KWAME NKRUMAH UNIVERSITY OF SCIENCE AND TECHNOLOGY

COLLEGE OF SCIENCE

DEPARTMENT OF THEORETICAL AND APPLIED BIOLOGY

IMPACT OF PIT LATRINES ON GROUNDWATER IN SOME SELECTED TOWNS IN THE TANO DISTRICTS

BY

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JULY, 2012

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A thesis submitted to the Department of Theoretical and Applied Biology, Kwame Nkrumah University of Science and Technology, in partial fulfillment of the requirements for the degree of Master of Science (Environmental Science)

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July, 2012

DECLARATION

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

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DEDICATION

I wish to dedicate this work to the one who is, who was and who is about to come, the Lord Jesus for his hand that has been upon me up to this time. Also to my cherished parents, Mr. Edward Manu and Madam Rose Duku through their pieces of advise I have derived a lot of lessons in my life

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ABSTRACT

In resource-poor and low-population-density areas, on-site sanitation is preferred to off-site sanitation and groundwater is the main source of water for domestic uses. Groundwater pollution potential from on-site sanitation in such areas conflicts with Integrated Water Resources Management (IWRM) principles that advocate for sustainable use of water resources. Given the widespread use of groundwater for domestic purposes, maintaining groundwater quality is a critical livelihood intervention.

This study assessed impacts of pit latrines on groundwater quality in some selected towns in the Tano districts, Ghana. Groundwater samples from 5 boreholes and 10 hand dug wells were analyzed during 4 sampling campaigns, in the latter part of March, 2011 and part of November, 2011. Parameters analyzed were total and faecal coliforms, E coli, Samonella, Enterococci, both for boreholes and hand dug wells. Depth from the ground surface to the water table for the seasons, dry and wet was determined for all sampling points using a tape measure. Soil from the monitoring wells was classified as clayey. The soil infiltration layer was taken as the layer between the pit latrine bottom and the water table. A questionnaire survey revealed the prevalence of diarrhoea .Results indicated that pit latrines were microbiologically impacting on groundwater quality even at 44.7m lateral distance. Salmonella were of no immediate threat to health. The shallow water table increased pollution potential from pit latrines. Raised and lined pit latrines and other low-cost technologies should be considered to minimize potential of groundwater pollution.

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ACRONYMS

ANOVA	**Analysis of variance**
PLD	Depth of pit latrine
LS	Lateral Separation
TC	Total coliform
FC	Faecal coliform
EC	Enterococci
Sri	Serial
WHO	World Health Organisation
UNICEF	United Nations Children's Educational Fund
MWRWH	Ministry of Water Resources Works and Housing

CHAPTER ONE

INTRODUCTION

1.1. Background Information

Water is essential to the existence of man and all living things. Water is a crosscutting element of the growth and poverty reduction strategy (GPRS) of the Republic of Ghana and is linked to the entire Millennium Development Goal. Improving water services and uses are essential for increasing hygiene and sanitation service levels that affect productive lives of people. This enhances enrolment and retention of girls in school. It also enhances women's dignity and their ability to lead a healthy life to reduce mortality, pre and post natal risk and to prevent vector and water borne diseases. Above all, health, nutrition and food production are dependent on availability of water in adequate quantities and good quality.

Worldwide, water-borne diseases are a major cause of morbidity and mortality in humans (WHO, 1996). Whilst water-borne pathogens infect around 250 million people per year, resulting in 10–20 million deaths (Anon, 1996), many of these infections occur in developing nations that have sanitation problems (Nsubaga *et al*., 2004). Lewis *et al*. (1980) also reiterated that diseases caused by pathogens and related to the use of contaminated groundwater, are the greatest cause of death in developing countries. In countries such as Zimbabwe, South Africa and Ghana, most of the rural communities are poverty-stricken, lack access to potable water supplies and rely mainly on shallow wells, rivers, streams and ponds for their daily water needs (Nevondo and Cloete, 1999).

In most cases water from these sources is used directly without treatment and the water sources may be faecally contaminated (WHO, 1993). Simple low-cost on-site sanitation methods have been developed to dispose faecal matter, mainly because of their economic advantage. However, the biggest drawback is the well-recognized potential to pollute groundwater resources (ARGOSS, 2001; Lewis *et al*., 1980), which conflicts with Integrated Water Resources Management principles, in particular to preserve the integrity of vital ecosystems and to maintain water quality and quantity. Given the widespread use of groundwater for domestic purposes in rural areas, maintaining groundwater quality is a critical livelihood intervention.

Globally, the larger part of the population lives in rural areas and in Africa it is estimated that these people represent approximately 70–80% of the continent's population. The rural population is about 70% (the derived figure is 68%), with that same percentage relying on groundwater (Chenje *et al*., 1998). The reliance may be higher in some districts where rural communities mainly use groundwater for domestic purposes with very little reliance on surface water and the predominant form of sanitation is pit latrines. Yet there is an information gap on the levels of groundwater contamination from pit latrines (Chenje *et al*., 1998; Chidavaenzi *et al*., 1999). Therefore the quality of groundwater, which potentially can be affected by on-site sanitation systems, must be carefully assessed in order to reduce the health and environmental risks.

In Ghana, the situation is not different. As is the case with most Districts in the country, the people of the Tano Districts, where this study was conducted, mainly use groundwater as a source of domestic water and for other purposes and pit latrines for sanitation. The geological set up and soil types in the area, compounded by a generally high water table, are thought to have caused several pit latrine failures such as cracking and sinking (Tano North District Profile, 2010). According to Lewis *et al*. (1980), failure of on-site sanitation systems may result in serious pollution of groundwater, the primary cause for health concerns being the excreted pathogens and certain chemical constituents like nitrate.

1.2 Statement of the problem

The vital position of water in the lives of humankind underscores the need to vividly ensure that certain measures are put in place to make the right quality of water available as it is needed. Ampofo (1996), reported that serious outbreak of cholera and diarrhea related diseases are due to faecal contamination of water bodies from overdependance on pit and KVIP latrines. According to Kimani-Murage and Ngindu (2003), where the distance between wells and pit latrines is not adequate, micro organisms can migrate from the latrine to the water in the well.

Contact with Human excreta and lack of adequate personal and domestic hygiene have been implicated in the spread of many infectious diseases including cholera, typhoid, polio, cryptosporidiosis, ascariasis and schistosomiasis. It is estimated that one third of deaths in developing countries are caused by the consumption of contaminated water and on average as much as one tenth of each person's productive time is sacrificed to water related diseases. The world health organization estimated that 2.2 million people die annually from diarrhea diseases and 10% of the populations of the developing world are severely infected with intestinal worm related to improper waste and excreta management.

Kimani-Murage and Ngindu (2003) have reported that where groundwater is used as a source of domestic water, the use of pit latrine is not recommended because the two are incompatible unless the water table is extremely low and soil characteristics are not likely to contribute to contamination of groundwater. Where they co-exist, although it is difficult to give a general rule for all soil conditions, the commonly used guidelines are that, the well should be located in an area higher than at least 15m from the pit latrine and should be at least 20m above the water table. However, in Tano North District of Brong Ahafo Region, people construct pit latrines without considering any guideline despite the reliance of many people on wells and boreholes as sources of drinking water and water for domestic purposes. Recent reports from the Tano North District Health Directorate (2011), indicate that many people in the Districts complain of typhoid and other diarrhea related diseases. The information indicated that in the year, 2009, 656 people in the District reported on diarrhoea related diseases. This increased to 1013 in 2010 and 1020 in 2011.The report also showed that most of these people are inhabitants of the Zongo community where the people use wells as the main sources of water for domestic purposes and pit latrine for sanitation.

It is in the light of this that this study assesses the contribution of pit latrine to the menace, taking levels of total and faecal coliforms, *Ecoli*, Samonella and enterococci as impact indicators. The parameters were chosen because a wide range of studies internationally have demonstrated that they are problematic with regards to onsite sanitation. Some of the parameters also tend to have an effect on the perceived water quality and health. The overall aim of the study is to help improve safe groundwater supply and sanitation.

1.3 Purpose of the study

The promotion of pit latrine has traditionally been done with very little knowledge of its impact on the groundwater in Ghana. The presence of poorly designed pit latrines as well as poor and inadequate groundwater protections in the Tano North District have the potential to contaminate spring water and water wells. This might have led to several reports (2010) from the District Health Directorate of water borne diseases, especially, diarrhea and typhoid. The purpose of this study is to identify the effects of pit latrines on the groundwater in the Tano Districts.

1.4 Research question

This research seeks to find answers to the following research questions.

1. What type of pathogens can be found in groundwater sources in the study area?

2. Are pit latrines responsible for this level of pollution/contamination of groundwater in the study area in relation to;
    a) the lateral separation between the pit latrines and the wells in the study area?
    b) the infiltration layer between the bottom of the pit latrine and the water table in the area under study?

