4.5	3.3
	SW3	1.2	1.3	1.6	1.2	1.6	1.4
MEAN							
>30m	**PW2**	1.8	1.2	1.5	1.2	1.8	1.5
	MW4	0.2	0.7	1.3	0.2	1.3	0.7
	SW1	0.4	2	2.4	0.4	2.4	1.6
MEAN							

APPENDIX A10: Nitrogen nitrite(mg/l) at the sampling site

	MONTH						
DISTANCES	**SITE**	**FEB**	**MAR**	**APR**	**MIN**	**MAX**	**MEAN**
0-15m	**PWI**	0.009	0.009	0.006	0.006	0.009	0.008
	MW1	0.007	0.008	0.014	0.007	0.014	0.01
	MW3	0.002	0.011	0.019	0.002	0.019	0.011
	SW2	0.048	0.032	0.038	0.032	0.048	0.039
MEAN							
16-30m	**PW3**	0.011	0.007	0.009	0.007	0.011	0.009
	MW2	0.018	0.005	0.007	0.005	0.018	0.01
	PW4	0.051	0.033	0.042	0.033	0.051	0.042
	SW3	0.032	0.276	0.286	0.032	0.286	0.198
MEAN							
>30m	**PW2**	0.115	0.006	0.004	0.004	0.115	0.042
	MW4	0.006	0.007	0.003	0.003	0.007	0.005
	SW1	0.008	0.011	0.017	0.008	0.017	0.012
MEAN							

APPENDIX A11: Chloride(mg/l) at the sampling site

	MONTH						
DISTANCES	**SITE**	**FEB**	**MAR**	**APR**	**MIN**	**MAX**	**MEAN**
0-15m	PWI	1401.5	193.8	295	193.8	1401.5	630
	MW1	525	459.1	523.4	459.1	525	502.5
	MW4	1261.4	1009.7	1125	1009.7	1261.4	1132
	SW2	315.3	323.9	345	315.3	345	327.9
MEAN							
16-30m	PW3	1106.2	1250	1265	1106.2	1265	1207.1
	MW2	665.7	1084.8	1235	665.7	1235	995.2
	PW4	1466.6	1219	1324	1219	1466.6	1336.5
	SW3	460.5	469	520	460.5	520	483.2
MEAN							
>30m	PW2	165	158.8	162.5	158.8	165	162.1
	MW3	190	198.8	212.8	212.8	190	200.5
	SW1	95.1	63.7	58.9	63.7	95.1	72.6
MEAN							

APPENDIX A12: Sulphate(mg/l) at the sampling sites

	MONTH						
DISTANCES	**SITE**	**FEB**	**MAR**	**APR**	**MIN**	**MAX**	**MEAN**
0-15m	**PWI**	240	90	120	90	240	150
	MW1	108	430	485	108	485	341
	MW4	184	150	132	132	184	155
	SW2	76	75	82	75	82	77.7
MEAN							
16-30m	**PW3**	112	440	512	112	512	354.7
	MW2	112	460	476	112	476	349.3
	PW4	180	530	765	180	765	491.7
	SW3	73	33	48	33	73	51.3
MEAN							
>30m	**PW2**	21	18	14	14	21	17.7
	MW3	100	49	54	49	100	67.7
	SW1	41	37	29	29	41	35.7
MEAN							

APPENDIX A13: Nitrogen ammonia(mg/l) at the sampling site

	MONTH						
DISTANCES	**SITE**	**FEB**	**MAR**	**APR**	**MIN**	**MAX**	**MEAN**
0-15m	PWI	0.04	0.02	0.03	0.02	0.04	0.03
	MW1	0.01	0.23	0.21	0.01	0.23	0.15
	MW4	0.21	0.23	0.03	0.03	0.23	0.16
	SW2	0.03	0.01	0.02	0.01	0.03	0.02
MEAN							
16-30m	PW3	0.01	0.01	0.02	0.01	0.02	0.01
	MW2	0.02	0	0.01	0	0.02	0.01
	PW4	0.02	0.17	0.19	0.02	0.19	0.13
	SW3	0.04	0.06	0.02	0.02	0.06	0.04
MEAN							
>30m	PW2	0	0.01	0.02	0	0.02	0.01
	MW3	0	0.04	0.03	0	0.04	0.02
	SW1	0.01	0.02	0.02	0.01	0.02	0.02
MEAN							