1.5 Significance of the study

Decrease in the quality of water makes it unsuitable for all of its desired usage.

Institutions responsible for quality of water encounter problems when making decision about the quality of water without the requisite knowledge base.

- The result of this study will therefore help sanitary inspectors at the District assemblies to determine the depth to which pit latrine should be allowed to be constructed.
- It will also enable the sanitary inspectors to determine a safe distance that should be allowed between pit latrine and wells.
- In addition, the study will assist Ministry of Water Resources, Works and Housing and NGO's to promote and strengthen development in community water and sanitation.
- The result will also help the Government of Ghana to develop water treatment structures for communities which depend on groundwater.

1.6 Objectives of the study

- To determine the presence of fecal contaminants (from pit latrines in the study area) in the groundwater.

- To establish either the distance between wells and pit latrine has a significant effect on microbial quality of groundwater.
- To determine the kind of microbial pathogens contained in pit latrine.
- To identify the risk for hand dug wells and borehole water contamination with faecal bacteria in the Tano Districts.
- To establish whether there is any relationship between the quality of groundwater and the infiltration layer between the bottom of pit latrines and the water table.

CHAPTER TWO

LITERATURE REVIEW

2.1 Pathogens that can be found in water provided by groundwater.

Until the 1970's scientific concepts and methods limited our knowledge of groundwater microbiology. First it was common to assume that the ground water environment was devoid of life. Second methods for sampling groundwater environment for microbes were very limited. Third, it was generally assumed that water passing through the soil was purified by active microbial process and by filtration; therefore there was little concern with groundwater contamination. As groundwater contamination became more and more evident during the 1980's the motivation for understanding groundwater environments increased. In addition, new methods in microbiology based on advances in molecular biology, provided microbiologist with new tools to explore this difficult- to sample microbial habitat (lakes, rivers, streams, wetlands). This means that groundwater environment is not devoid of life as commonly assumed that water passing through the soil was purified by active microbial process and filtration. As groundwater contamination became more and more evident there should be the motivation for understanding groundwater environment

Madsen and Ghiorse (1993) explored the suitability of groundwater habitat for microbial growth, and compared groundwater environments to other aquatic habitats (lake, rivers, streams, wetlands) where microbes are abundant. Like lakes, rivers, streams, wetlands, the condition of groundwater environment seem rather unfavourable to microbial life. The lack of light excludes photosynthetic organisms and their primary production for heterotrophic microorganisms. However, it is now well known that bacteria are able to live in several extreme environments. Thus, it is not surprising that they have developed structural and physiological adaptations in the subsurface sediments (Madsen and Ghiorse 1993).

Chapelle *et al*, (1993) related microbial activities in groundwater to surface geochemistry and Fyfe (1996) have recently proposed that the term biosphere be extended to include subterranean habitats, based on recent research demonstrating the presence of bacteria in deep subsurface, oil and gas deposits and their role in mineral formation. Recent research summarized in these reviews lead to several general statements that can be made about groundwater microbiology.

1. Most subsurface materials contain bacteria which can be cultured
2. Most of the bacterial types found in the soil and surface waters have also been found in shallow unconfined and confined aquifers
3. The groundwater environment is also different from other aquatic environment in that organic carbon is not replenished by photosynthetic organisms but must be supplied from the surface or from the aquifer materials themselves.
4. Groundwater environment is also different from other aquatic environment in that bacteria are dominant inhabitants, although protozoa may also be common and subterranean caves may harbor unique invertebrates-faunas.
5. The majority of the number and types of microbes in groundwater environments are found attached to aquifer solids and not free in the ground water itself.
6. Many groundwater quality parameters, such as pH, oxidation-reduction redox status, dissolved oxygen or the presence of specific mineral constituent may be influenced by microbial activity in the aquifer. This is especially true when the aquifer is contaminated with substances that bacteria use for growth.

Center for Diseases Control and Prevention (CDC) of United States (1994) says if faecal indicator bacteria or pathogens commonly associated with human faeces are present in groundwater in measurable numbers, there is most likely a nearly connection with contaminated surface environment or surface source of contamination such as septic tank, broken or leaking sewer line or an old or improper designed landfill. In this study, the impact of pit latrines on groundwater quality was assessed. The main parameters that were measured were total coliform, faecal coliform, enteroocci, *E coli* and salmonella. Surface water or surface source of contamination such as septic tank, a broken or leaking sewer line, or an old or improper designed landfill will also be considered.

2.2 Health effects of microbes in groundwater

Although, there are some bacteria in groundwater that carry beneficial processes, some bacteria and other microorganisms may cause diseases in humans. Geldreich (1990) reviewed the microbiological quality of source water environment and the instances of waterborne disease outbreaks attributed to untreated or poorly- treated groundwater which contained pathogens.

The risk of contaminated water for people was manifested in Lake Erie, Ohio, USA in 2004 when 1,450 people became ill because of a pathogen in the well water (Fong *et al*, (2007). Pedley and Howard (1995) indicated that microbiological contamination of groundwater has profound and severe implications for public health, particularly in small communities and developing countries where groundwater is often the preferred source of drinking water. They said that contaminated groundwater can contribute to high morbidity and mortality rates from diarrhoeal diseases and sometimes leads to epidemics. They reported that the use of poorly constructed sewage treatment and works and lands application of sewage can lead to groundwater contamination close to water supply source.

2.3 Pit latrine and groundwater pollution in developing countries.

Lufthyg (2000) indicates that there is a growing concern about the likelihood of pit latrine effluent infiltration into groundwater reservoirs for well water supply systems. He also indicated that groundwater flows in the direction of surface runoff and that there is no lateral soil pollution above the groundwater in Zimbabwe and that pit latrine contents leach downwards and down slopes for distance that vary per season and soil type.

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Mtine (2010) in his attempt to explain the outbreak of cholera in Zambia, Kapoto residence reported that continuous use of water from shallow wells located near a pit latrine was dangerous and exposing the community to more water borne diseases. He said people compromise their health when they drink from shallow wells located near pit latrine.

2.5 Flow of materials to pollute/contaminate groundwater

Hornsby (2003) reported that the movement of contaminant through soil to groundwater is affected by many variables, including properties of the contaminant itself, soil conditions and climatic factors. The combination of these factors makes the likelihood of groundwater contamination a very site-specific science. An understanding of these processes and variables is critical to effective management of potential groundwater contaminants. Hornsby went on to say that groundwater is the source of drinking water of 50% of the population in the United States. In rural areas 85%-90% of the residents obtain their drinking water from groundwater. Because the quality of drinking water supply is important, groundwater merits protection from contamination. There are two basic processes by which contaminants move from the earth's surface through soils and groundwater. These processes are **diffusion** and **mass flow.** Substances diffuse through soils and aquifer materials in response to differences in energy from one point to another. These energy gradients may be caused by differences in concentration or temperature within the system. The principal process of movement of contaminants in soils and groundwater is mass flow. Dissolved constituents in water move through the soil, with the water acting as carrier of the contaminants.

Diffusion and mass flow are affected by properties of the contaminants, the soil, the intermediate vadose zone and the aquifer, climatological factors; and vegetation patterns: Properties of contaminants that determine their movements and potential threat to water quality include water solubility, tendency to adhere to soil materials, persistency and toxicity.

Properties of soil, the intermediate vadose zone and the aquifer that affect rate of contaminant movement include infiltration characteristics, pore size distribution, microbial population density and diversity, organic matter content, total porosity, ion exchange capacity, hydraulic properties, pH and oxygen status.

Climatic factors include temperature; wind speed; solar radiation; and frequency, intensity and duration of rainfall.

Vegetation may act as a sink for contaminants by uptake or assimilation, thus reducing the amount of contaminant available for transport to groundwater.

Hornsby (2003) states that pathogens are carried in suspension with water through soil, two factors affect the mobility of bacteria and viruses in the underground environment; the size of the water-filled pores and the actual velocity of the water in these pores. Other factors affecting the survival of pathogens in the intermediate vadose zone are pH, temperature and oxygen concentration.

Pathogens (bacteria and virus) may occur in sewages, sludge, seepage, animal wastes, some food processing waste and septic tank effluent. These waste streams enter the soil environment in several ways. Some are applied to the land as fertilizer, some are disposed into landfills and other deep into the soil either by design or happenstance.

2.6 Impact of proximity of a pit larine on a well

Kimani-Murage and Ngindu (2003), in their attempt to explain the impact of proximity of a pit latrine to a well state that where the distance between wells and pit latrine is not adequate, micro organisms can migrate from the latrine to the water in the well. They went on to say that where the pit latrine and wells co-exist the commonly used guideline is that the well should be at least 15 m from the pit latrine.

According to Sugden (2006) the farther the horizontal distance the pathogen has to travel from the point of entry into the water table from the point, the longer it is retained and the more likely the pathogen will die.

Parry-Jones (1999) stated that where the source of drinking water is an aquifer with a high groundwater table, the risk of contamination from pit latrine needs to be considered. Lewis *et al* (1980) indicates that linear travel of pollution is governed primarily by the groundwater flow velocity and the viability of the organism. A useful and widely accepted guidelines based on this research is that the maximum distance faecal pathogen will move through unfissure soil (including sand) is as far as the groundwater moves in ten days.

In low- lying flat areas, with a higher groundwater, the groundwater flow is almost certain to be less than one metre per day, so a distance of ten metres from latrine to source is adequate.

Brandberg (1997) also stated that if it is considered to be a real risk of pollution of groundwater from pit latrine, the risk can be reduced by constructing an artificial sand inner barrier around the pit to create a filter effect. This is an expensive solution and it may often be more practical to develop alternative drinking water sources, at a safe distance from the on- site sanitation facilities. Pathogens are removed within meters of the disposal site. Even so there are cases where pathogens are detected as far away as 30 meters or in very real cases with very specific conditions. As a result most guidelines and regulation require pit latrine to be 30 meters or more from water source such as boreholes, streams etc (Fourie *et al*, 1997; Crane *et al*, 1984).

2.7 Infiltration Layer between the bottom of pit latrines and groundwater water contamination.

Vertical separation also known in this context as infiltration layer is the depth of permeable, unsaturated soil that exists between the bottom of a subsurface soil absorption system and some restrictive or limiting layer or feature such as a water table, bedrock hardpan, unacceptable fine textured soils, or excessively permeable material. In terms of pit latrine this is the layer between the pit bottom and the water table.

Saturated flow in soil occurs when the water content of the soil is great enough to fill even the largest continuous pores and then moves downward strictly by gravity. This movement is relatively rapid in soils with coarse texture and/or good structure. Since the pores are filled with water, air is prevented from entering, thereby promoting anaerobic conditions.

Unsaturated flow occurs when water moves through the micro pores and along surfaces of the soil particles by capillary forces. Water moves from the wetter to drier areas and moves much slower than in saturated flow conditions. In addition, the larger pores are filled with air, thus promoting aerobic conditions in the soil. It should be noted that there is a continuum from unsaturated to saturated flow, and the definitions here are the extremes of the continuum.

According to Brown *et al*, (1977), removal of pathogens is accomplished during slowed passage by their bonding to soil particles and by natural die-off due to an unfavorable environment of aerobic soils and predatory soil organisms. The organic nutrients are metabolized by the soil organisms, a process that is nearly complete under aerobic, unsaturated flow conditions. Removal efficiencies of the various inorganic compounds vary with the compound and the soil conditions. Nitrogen enters the system largely as ammonia, which is oxidized in the aerobic treatment process to nitrate, a highly soluble ion. It then passes through most soils unaltered into the groundwater. Most onsite sewage systems rely on dilution to lower the nitrate concentration to drinking water standards (Brown *et al*, 1977). Phosphate, the other common contaminant of domestic wastewater, is readily absorbed in the soil. Brown *et al*, (1977), state that most published field research shows that little or no phosphate moves from the onsite system to groundwater even under saturated conditions. They further indicate that phosphate contamination is limited to shallow groundwater adjacent to onsite disposal systems where the soil is coarse-textured and low in hydrous oxides, or where there is poor effluent distribution and rapid movement of effluent away from the onsite sewage system. Vertical separation has been shown to be essential for removal of pathogenic and biochemical sewage contaminants to an acceptable level. In order to achieve vertical separation as defined, the hydraulic loading must be low enough so that movement of the wastewater occurs under unsaturated conditions. During unsaturated flow, water moves through the soil by matric forces, which hold the wastewater in close proximity to the soil surfaces and the soil microorganisms, where treatment readily occurs.

Hansel and Machmeier (1980) state that if the groundwater table or other barrier layer is too close to the bottom of the trench, saturated flow will result. Under those conditions saturated flow results due to groundwater mounding under the drain field. An exception to this general pattern would be where good disposal capability prevents the groundwater mounding, such as when a coarse sandy soil overlies a shallow restrictive layer on a steep slope. Under saturated soil conditions, water flows through the macro pores, and can result in short circuiting of the soil purification process. This is of particular concern in soils overlying creviced bedrock or high water tables. It is also important on shoreline properties adjacent to shellfish and water recreation areas. Stiles and Crohurst (1923) compared the movement of coliform organisms with that of the chemical uranin, from polluted trenches intersecting the groundwater (saturated conditions). They found bacteria 232 feet and uranin 450 feet from the trench. They also concluded that the ultimate distance to which the pollution will be carried is dependent upon a number of complex and interlocking factors, namely wet and dry weather, with resulting rise and fall of the ground water; the length of each of these periods; the rate of the groundwater flow (depending upon the "head," which in turn is dependent on the rainfall); and also the factor of the viability of the organisms under conditions of moisture, pH, food supply, etc. Yates and Yates (1989) cite reports of viral migration of 1600 meters (5249 feet) in karst terrain (porous limestone with deep fissures) and 400 meters (1312 feet) in sandy soil (Gerba, 1984; Keswick and Gerba, 1980). Macro pore flow through saturated strongly structured soils or soils of the sandy textural family may result in pathogen travel over relatively long distances with minimal treatment. Romero (1970) cites a number of pit privy studies where the pits intersected, or were within close proximity to, the water table. Elevated bacterial levels were temporarily detected up to 24.4 meters (80 feet) horizontally from the source. Reneau *et al*. (1985) cite studies where vertical movement of the bacteria through a fragipan was limited. Horizontal movement of effluent above the fragipan resulted in significant removals of the bacteria but only after effluent had travelled horizontally a minimal distance of 6.1 to 12 meters (20 to 39 feet). The fecal coliform counts in water samples collected at 12 meters were only slightly lower than in samples collected at 6.1 meters. Hagedorn *et al* (1978) found that flushes of bacteria (reaching a horizontal distance of 15 meters (49 feet) coincided with rainfall events and a water table rise to within 15 centimeters (6 inches) of the surface, and that macro pores aided in the rapid transport of the bacteria under saturated flow conditions. The following types of soil conditions would prevent safe soil treatment and disposal. They each result in saturated flow conditions before adequate treatment can occur: (1) shallow soils over creviced bedrock (or excessively permeable soils), (2) shallow soil over high groundwater tables, and (3) impermeable soils.

The efficiency of unsaturated flow conditions at removing biological contaminants has been demonstrated. Unsaturated conditions in sand columns were more effective for virus inactivation than saturated conditions (Lance *et al*, 1976; Lance and Gerba, 1980). Reneau *et al* (1989) summarizes and restates the conditions that several researchers (Bouma *et al*, 1972; Caldwell 1937, 1938a and 1938b; Caldwell and Parr, 1937) concluded were important for unsaturated flow: uniform effluent distribution, development of a surface clogging mat (in coarse textured soils), well drained soils, and moisture deficits. It should be noted that the clogging mat is most needed (and least likely to develop) in the coarse-textured soils and therefore some other means of uniform distribution needs to be used. Stewart and Reneau (1988) reported that the migration of fecal coliforms is restricted even during high water periods if the STE (septic tank effluent) is uniformly distributed, the

OSWDS (onsite wastewater disposal system) is placed in the more biologically active and aerobic soil horizons, and the unsaturated flow is maximized. Another key factor regulating bacterial removal from wastewater during percolation is the liquid flow regime in the soil.

The separation distance required by agencies varies widely from state to state around the U.S. and the evidence is not yet completely assembled to say exactly what separation is adequate in the range of soil conditions, effluent qualities, and effluent loading rates that may be found around the country. Meanwhile the USEPA Design Manual recommends a minimum water-unsaturated soil thickness of 24 to 48 inches. In column studies, viral deactivation occurs within 40 centimeters (16 inches) with unsaturated flow (Lance *et al*, 1976; Lance and Gerba, 1984). Under unsaturated flow conditions, bacteria can be adequately removed within 9 to 12 meters (3 to 4 feet) of effluent travel through soils (USEPA, 1980; Hansel and Machmeier, 1980). Hagedorn *et al* (1981) reviewed a report by Bouma *et al* (1972) that examined 19 subsurface soil disposal systems. Fecal coliforms were reduced to background levels within 61 centimeters (2 feet) of the trench bottom. Even in a sandy soil, Ziebell *et al* (1974) reported a 3000-fold reduction in bacteria levels 38 centimeters (15 inches) below the trench bottom and 30 centimeters (1 foot) laterally. Low pressure distribution can be used to provide equal distribution over the entire drain field surface where site conditions yield minimal vertical separation. Stewart and Reneau (1984) installed a shallow-placed, LPD (low pressure distribution) system to increase the unsaturated zone in a Typical Ochraquult (high water table) soil. After 2 years, fecal coliforms had been detected in only 5% of the 150 samples collected from shallow wells (150 centimeters deep). Samples that contained fecal coliforms were restricted to periods of high water tables and were confined to the effluent distribution area. Stewart and Reneau (1988) installed and tested a low pressure distribution system in soils with a fluctuating high water table. Few fecal coliforms were present at the 1.5 meters (5 feet) depth within the

OSWDS even during the period of highest water tables, January through March of 1982, when macro pore flow would be at a maximum.