APPENDIX A14: Phosphate(mg/l) at the sampling sites

	MONTH						
DISTANCES	**SITE**	**FEB**	**MAR**	**APR**	**MIN**	**MAX**	**MEAN**
0-15m	**PWI**	0.39	1.25	1.52	0.39	1.52	1.1
	MW1	0.35	0.36	0.45	0.35	0.45	0.39
	MW4	0.96	0.65	0.73	0.65	0.96	0.78
	SW2	0.42	0.37	0.42	0.37	0.42	0.4
MEAN							
16-30m	**PW3**	0.12	0.43	0.48	0.12	0.48	1.03
	MW2	0.17	0.14	0.23	0.14	0.23	0.18
	PW4	0.38	0.53	0.65	0.38	0.65	0.52
	SW3	0.42	0.53	0.59	0.42	0.59	0.51
MEAN							
>30m	**PW2**	0.09	0.31	0.35	0.09	0.35	0.25
	MW3	0.22	0.48	0.57	0.22	0.57	0.4
	SW1	0.26	0.15	0.29	0.15	0.29	0.23
MEAN							

APPENDIX A15: Sodium(mg/l) at the sampling sites

	MONTH						
DISTANCES	**SITE**	**FEB**	**MAR**	**APR**	**MIN**	**MAX**	**MEAN**
0-15m	**PWI**	23.4	14.7	23.2	14.7	23.4	20.4
	MW1	21.3	49.5	58.2	21.3	58.2	43.1
	MW4	21.7	18.9	14.8	14.8	21.7	18.5
	SW2	15.7	14.6	14.5	13.4	15.7	14.9
MEAN							
16-30m	**PW3**	17.9	16.3	15.4	15.4	17.9	16.5
	MW2	18.4	15.1	12.8	12.8	18.4	15.4
	PW4	21.6	18.2	15.7	15.7	21.6	18.5
	SW3	16.6	15	13.9	13.9	16.6	15.2
MEAN							
>30m	**PW2**	9.9	9.4	8.5	8.5	9.9	9.3
	MW3	15.8	9.6	14.5	9.6	15.8	13.3
	SW1	3.2	6.2	9.4	3.2	9.4	6.3
MEAN							

APPENDIX A16: Salinity(mg/l) at the sampling sites

	MONTH						
DISTANCES	**SITE**	**FEB**	**MAR**	**APR**	**MIN**	**MAX**	**MEAN**
0-15m	PWI	2.6	0.4	1.2	0.4	2.6	1.4
	MW1	1.2	1.1	0.9	0.9	1.2	1.1
	MW4	2.6	2.1	2.2	2.1	2.6	2.3
	SW2	0.9	0.9	1.1	0.9	1.1	1
MEAN							
16-30m	PW3	2.5	1.6	1.8	1.6	2.5	2
	MW2	1.4	1.8	2.1	1.4	2.1	1.8
	PW4	2.5	2.3	2	2	2.5	2.3
	SW3	1.1	1.1	1	1	1.1	1.1
MEAN							
>30m	PW2	0.4	0.4	0.2	0.2	0.4	0.3
	MW3	0.6	0.6	0.8	0.6	0.8	0.7
	SW1	2.1	0.2	0.2	0.2	2.1	0.8
MEAN							

APPENDIX A17: Total alkalinity(mg/l) at the sampling sites

	MONTH						
DISTANCES	**SITE**	**FEB**	**MAR**	**APR**	**MIN**	**MAX**	**MEAN**
0-15m	**PWI**	102	175	120	102	175	132.3
	MW1	26	20	34	20	34	26.7
	MW4	140	276	186	186	140	200.7
	SW2	260	93	120	93	120	157.7
MEAN							
16-30m	**PW3**	460	128.6	230	128.6	230	272.9
	MW2	660	217.2	320	217.2	660	399
	PW4	128	261	185	128	261	191.3
	SW3	34	57	68	34	68	53
MEAN							
>30m	**PW2**	23	15	28	15	28	22
	MW3	24	34.6	42	42	24	33.5
	SW1	140	41	38	38	140	73
MEAN							