Brown *et al*, (1979),in their work on movement of faecal coliforms and virus below septic leach fields noted that most fecal coliform bacteria and coliphage virus were removed within the first 30 centimeters (1 foot) of unsaturated soil beneath absorption trenches in east Texas. Occasionally a few coliforms were observed 120 centimeters (4 feet) below the trenches. Cogger *et al* (1988) and Moe *et al* (1984) found substantial although not total removal of bacteria and viruses in a sandy soil on the North Carolina coast where the water table fluctuated from 30 to 90 centimeters (1 to 3 feet) beneath the absorption trenches. Microbial removal was 1 - 2.5 orders of magnitude less beneath an adjacent system where the ground water table was 30 centimeters higher (i.e. at or near the bottom of the absorption trenches). In laboratory studies, Magdoff *et al*, (1974) noted complete removal of fecal coliforms and fecal streptococci in a 90 centimeters (3 foot) column containing sand underlain by silt loam, while Willman *et al* (1981) obtained substantial but incomplete coliform removal in a series of 60 centimeter (2 foot) columns containing a variety of sand and clay mixtures. These (field and column) studies, along with others not reported here, indicate that substantial bacterial and viral removal occur within the first foot of unsaturated soil, and removal is nearly complete within 60 to 120 centimeters (2 to 4 feet) beneath the trenches.

Tyler *et al*, (1977) stated that at a distance of 1 foot into the soil surrounding the trench, there was a 3 log reduction in bacterial numbers and within the second foot counts were to the acceptable range for a fully treated wastewater. Some bacteria and viruses in the wastewater are pathogens. Their movement during unsaturated flow is expected to be limited to within a meter (40 inches). Studies have shown that where it is sufficiently unsaturated, 60 to 90 centimeters (2 to 3 feet) of soil is adequate to remove nearly all fecal indicator bacteria and viruses. Lysimeter tests of the impact of septic field leachate on groundwater indicates that coliphage viruses and fecal coliform bacteria were removed by passage through approximately 100 centimeters (40 inches) of any of the soils tested.

Considering chemical treatment in relation to vertical separation, Brown *et al*, (1977) reported that heavy metals accumulated immediately adjacent to the point of application in the soil. Phosphates moved only slowly in the soil and their movement was greatest in sandy soils. Under reduced (anaerobic) conditions, ammonia accumulated in the soils and moved only about as far and as fast as phosphates. When the soil was allowed to become oxidized large amounts of nitrogen were converted to nitrate which rapidly leached to the groundwater. Therefore nitrate leachate was the greatest environmental hazard identified in this study. Reneau *et al*, (1985) summarized the research on processes and transport through the soil of nitrogen and phosphorous. They concur with findings of Brown *et al*, (1977).

The amount of vertical separation required in various states is highly variable. Where the separation is allowed to be less than two feet, there is no statement of the technical justification for doing so. The following data were extracted from the regulations from the listed states.

Table 2.1: Recommended infiltration for various countries guidelines

Alabama	1.5 feet	Minimum
Colorado	4 feet	May be reduced if designed by a registered engineer and approved by the local board of health (where local regulations permit such variances for exclusively domestic

		wastes).
Florida	2 feet 3.5 feet	To highest level of the water table To impervious layer
Idaho	4 feet 3-6 feet	To water table or fractured bedrock, depending on soil type To an impervious layer
Louisiana	4 feet 4 feet	To the maximum level of water table To impervious layer
Maine	1-2 feet	Depending on soil and subsoil
New Jersey	4 feet	
North Carolina	1 foot	
Oregon	4 feet 5 foot 0 feet	To permanent water table To impervious layer when bottom of trenches are in rapidly or To temporary water table (dries up for period of time each year) or permanent water table where it is determined by groundwater study that degradation of the groundwater and public health hazard will not occur and where water table is 2 feet below the ground surface very rapidly permeable soils
Ghana		
KVIP	5.4 - 6 feet	To the maximum level of water
VIP	6 – 9 feet	the maximum level of water table

Source: Seldon Hall (1990)

The amount of vertical separation necessary is still being debated, as there is disagreement over the degree of treatment needed. Research so far shows that 0.61 to 1.2 meters (2 to 4 feet) of vertical separation will adequately remove bacteria (<200 fecal coliforms per 100 milliliters) depending on soil type and conditions. In order to assure an unsaturated zone of 2 feet, it usually is necessary to construct a system with even greater separation in order to account for groundwater mounding. Therefore, the scientific literature is strongly indicating a final (as constructed) vertical separation that is greater than 2 feet. It should also be noted that there is often loss of soil depth during lot development, making it reasonable to require additional vertical separation in the preliminary design to allow for such damage.

The further water containing the pathogen has to travel to the water table, the more tortuous its route and the longer it is retained. This additional time allows for greater numbers of pathogens to die off naturally, Sugden, (2006). Care is needed when assessing this factor to consider the higher water table level in the wet season and not just the dry season water levels. This is to say that, the greater the distance between the base of the pit and the water table, the lower the risk of contamination

2.8 Pathogen size and groundwater contamination

Helminth (worm) eggs and protozoa are relatively large and are efficiently removed through the physical filtration process in the soil (Lewis, Foster *et al* 1980). The bacteria and viruses are much smaller and are much more able to travel unrestricted through the soil. The bacteria and the viruses in the table below are some of the greatest causes of concern.

Table 2.2 Viral diseases and pathogens associated with them

Viral disease	Pathogen
Infectious hepatitis	Hepatitis A virus
Poliomyelitis	Polio virus
Diarrhoea disease	Rotavirus, Norwalk, other virus
Bacterial disease	Pathogen
Cholera	*Vibrio cholera*
Typhoid	*Salmonella typhi*
Parathyphoid	*Salmonella prartyphi*
Baciallliary dysentery	*Shigella spp*
Diarrhoea disease	Enterotoxigenic *E coli*, *Salmomella spp*, *Samplobacter spp*.

Source: Lewis, Foster *et al* 1980

The large size of bacteria means that soil acts as a filter, limiting bacterial transport

This means that pathogens which are much smaller are able to travel through porous spaces through the soil to pollute groundwater.

2.9 Die-off rate of pathogens and groundwater contamination

Sugden (2006) reported that faecal micro-organism, like all life form have a limited life span in the environment and die off exponentially at rate, which vary enormously from few hours to several months. In groundwater, some pathogens are known to survive for up to 150 days. In the case of *E coli* indicator bacteria, an estimated half-life in temperate groundwater has been noted as being high. 10 to 12 days with survival of high number up to 32. Some *Salmonella species* have been shown to persist for up to 42 days. If the time taken for the pathogen to be transferred to the water point is long, the pathogen will have died off and the water will no longer present a threat to public health. Assessing the risk of water point contamination from latrines is based on gaining an understanding of the amount of time it would take for the water, and the pathogens it contains, to travel from the pit to the water point. The longer it takes, the greater the reduction in the number of pathogens through natural die-off. The overall aim in either sitting a latrine or water point is to ensure that the pathogen die-off has been sufficient to reduce the risk to a level where it is not a public health concern.

The time taken can be used as a proxy indicator for risk of contamination. The Guidelines for Assessing the Risk to Groundwater from On-Site Sanitation (ARGOSS) produced by the British Geological Survey (BGS) states that the following times are applicable to assessing risk from microbiological contaminates.

Significant risk	Time taken is less than 25 days
Low risk	Time taken is more than 25 days
Very low risk	Time taken is more than 50 days

(BGS - ARGOSS 2001)

ARGOSS takes care to stress that the 'low risk' category should provide confidence, but no guarantees, that the travel time would result in levels of micro-organisms which are unlikely to represent a major risk to health. The 'very low risk' category provides a further margin of safety and therefore greater confidence that the water will meet WHO guidelines and that the more persistent pathogens will have been removed.

2.10 Amount of liquid in the pit latrine and groundwater contamination

Majority of disease causing organisms (pathogens) lack the property to propel themselves through the environment in which they live and those that can are not capable of traveling very long distances. Instead pathogens are carried from one point to another within the medium in which they live and the case of water point contamination from pit latrines this is the liquid that accumulates within the pit. Sugden (2006), states here that, the smaller the amount of liquid in the pit, the lower the risk of water point contamination. This means with dry latrine systems the pathogens remain within the pit and water point contamination does not occur.

Still and Nash (2002) state that waste water in pit latrine percolates down the groundwater carrying with it nitrates from organics and waste around the well area. This means that the higher the amount of waste water in the pit latrine the higher will be the amount of contaminants that percolate down the groundwater table.

2.11 Depth of pit latrine and groundwater contamination.

According to Kimani-Murage and Ngindu (2003) where pit latrine and the use of groundwater as domestic water source exist, although it is difficult to give a general guideline, the commonly used guidelines are that, well should be located in an area higher than at least 15m from the pit latrine and the base of the pit latrine should be at least 20m above the water table.

2.12 Nature of the unsaturated zone and groundwater contamination.

The spaces between the grains in some type of sub-soil are so small that they physically prevent the passage of a pathogen. In effect the sub-soil acts as a filter. This filtration process is enhanced in the established latrine when an organic film of micro-organisms develops on the surface of the soil (as in a slow sand filter) and this effectively further restricts the passage of the pathogen. Some clay soils also have the capacity to absorb viruses and prevent their passage to the saturated zone. Sugden (2006) stated that the general rule is that, the smaller the sediment grain sizes the lower the risk of contamination.

According to Muszkat *et al*, (1989) xenobiotic organics penetrate into the depth of the unsaturated zone and reach groundwater. It must be pointed out that the rate of movement among other factors may be determined by the distance between the grains in the unsaturated zone. Organic pollutants migrate through unsaturated zone attached to colloidal particles (Wood and Petraitis 1984; Magaritz *et al* 1990; Muszkat *et al* 1989). Another concern of utilization of a sewage effluent is the possibility of the virus transport to the groundwater (Goyal *et al* 1984). This transfer is influenced by the nature of the unsaturated zone since this pathogen will have to cross the unsaturated zone before reaching the groundwater.

2.13 Nature of saturated zone and groundwater contamination (aquifer)

The ease at which water can flow through a rock is known as its permeability (measured in metres/days (m/d)) and is depended on both the size of the spaces or pores and how well they are connected with each other. Sand and gravels have large well connected pore space between their grains and allow water to flow relatively easily. Some soil types have high porosity but are poorly connected and water has difficulty in passing through them easily. As a result clay has permeability ranging from only 0.01 to 0.1 m/d. The greater the aquifer permeability, the higher the risk of water point contamination (Sugden 2006).

Groundwater flows slowly through water-bearing formation (aquifer) at different rates. In some places, where groundwater has dissolved limestone to form caverns and large opening, its rate of flow can be relatively fast.

In some permeable materials groundwater may move several meters in a day. In other places, it moves only a few centimeters in century. This means the movement and spread of faecal pathogen using water, as a medium of transport will be determined by the type of aquifer.

2.14 Direction and velocity of groundwater flow

According to Sugden (2006), the rule that water flows down hill holds true for the vast majority of groundwater, although there are exceptions. Sugden went on to say that generally the greater the hydraulic gradient toward the water point, the higher the risk of water point contamination. It will be more accurate to say that water always travels down hydraulic gradient from areas of higher water pressure to areas of lower pressure. Groundwater will generally follow the slope of hill and flow towards a river, sea or lake. The steeper the hydraulic gradient the faster the groundwater and the pathogen it contains will travel towards the water point.

Rusinga (2004), in his attempt to explain how potential groundwater contamination sources such as pit latrines and others can impact groundwater made it clear that spring water (groundwater) move downhill through soil or cracks in rock until it is forced out of the ground by natural pressure.

In an attempt to describe the relationship between slope of land and pit latrine groundwater contamination, Still and Nash (2002) said that water table varies according to topography, but is generally between 5 and 20 meters below the surface. This is in support of Sugden (2006) described above

2.15 Climate and pit latrine groundwater contamination

In the words of Bartram *et al*, (2010), available evidence suggests that dry and low flush pit latrines have high climate resilience because there is significant adaptive capacity through change in design. In an environment which is getting drier and where groundwater level declines, pit latrines will be highly resilient because of an increasing potential for the attenuation or death of pathogens. Where increased rainfall (even seasonally) leads to rising of groundwater levels, this can lead to flooding of the pit and contamination of shallow groundwater. This has often been given as a justification for not installing latrines where groundwater is used as a dinking water source. The risks might increase in an environment that is getting wetter but changes in design and the implementation of simple risk-based approaches to defining separation distances (Mcdonald *et al* 1999, ARGOSS 2001: Chave *et al* 2006). In an environment that are getting wetter, low flush systems are more likely than dry latrine to cause groundwater contamination because of the use of water, even small quantities can significantly increase pathogen breakthrough (Pedley *et al*, 2006). This risk may be compounded in situations where groundwater levels are rising.

2.16 Biological contamination of hand-dug well from faecal matters in Ghana.

Colliform bacterial is unwanted in water since their presence indicate faecal contamination and eventually, possible contamination by pathogenic organisms (Dua2006). In the past-unlined pit latrines have been sited close to wells resulting in the migration of faecal coliforms into the wells. In the words of Odai and Dugbantey (2003), pollution levels in groundwater supplies depend on the distance between groundwater supplies and pit latrines. However, Biological contamination is perceived by many as not widespread in Ghana. The rule of the thumb is to site wells at a minimum distance of 50m from sanitation facilities, cemeteries, refuse dumps, land fills, pit latrine etc. once groundwater systems become contaminated, it is almost impossible to clean them up. Many contaminants are persistent and remain hazardous even at low concentrations (due to limited access to the groundwater).

2.17 Diffuse pollution of urban groundwater in Zimbabwe.

Love (2006), reported that diffuse pollution of urban groundwater can be a threat to domestic water supplies and a challenge to water and land management. When boreholes were drilled, groundwater sampled and chemical and microbiological analysis carried out in Zimbabwe. It was determined that industrial sites raise problems of materials of metal and acidity, whilst the other sites studies showed problems with nutrients and coliform bacteria.

2.18 Urban pit latrine-groundwater contamination

On a global scale, pit latrines among others are the most serious distributed source of contamination. Commonly, about three quarters of the water utilized in an urban area is returned as waste water for disposal or treatment and it must be stated that where this water is released to the ground via pit latrines, cesspits and septic tank, nutrients, pathogens cleaning fluids and salinity can readily render the water undrinkable and also pose a hazard to human health (Howard 2002).

2.19 Conclusion

The impact of pit latrines on groundwater contamination has been studied to some extent in certain areas. However it some times becomes very dangerous to generalize certain ideas just because they have worked best in one environment. Environmental conditions might not be the same. These different conditions have the potential to affect results. There is therefore the need to experiment these ideas to see how they work in these rejected areas like the Tano Districts.

Also works done by Kimani-Murage and Ngindu (2003) reported on the effect of horizontal distant between a well and pit latrine on groundwater contamination. Sugden (2006) also reported on the fact that greater distance between the base of pit latrine and the water table decreases groundwater contamination with the converse being true. These researchers seem to consider the individual effects of these factors and remain silent on their combined effects. The imperative for research in this study is to deduce how the various factors cumulatively impact pit latrine groundwater contamination. Recommend and among these factors are the ones with the greatest effect.

CHAPTER THREE

METHODOLOGY

3.1 Organisation of the study

Water quality analysis using water sample from 5 boreholes and 10 hand-dug wells was carried out. The samples were analyzed for indicators of faecal contamination: total coliforms and faecal coliforms, *E coli*, *Salmonella and Enterococci*. The laboratory analysis of the samples collected from the study area was carried out in environmental science laboratory of the Department of Theoretical and Applied Biology of the Faculty of Biosciences of the Kwame Nkrumah University of Science and Technology.

In addition, the Tano Districts Health Directorates were contacted for data on cases of water borne diseases, especially, on diarrhoae and typhoid.

3.2 Study Area (profile obtained from the Tano District Assemblies)

The study area composed of Tano North District and Tano South District, which together is referred to as Tano Districts in this study. Duayaw Nkwanta and Techire are within the Tano North whilst Tehimantia is in the Tano South District. These areas fall within the granite metasediment belt, whilst the soil is basically clayey in nature and therefore have greater capacity in retention of water for plant use (District profile, 2010).

The areas lie in the semi-equatorial climatic zone which experience double maximum rainfall. The major season is between March to July and the minor rainy season occurs between September and November. The mean annual rainfall is about 1250 mm. The Districts have relatively mild temperature between 26-30 degrees. In terms of humidity, it generally ranges from between 75-80%. The temperature conditions in these areas readily support the cultivation of tropical crop such as cocoa, plantain, cassava, palm oil and maize.

The main domestic sources of water of these areas include hand dug wells, boreholes and pipe borne.

The areas are within the high topographical areas of the country with elevation in most parts above 270 m. The landscape is generally with average height of about 380m.The highest elevation ranges between 360 m to760 m above sea level

According to the Tano North planning unit, 2010 census recorded that, Duayaw Nkwanta has a population of 16,541 and that of Techire is 4,608. From Tano South planning unit, the population of Techimantia is 10,800 (2010 census). The maps of Tano North and south are indicated below.