APPENDIX A18: Potassium at the sampling sites

	MONTH						
DISTANCES	**SITE**	**FEB**	**MAR**	**APR**	**MIN**	**MAX**	**MEAN**
0-15m	**PWI**	25	33	42	25	42	33.3
	PW2	11.7	9.2	8.3	8.3	11.7	9.7
	MW3	6.5	5.3	6.2	5.3	6.5	6
	SW2	1.7	2.4	3.2	1.7	3.2	2.4
MEAN							
16-30m	**MWI**	50.9	49.5	46.5	46.5	50.9	48.9
	MW2	2	2.6	2.9	2	2.9	2.5
	MW3	2.9	3.1	4.3	2.9	4.3	3.4
	MW4	35.7	19	23.6	19	35.7	26.1
MEAN							
>30m	**SW1**	3.2	2	3.9	2	3.9	3
	SW2	7.9	5.8	6.3	5.8	7.9	6.7
	SW3	8.1	5	7.2	5	8.1	6.8
MEAN							

APPENDIX A19. Total coliform(cfu/100ml) at the sampling site

	MONTH						
DISTANCES	**SITE**	**FEB**	**MAR**	**APR**	**MIN**	**MAX**	**MEAN**
0-15m	**PWI**	480	570	340	340	570	463
	MW1	280	320	400	280	400	333
	MW4	420	300	210	210	420	310
	SW2	180	250	310	180	310	247
MEAN							
16-30m	**PW3**	300	280	290	280	300	290
	MW2	190	260	300	190	300	250
	PW4	360	260	150	150	360	257
	SW3	120	180	240	120	240	147
MEAN							
>30m	**PW2**	100	120	70	70	100	97
	MW3	80	60	76	60	80	72
	SW1	40	30	90	30	90	53
MEAN							

APPENDIX A20 : Faecal coliform(cfu/100ml)at sampling site

	MONTH						
DISTANCES	**SITE**	**FEB**	**MAR**	**APR**	**MIN**	**MAX**	**MEAN**
0-15m	**PWI**	30	210	190	30	210	143
	MW1	80	40	60	40	80	60
	MW4	20	60	40	20	60	60
	SW2	40	0	20	0	40	20
MEAN							
16-30m	**PW3**	20	120	110	20	120	83
	MW2	60	30	40	30	60	43
	PW4	10	40	20	10	40	23
	SW3	20	0	10	0	20	10
MEAN							
>30m	**PW2**	0	20	0	0	20	10
	MW3	10	0	0	0	10	3
	SW1	0	0	10	0	10	3
MEAN							

APPENDIX B: ANOVA FOR WATER QUALITY PARAMETERS

Parameter	**P-value**	**Mean**	**Standard Error**	**95% Confidence Interval for the Mean**	
				Lower	**Upper**
pH	0.541	6.6	0.07164	6.4541	6.7459
Temperature	0.328	29.5	0.20042	28.7554	29.5719
Conductivity	0.00	2867.8	294.27137	2268.3464	3467.1687
Total Dissolved Solids	0.00	1834.5	168.38887	1491.4688	2177.4636
Total Suspended Solids	0.045	19.5	1.55827	16.3714	22.7195
Turbidity	0.017	3.1	0.27093	2.5693	3.6731
Sulphate	0.004	190.2	34.49633	119.9151	260.4486
Nitrogen- Nitrate	0.036	8.7	1.18979	6.2250	11.0720
Nitrogen- Nitrite	0.156	0.04	0.011683	0.01126	0.05886
Dissolved Oxygen	0.392	4.6	0.18056	4.2231	4.9587
Chloride	0.00	640.9	83.33893	471.1381	810.6498
Sodium	0.004	17.4	1.83838	13.6462	21.1356
Potassium	0.00	13.5	2.68326	8.0768	19.0080
Salinity	0.001	1.3	0.13445	1.0564	1.6042
Nitrogen-ammonia	0.078	0.05	0.01299	0.0278	0.0807
Biochemical Oxygen demand	0.109	1.7	0.15347	1.4207	2.0459
Total Alkalinity	0.006	142.0	24.52058	92.0653	191.9589
TC(CFU/100ml)	0.215	229	245.75616	-320.14	765.03
FC(CFU/100ml)	0.242	41.6	38.57435	-43.4719	85.3709
Phosphate	Mg/l	-	<0.3	-	-

APPENDIX C: Correlation Matrix for physico-chemical parameters of water sample in the study area.