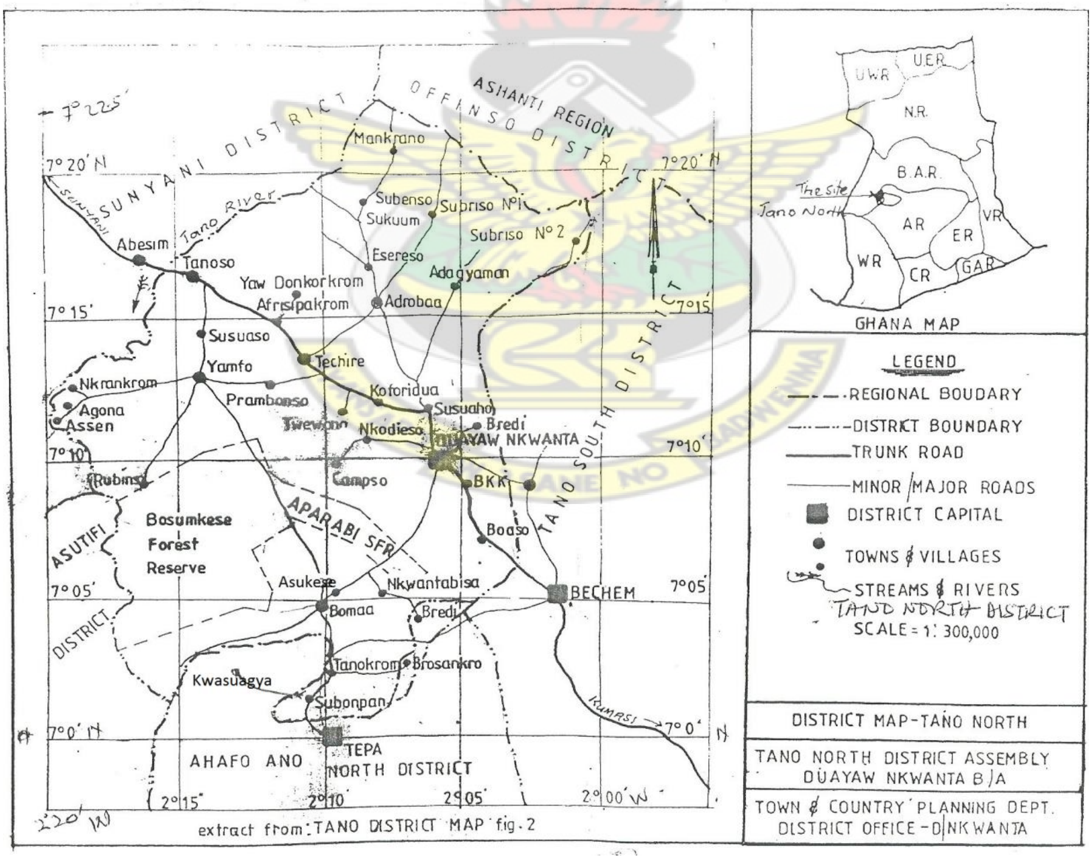

Fig 3.1: **District Map – Tano North**

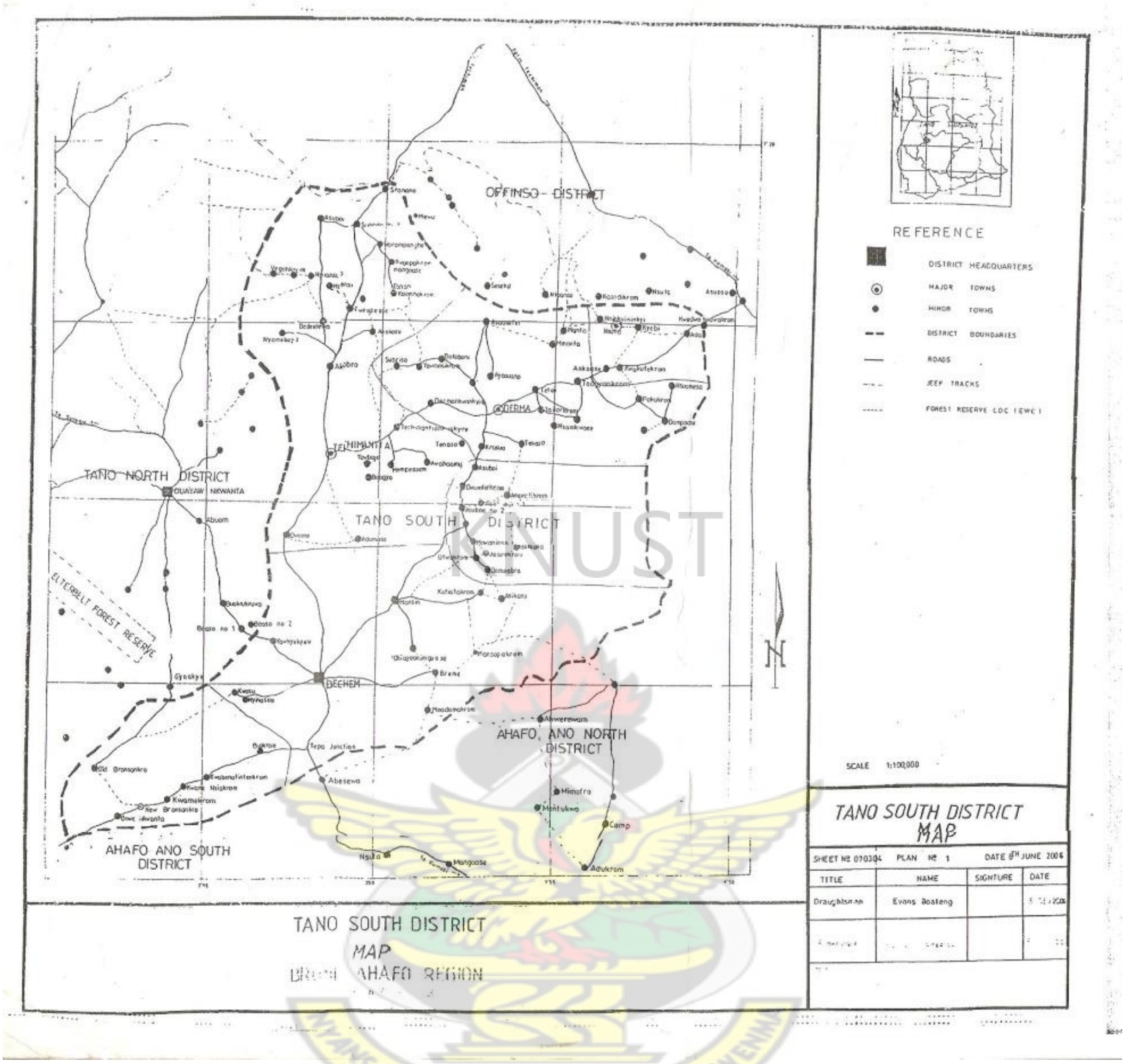

Fig 3.2: District Map – Tano South

3.3 Sampling Procedure

Simple random sampling method was employed to get the sample size. In the application of this method, 01 to 160 representing the total number of wells in the study area were written on pieces of paper and put into a box. This was then vigorously shaken and raised beyond the eye level. One piece of paper was selected at a time and the number on it recorded as a site to be administered with questionnaire. In order to minimize biases and to ensure that each piece of paper has equal and independent chance of being included in the sample, the selected piece of paper in each case was put back into the box to make sure that in each time of picking there was 160 pieces of paper in the box. This was repeated until fifteen wells were obtained to represent the study area.

3.4 Research Design

According to Gay (1992) descriptive, sampling involves collecting data in order to test a hypothesis or to answer questions concerning the status of the subset of study. In this study, the type of descriptive research known as survey type was employed. Surveys are aimed at describing accurately the characteristics of a population for specific variables. It was therefore employed to establish the attitudes, opinions, beliefs with reference to the effects of pit latrines on groundwater contamination in some selected towns and in the Tano Districts (Appendix C).

3.5 Research Instruments

The research instrument used in this research was a questionnaire. According to Cambell *et al.*, (1963), questionnaire is the most preferred instrument for soliciting ideas. The questionnaires in this study were administered to the selected landlords, and the hand-dug well, bore hole and Pit latrine constructors in the selected areas. The questionnaires were pre-tested to see how they would work, and whether changes were necessary before the start of the actual survey. They were then revised and finalized on the basis of the pre-test results. The questionnaires consisted of seven sections: A, B, C, D, E, F and G. The items under section 'A' elicited information on the demography of the respondent, the items in section 'B' were to seek information about general water sources, sites of wells (source). Section C elicited information about treatment of domestic water and information about diarrhoea related disease in household/ vicinity were sought in section D. Information about the people's perception of possible source of domestic water contamination were sought in section E. Section F had to do with the people's use of water from household/vicinity.

Section G sought information about topographic relationship between the bore holes/ wells and the pit latrines in the selected households and other parts of the neighborhood.

3.6 Validity and Reliability

The construct validity of the instrument was established by having the supervisor of the researcher to evaluate the items and approve it. The original instrument was given to him to see to it that various sections of research instruments and their various items were in agreement with the research questions. The comments that he made and the suggestions which he gave were considered in the modification of the original instrument.

Also all the targeted respondents were contacted and questionnaires were administered to them. In addition, after the items were answered few key questions were selected and asked again and the responses compared with the ones given earlier by the same respondents.

3.7 Administration of Questionnaire and Data Collection Procedure

A letter of introduction was obtained from the Department of Theoretical and Applied Biology of the Faculty of Biosciences of the Kwame Nkrumah University of Science and Technology. This letter which served as a form of identification and request, allowed the administration of the instrument. The questionnaires were personally administered to the respondents who were members of the households that were selected; landlords, tenants etc, assembly men and women of the selected areas and the hand-dug well constructors of the area. In order for the respondents to have clear conscience and answer the various items on the questionnaire, they were made aware of the fact that the questionnaires were not to put their integrity to a test but were designed in order to solicit information about the impact of pit latrines on groundwater. The respondents were assured of confidentiality and were advised to give the right responses as freely as they could. The prepared questionnaires were given to the respondents to answer. They were then assisted to fill them. There after the researcher collected the answered questionnaire. In each of the households and the sites that were visited, water sample from the hand dug wells and boreholes and the water table were taken and distance between the various wells (as explained under determination of static water level).

3.8 Sample Collection

The well and borehole water samples were the main experimental materials. Five boreholes and ten hand dug wells were chosen for the study.

This choice was borne out of their proximity to pit latrines. The water samples were collected using 2-liter hard plastic and screw capped bottles that have been sterilized to avoid contaminating by any physical, chemical or microbial means. The samples were transported within 2 hours of collection in a cool box containing ice packs to the Environmental Science Laboratory of Department of the Theoretical and Applied Biology of the Faculty of Bioscience, Kwame Nkrumah University of Science and Technology for analysis.

3.9 Laboratory Procedures

3.9.1 Total and faecal coliforms

The Most Probable Number (MPN) method was used to determine total and faecal coliforms in the samples. Serial dilutions of 10^{-1} and 10^{-11} were prepared by picking 1ml of the sample into 9ml sterile distilled water. One milliliter aliquots from each of the dilutions were inoculated into 5ml of MacConkey Broth (1:5) with inverted Durham tubes and incubated at 35^{o}C for total coliforms and 45^{o}C faecal coliforms for 18- 24 hours. Tubes showing colour change from purple to yellow and gas collected in the Durham tubes after 24 hours were identified as positive for both total and faecal coliforms. Counts per 100ml were calculated from the appropriate Most Probable Number (MPN) tables.

3.9.2 *E coli* (Thermotolerant Coliforms)

From each of the positive tubes identified a drop was transferred into a 5ml test tube of tryptone water and incubated at 44^{o}C for 24 hours. A drop of Kovacs' reagent was then added to the tube of tryptone water. All tubes showing a red ring colour development after gentle agitation denoted the presence of indole and were recorded as presumptive for themotolerant coliforms (*E coli*). Counts per 100ml were calculated from Most Probable Number (MPN) tables.

3.9.3 Faecal enteroccoci

Serial dilutions of 10^{-1} to 10^{-11} were prepared by picking 1ml of the sample into 9ml sterile distilled water. One milliliter aliquots from each of the dilution were inoculated on a Slanetz and Barltey Agar prepared on sterile Petri dishes. The Petri dishes were reincubated at a temperature of 37^{o}C for 4 hours to aid bacteria resuscitation. The plates were then incubated at 44^{o}C for a further 44 hours. After incubation all red, maroon and pink colonies that were smooth and convex are counted and recorded as faecal enteroccoci.

3.9.4 Salmonella

Prepared 10ml of manufactured formula of buffered peptone water (BPW) was in a universal bottle and serial dilution of 1ml sample added to it. It is incubated at 37^{o}C for 24 hours. Then 0.1ml of the sample from the BPW was placed in a 10 ml of serenity broth in universal bottle and incubated at 44^{o}C for 48 hours. Swaps transferred from the bottle onto SS agar and incubated at 48 hours at 37^{o}C. The absence of black colonies on the SS agar indicates the absence of salmonella.

3.10 Determination of static water level (SWL), pit latrine depth (PLD), Infiltration layer (IL) and Slope.

The depth from the ground surface to the static water level was determined for all sampling points using tape measure. The depth of the pit latrines at all sampling points were acquired through consultation with the Landlords and the pit latrine constructors of the various pit latrines. The soil infiltration layer was taken as the layer between the pit latrine bottom and the static water level. This was calculated by subtracting pit bottom elevation from static water level elevation. The slope expressed as a percentage in this study was calculated by dividing the difference between the elevations of the two points (wells and pit latrines) by the distance between them and then multiplying the quotient by 100 (Dr. Bukari Ali, personal communication).

CHAPTER FOUR

4.0 RESULTS

4.1 Influence of season on pit latrine groundwater contamination

Seasons, wet and dry have greater influence on pit latrine groundwater contamination. Table 4.1 illustrates seasonal influence on pit latrine groundwater contamination. It is indicated in the table that total coliform, faecal coliform and enterococci counts that were recorded in the wet season were higher than those that were recorded in the dry season for all sample sites. The differences between all the counts were statistically significant.

Table 4.1: **T-test on differences between dry and wet season microbial counts**

	Microbial counts / Log_{10} Geo mean counts/100ml		
Season	**TC**	**FC**	**EC**
Wet	3.914	2.245	2.207
Dry	2.783	1.734	1.775
Pr	<0.001	0.004	<0.001

TC=total coliform, FC=faecal coliform, EC=enterococci

4.2 Influence of lateral distance between pit latrines and wells on groundwater contamination

The study shows that none of the sites satisfies the Ministry of Water Resources Works and Housing (MWRWH) of Ghana (2010) guideline for lateral separation between a well and a pit latrine which is 50m (Table 4.2)

The results show that water samples taken from different locations display varying levels of bacterial counts. The results obtained in the dry season showed that lateral distances between pit latrines and water sources (borehole / well) do not have much influence on the total and faecal coliform counts of the water (Table 4.2). From the results (Table 4.3), average total coliform counts of log 3.20, 2.87 and 2.47 were recorded for lateral distances between 1-10, 11-20 and > 20 meters respectively. These differences were not statistically significant (p>0.05). A similar trend was observed for faecal coliforms with average count of log 2.07, 1.82 and 1.41 for lateral distance ranges of 1-10, 11-20 and > 20 meters respectively. For enteroccoci, the average counts recorded for the ranges of lateral distances, 1-10, 11-20 and > 20 meters were log 2.06, 2.04 and 1.21 respectively. Statistically, the differences between the enterococci counts were significant (P<0.05). The result further indicated that mean *E.coli* counts of log 0.95 and 1.36 were detected in water samples from locations D306/3 and Susuanmu (B) respectively. There was no detection of *Salmonella* in all the waters sampled. Generally, it was observed that water samples which were in close proximity to the pit latrines had higher bacterial counts than those that are distant from them (Table 4.3).

Water from Susuanmu (B) has the highest total coliforms compared to the other suburbs. The lateral distance separating the pit latrine and the well is 10 m. The lowest total coliform count was recorded in the suburb of Nurses. The lateral distance between pit latrine and the water source in this suburb is 39.9 m.

There was not much difference between the pattern of results obtained during the dry season and the wet season; except a higher microbial counts that was recorded during the wet season (Tables 4.2). From Table 4.4 below, the result(wet season) indicated that average total coliform counts of log 4.80, 3.79 and 3.55 were recorded for lateral distances between 1-10, 11-20 and > 20 meters respectively. These differences recorded in the counts were not statistically significant (p>0.05). Similar trend was observed for faecal coliforms with average counts of log 3.21, 2.20 and 1.73 for lateral distance ranges of 1-10, 11-20 and < 20 meters respectively. For enteroccoci, the average counts recorded for the ranges of lateral distances, 1-10, 11-20 and < 20 meters were log 3.07, 2.33 and 1.51, respectively, with the differences between the counts being significant (p<0.05). The results obtained in the wet season shows that mean E. coli counts of log 1.36 and 1.62 were detected in water samples from locations D 306/3 and Susuanmu (B) respectively. Also, in the wet season there was no detection of Salmonella in all the water samples collected from all the locations.