	EC	pH	TDS	TEM	TSS	TUR	DO	NO$_3^-$	BOD	NO$_2^-$	Cl$^-$	SO$_4^{2-}$	NH$_3$	PO$_4^{2-}$	Na	K	ALKA	SAL
EC	1	0.234	0.94^{**}	0.06	0.326	0.20	-0.23	-0.068	0.49	-0.01	0.726^{*}	0.299	0.380	0.469	0.735^{*}	0.348	0.391	0.552
pH		1	0.392	0.13	-.133	-0.19	-0.08	-0.360	0.08	-0.25	0.683^{*}	0.762**	-0.07	0.088	0.170	0.221	0.167	0.308
TDS			1	0.05	0.324	0.26	-0.28	-0.05	0.47	0.02	0.73^{**}	0.37	0.426	0.597	0.74^{**}	0.37	0.328	0.488
TEM				1	-0.246	-0.25	0.47	-0.038	-0.05	-0.04	-0.148	-0.15	0.062	0.184	-0.018	0.15	-0.243	-0.206
TSS					1	0.23	-0.17	0.234	0.08	0.33	0.36	0.320	0.252	0.102	0.075	0.113	0.019	0.300
TUR						1	-0.28	0.192	0.09	0.43	0.04	0.113	0.084	0.280	0.066	-0.04	0.166	0.038
DO							1	-0.053	-0.08	0.73^{**}	-0.01	-0.062	-0.23	-0.15	-0.162	-0.14	-0.183	-0.127
NO$_3^-$								1	-0.13	0.52	-0.532	-0.213	0.223	0.150	0.333	0.321	-0.39	-0.279
BOD									1	0.02	0.360	0.219	0.092	0.033	0.173	0.049	0.306	0.236
NO$_2^-$										1	-0.09	-0.203	-0.07	0.01	-0.103	-0.18	-0.150	-0.117
Cl$^-$											1	0.89^{**}	0.293	.042	0.809^{**}	-0.02	0.452	0.874^{**}
SO$_4^{2-}$												1	0.489	0.020	0.87^{*}	0.083	0.22	0.76**
NH$_3$													1	.271	.626	0.438	0.00	0.290
PO$_4^{2-}$														1	.140	.479	-0.08	0.07
Na															1	.695	-0.06	0.14
K																1	-0.23	0.02
AKAL																	1	0.50
SAL																		1

**.Correlation is significant at the 0.01 level (2-tailed).

*. Correlation is significant at the 0.05 level (2-tailed).

APPENDIX D: Drinking water standard of WHO, USEPA, EU and Ghana.

Parameter	Units	WHO	USEPA	EU	GHANA
pH Range	-	6.5-8.5	6.5-8.5	6.5-9.5	6.5-8.5
Temperature	^{0}C	22-29	-	-	-
Conductivity	µS/cm	250	250	250	-
Total Dissolved Solids	mg/l	1000	500	-	1000
Total Suspended Solids	Mg/l	NA	-	500	-
Turbidity	NTU	< 1-5	5	0-4	5
Sulphate	Mg/l	250	250	250	250
Nitrate	Mg/l	10	10	50	-
Salinity	Mg/l	200	-	-	-
Dissolved Oxygen	Mg/l	7.5	-	8.5(24^{0}C)	-
Chloride	Mg/l	250	250	250	-
Sodium	Mg/l	200	200	-	200
Calcium	Mg/l	200	-	-	-
Zinc	Mg/l	5	5	5	5
Iron	Mg/l	0.3	0.3	0.3	0.3
Copper	Mg/l	1.0	1.0	1.0	1.0
Alkalinity	Mg/l	400	-	-	500
TC(CFU/100ml)	0	0	0	0	0
FC(CFU/100ml)	0	0	0	0	0
Phosphate	Mg/l	-	-	-	-

Source: Gleick (1993) and Ghana standard Board (1997). (-) Not Determined, NA (Not Available).

APPENDIX E: QUESTIONAIRE

UNIVERSITY OF GHANA

INSTITUTE OF ENVIRONMENT AND SANITATION STUDIES

M.PHIL ENVIRONMENTAL SCIENCE PROGRAMME

TOPIC: SOCIO-ECONOMIC SURVEY ON BOREHOLE AND HAND DUG WELL WATER QUALITY AND SEPTIC TANK DISTANCES OF GA WEST DISTRICT OF GHANA.

INTRODUCTION: The administration of this questionnaire is to solicit responses from households and community members in order to assist the establishment of facts relating to the impacts of septic tank distances on well water quality. All the information is strictly for academic purposes and will be highly treated with the greatest level of confidentiality.

Date…………………………………………………………………………………………
…

Locality……………………………………………………………………………………
…..

Interviewer…………………………………………………………………………………
….

PART A: DEMOGRAPHIC INFORMATION OF RESPONDENTS

1 .House number……………………………………………………………………………

2. Sex ☐ male ☐ female

3. Age ☐ <20yrs ☐ 20-29 yrs ☐ 30-39yrs ☐ 40-49yrs ☐ 50-59 yrs ☐ >60yrs

4. Household size ☐ 1-4 ☐ 5-8 ☐ >9

5. Marital status ☐ single ☐ married ☐ divorced ☐ widowed

6. Occupation ☐ Farming ☐ ☐ trading ☐ public service others, specify…………….

7. Level of Education

☐ None ☐ primary/JSS ☐ SSS/6th Form ☐ Tertiary ☐ Non Formal

PART B. KNOWLEDGE OF RESPONDENT.

8. Do you have a toilet facility in your house ☐ Yes ☐ No

8a. if yes what type of toilet facility do you have in your home or community?

☐ Lined pit latrine ☐ unlined pit latrine ☐ KVIP ☐ vater closet

8b.if no where do you defecate?

☐ Refuse dump ☐ public toilet nearby ☐ others, specify…………

9. Do you have a water facility in your house ☐ Yes ☐ No

9a. .if yes what type of water facility ☐ Borehole ☐ Hand dug well ☐ pipeborne

9b. if no where do you or people without water access water?

☐ Borehole ☐ Hand dug well ☐ pipe borne streams ☐

10. What is the nature of the water from the well or borehole?

☐ Turbid ☐ Saline ☐ Clear ☐ coloured ☐ thers/specify

11. Do you have a septic tank in your house Yes ☐ No ☐

11a.If yes what type of septic tank ☐ soaks away ☐ soak away ☐ n’t know

12. How often do you pump the sewage from it? ………………………………………..

13. How old is the septic tank ☐ <1year ☐ 1-10yrs ☐ 11- 20yrs ☐ >20yrs

14. How far is the septic tank from the water source?

☐ 0-30m ☐ 31-60m ☐ 61-70m ☐ 71-90m ☐ >100m

15. Do you think the distance can have any impact on the water quality ☐ Yes ☐ No

15a. if yes what kind of impact?

☐ Poor odour ☐ water borne diseases ☐ poor taste ☐ others specify …………..

16. What human activities do you observe around the water source?

☐ Washing of automobiles ☐washing clothes ☐refuse dumping ☐others, specify…….

17. Do you receive health, water and sanitation education on proper use of toilet☐ Yes ☐ No

17a.If yes what are the sources of these messages?

☐ Radio ☐WATSAN Committee☐Environmental Health assistance ☐Community Nurses

18 .How do you consider this message?

☐Very Helpful ☐ Helpful ☐ Not Helpful ☐ Not Necessary

19. Do you have water management associations in your community?

☐Yes ☐ No ☐ don't know

20. Do you have rules governing the use of water in your community?☐Yes ☐ No

20a.If yes who enforces those rules

☐Chiefs ☐ district assembly ☐ CWSA ☐ others/specify…………

21. Mention some water borne diseases due to improper disposal of human excreta……….

……………………………………………………………………………………

PART C.ATTITUDE AND PERCEPTION OF RESPONDENTS

22. (a). What source of water do you prefer for household use?

☐Ground water ☐Rain water ☐ Surface water ☐ pipeborne

22(. b) Give reasons for your response in 22(a) above ……………………………………….

23. What do you use the water for? Tick as many as applied to you.

☐Washing ☐ Cooking ☐ Drinking ☐ Bathing

24a. Do you think groundwater can be contaminated by septic tank effluent☐ Yes ☐ No

24b. If yes how?...

PART 4.EXCRETA DISPOSAL, WATER QUALITY AND HEALTH

25. (a) DO you have any refuse dump in your house or community? ☐Yes ☐ No

25(b) if no where do you dump your refuse?

☐ Backyard ☐ burning ☐ composting ☐others/specify

25. (c) if yes how far is the refuse dump from the well or borehole?

☐ < 50m ☐ >50m

26. Does the District Assembly inspect your water source regularly? ☐Yes ☐ No

Thank you.

APPENDIX F: Multiple comparism of the mean difference in distance using the Least Significant difference (LSD).

Parameter	(I) Distance	(J) Distance	Mean Difference (I-J)	Std. Error	P-value	95% Confidence Interval	
						Lower Bound	Upper Bound
Electrical conductivity	0-15	16-30	-173.6666	505.3164	0.73	1205.6	858.3271
		> 30	2543.9722*	545.8041	0.00	1429.2	3658.652
	16-30	0-15	173.66667	505.3164	0.73	-858.27	1205.660
		>30	2717.639*	545.8041	0.00	1602.9	3832.319
	> 30	0-15	2543.972*	545.804	0.00	-3657	-1429.2
		16-30	2717.639*	545.8041	0.00	-3832	-1602.95
pH	0-15	16-30	0.12500	0.17001	0.48	-.2222	0.4722
		>30	0.20000	0.18363	285	-.1750	0.5750
	16-30	0-15	0-0.12500	0.17001	0.46	-.4722	0.2222
		>30	0.07500	0.18363	0.68	-.3000	0.4500
	> 30	0-15	-0.20000	0.18363	0.29	-.5750	0.1750
		16-30	-0.07500	0.18363	0.69	-.4500	0.3000
Total suspended solids	0-15	16-30	-85.85833	297.0905	0.775	-692.5	520.881
		> 30	1420.147*	320.8944	0.000	764.79	2075.501
	16-30	0-15	85.85833	297.0905	0.775	-520.8	692.5981
		> 30	1506.0055*	320.8944	0.000	850.65	2161.359
	>30	0-15	1420.147*	320.8944	0.000	-2075	-764.793
		16-30	1506.005*	320.8944	0.000	-2161.	-850.651
Temperature	0-15	16-30	0.49167	0.46771	0.302	-.4635	1.4468
		>30	-0.24722	0.50518	0.628	-1.278	0.7845
	16-30	0-15	-0.49167	0.46771	0.302	-1.447	0.4635
		>30	-0.73889	0.50518	0.154	-1.770	0.2928
	>30	0-15	0.24722	0.50518	0.628	-.7845	1.2789
		16-30	0.73889	0.50518	0.154	-.2928	1.7706
Total dissolved solids	0-15	16-30	-5.91667	3.40409	0.092	-12.87	1.0354
		>30	3.44444	3.67683	0.356	-4.065	10.9535
	16-30	0-15	5.91667	3.40409	0.092	-1.035	12.8687
		>30	9.36111*	3.67683	0.016	1.8520	16.8702
	>30	0-15	-3.44444	3.67683	0.356	10.95-	4.0647
		16-30	-9.36111*	3.67683	0.016	-16.87	-1.8520
Turbidity	0-15	16-30	-1.33333*	.57333	.027	-2.504	-.1624
		>30	.41667	.61926	.506	-.8480	1.6814

Turbidity							
	16-30	0-15	1.33333*	.57333	.027	.1624	2.5042
		>30	1.75000*	.61926	.008	.4853	3.0147
	>30	0-15	-.41667	.61926	.506	-1.681	.8480
		16-30	-1.75000*	.61926	.008	-3.015	-.4853
Dissolved oxygen	0-15	16-30	-.04167	.42391	.922	-.9074	.8241
		>30	-.58333	.45787	.212	-1.518	.3518
	16-30	0-15	.04167	.42391	.922	-.8241	.9074
		>30	-.54167	.45787	.246	-1.476	.3934
	> 30	0-15	.58333	.45787	.212	-.3518	1.5184
		16-30	.54167	.45787	.246	-.3934	1.4768
Nitrate	0-15	16-30	5.86667*	2.58050	.030	.5966	11.1367
		>30	6.63611*	2.78726	.024	.9438	12.3284
	16-30	0-15	-5.86667*	2.58050	.030	-11.14	-.5966
		> 30	.76944	2.78726	.784	-4.923	6.4618
	>30	0-15	-6.63611*	2.78726	.024	-12.33	-.9438
		16-30	-.76944	2.78726	.784	-6.462	4.9229
Biological oxygen demand	0-15	16-30	-.37500	.34530	.286	-1.080	.3302
		>30	.43889	.37296	.249	-.3228	1.2006
	16-30	0-15	.37500	.34530	.286	-.3302	1.0802
		> 30	.81389*	.37296	.037	.0522	1.5756
	> 30	0-15	-.43889	.37296	.249	-1.201	.3228
		16-30	-.81389*	.37296	.037	-1.575	-.0522
Nitrate	0-15	16-30	-.047833	.026613	.082	.-1022	.00652
		>30	-.002750	.028745	.924	-.0615	.05596
	16-30	0-15	.047833	.026613	.082	-.0065	.10218
		>30	.045083	.028745	.127	-.0136	.10379
	> 30	0-15	.002750	.028745	.924	-.0559	.06146
		16-30	-.045083	.028745	.127	.10379	.01362
Chloride	0-15	16-30	357.3083*	139.959	.016	643.14	-71.472
		>30	503.1083*	151.174	.002	194.37	811.846
	16-30	0-15	357.3083*	139.959	.016	71.47	643.144
		>30	860.4166*	151.174	.000	551.64	1169.15
	>30	0-15	-503.108*	151.174	.002	-811.8	-194.370
		16-30	-860.416*	151.174	.000	1169.1	-551.67
Sulphate	0-15	16-30	-130.750	69.7689	.071	273.24	11.7373
		>30	140.66667	75.3591	.072	13.237	294.570
	16-30	0-15	130.75000	69.7689	.071	11.737	273.237
		>30	271.4166*	75.3591	.001	117.13	425.320
	>30	0-15	-140.6666	75.3591	.072	-294.5	13.2372
		16-30	271.4166*	75.35913	.001	-425.3	-117.512
Nitrogen Ammonia	0-15	16-30	.04167	.02890	.160	-.0174	.1007
		>30	.07250*	.03121	.027	.0088	.1362
	16-30	0-15	-.04167	.02890	.160	-.1007	.0174
		>30	.03083	.03121	.331	-.0329	.0946

	>30	0-15	-.07250*	.03121	.027	-.1362	-.0088
		16-30	-.03083	.03121	.331	-.0946	.0329
	0-15	16-30	.26667*	.11141	.023	.0391	.4942
		>30	.35361*	.12034	.006	.1078	.5994
	16-30	0-15	-.26667*	.11141	.023	-.4942	-.0391
		>30	.08694	.12034	.476	-.1588	.3327
	>30	0-15	-.35361*	.12034	.006	-.5994	-.1078
		16-30	-.08694	.12034	.476	-.3327	.1588
Sodium	0-15	16-30	7.80000*	3.69299	.043	.2579	15.3421
		>30	14.59722*	3.98888	.001	6.4508	22.7436
	16-30	0-15	-7.80000*	3.69299	.043	15.342	-.2579
		>30	6.79722	3.98888	.099	1.3492	14.9436
	>30	0-15	14.59722*	3.98888	.001	22.743	-6.4508
		16-30	-6.79722	3.98888	.099	- 14.94	1.3492
Potassium	0-15	16-30	24.34167*	4.23445	.000	15.697	32.9896
		>30	23.36667*	4.57373	.000	14.025	32.7075
	16-30	0-15	24.34167*	4.23445	.000	-32.98	15.6938
		>30	-.97500	4.57373	.833	-10.31	8.3658
	N>30	0-15	23.36667*	4.57373	.000	-32.70	14.0259
		16-30	.97500	4.57373	.833	-8.365	10.3158
Total Alkalinity	0-15	16-30	-99.73333	50.19685	.056	202.24	2.7823
		>30	86.48889	54.21880	.121	-24.24	197.2184
	16-30	0-15	99.73333	50.19685	.056	-2.782	202.2490
		>30	186.2222*	54.21880	.002	75.492	296.9518
	>30	0-15	-86.48889	54.21880	.121	-197.2	24.2407
		16-30	186.222*	54.21880	.002	296.95	-75.4927
Salinity	0-15	16-30	-.33333	.25844	.207	-.8611	.1945
		>30	.82222*	.27914	.006	.2521	1.3923
	16-30	0-15	.33333	.25844	.207	-.1945	.8611
		>30	1.15556*	.27914	.000	.5855	1.7256
	>30	0-15	-.82222*	.27914	.006	-1.392	-.2521
		16-30	-1.15556*	.27914	.000	-1.725	-.5855
*. The mean difference is significant at the 0.05 level.							