Table 4.2: Lateral Separation and Microbial Counts (n=60) Recorded in both the Dry and the Wet Seasons

	Location of Wells and Latrines		Log_{10} **Geo mean counts/100ml**					
			Dry season			Wet season		
Srl.		**LS/m**	**TC**	**FC**	**EC**	**TC**	**FC**	**EC**
1	C 62/4	6.0	2.62	1.62	1.90	4.37	2.63	3.20
2	D 77/3	18.4	2.62	1.36	1.60	4.37	1.36	1.78
3	D 382/3	19.2	2.37	1.62	1.95	2.96	1.97	2.20
4	D 369/3	20.0	2.96	1.62	2.18	3.62	1.38	2.59
5	D 156/3	15.8	2.62	1.62	2.15	3.37	2.38	2.35
6	D 306/3	11.6	3.46	2.62	2.41	4.62	2.97	2.88
7	78/3	7.0	2.62	1.62	1.78	4.37	2.38	2.08
8	C 31/3	19.8	2.37	1.96	1.85	2.96	1.96	2.00
9	D45/3	14.0	3.38	1.96	2.15	4.65	3.37	2.53
10	Nurses Qters A	22.9	1.46	1.36	1.16	2.62	1.37	1.45
11	Nurses Qters B	39.9	1.36	1.36	1.10	1.38	1.36	1.48
12	Susuanmu (A)	36.0	2.62	0.00	0.00	3.62	0.00	0.00
13	Susuanmu (B)	10.0	4.37	2.96	2.59	5.65	4.62	3.94
14	Saviour mission A	24.0	2.96	1.96	1.88	4.65	2.96	2.40
15	Saviour mission B	44.7	3.96	2.37	1.93	5.50	2.96	2.23

Town 1-11 is Duayaw Nkwanta, 12-13 is Techire, 14-15 is Techimamntia.LS=lateral separation, TC=total coliform, FC=faecal coliform, EC=enterococci,

Table 4.3: Comparison of means of microbial counts in relation to lateral distance (Dry season)

LS/m	Frequency	Log_{10} **Geo mean counts/100ml**		
		TC	FC	EC
1 - 10	3	3.20(1.01)	2.07(0.77)	2.06(0.47)
11 - 20	7	2.87(0.41)	1.82(0.41)	2.04(0.26)
>20	5	2.47(1.08)	1.41(0.90)	1.21(0.78)
Pr	Not applicable	0.454	0.394	0.042

TC=total coliform, FC=faecal coliform, EC=enterococci,

Table 4.4: Comparison of means of microbial counts in relation to lateral distance(wet season)

LS	**Frequency**	Log_{10} **Geo mean counts/100ml**		
		TC	FC	FC
1 – 10	3	4.80(0.74)	3.21(1.22)	3.07(0.94)
11 – 20	7	3.79(0.75)	2.2(0.76)	2.33(0.37)
Above 20	5	3.55(1.62)	1.73(1.26)	1.51(0.95)
Pr	Not applicable	0.326	0.187	0.032

LS=lateral separation TC=total coliform, FC=faecal coliform, EC=enterococci,

GENERATED CONTOUR MAP OF THE STUDY AREA

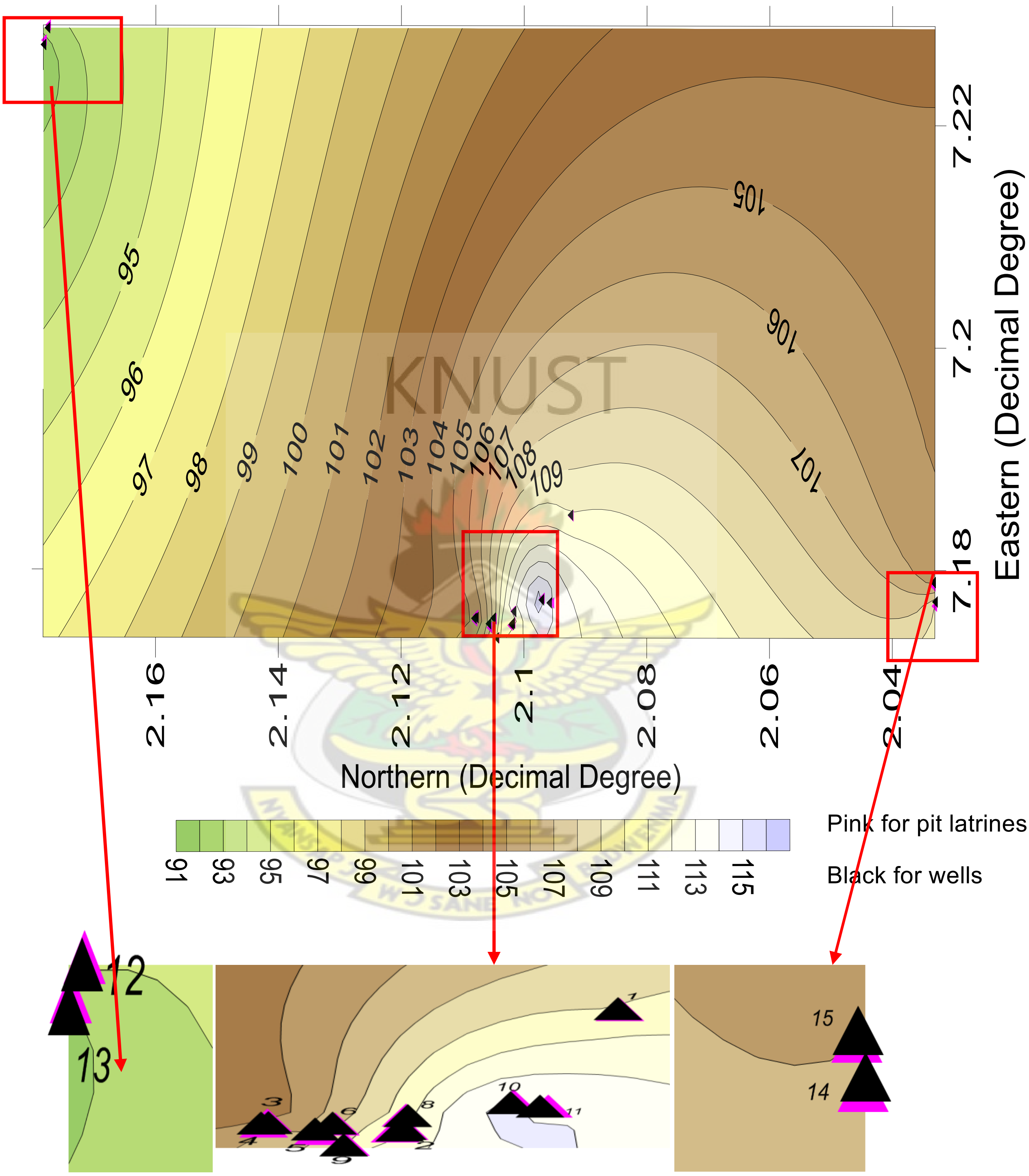

Fig 4.1: Area contour map with pits latrines and wells showed

Table 4.5: GPS Locations and Elevations for Wells and Pit Latrines

	Wells							Pit Latrines							
Srl.	N/dd	E/dd	CE/m	WSWL	DSWL	WSWLE	DSWLE	N/dd	E/dd	CE/m	PLD	PBE	Slope/%	WIL	DIL
1	2.09245	7.18493	110	17.6	18.4	92.4	91.6	2.09238	7.18485	111	7.2	103.8	16.7	11.4	12.2
2	2.10208	7.17508	114	17.6	18.6	96.4	95.4	2.10225	7.17501	112	7.5	104.5	-10.9	8.1 ‘	9.1
3	2.10785	7.17570	105	4.2	5.3	100.8	99.7	2.10788	7.17590	104	4.2	99.8	-5.2	-1	0.1
4	2.10817	7.17563	105	5.8	6.7	99.2	98.3	2.10805	7.17540	107	4.2	102.8	10.0	3.6	4.5
5	2.10580	7.17515	107	5.9	6.3	101.1	100.7	2.10565	7.17480	108	4.8	103.2	6.3	2.1	2.5
6	2.10503	7.17566	108	4.9	5.4	103.1	102.6	2.10490	7.17558	108	2.4	105.6	0.0	2.5	3.0
7	2.10193	7.17520	110	17.6	18.5	92.4	291.5	2.10185	7.17522	111	7.8	103.2	14.3	10.8	11.7
8	2.10170	7.17625	113	17.8	18.6	95.2	94.4	2.10178	7.17628	111	12	99	-10.1	3.8	4.6
9	2.10452	7.17388	110	5.2	6.1	104.8	103.9	2.10443	7.17390	111	4.5	106.5	7.1	1.7	2.6
10	2.09718	7.17730	116	22.6	22.6	93.4	93.4	2.09708	7.17745	115	7.2	107.8	-4.4	14.4	14.4
11	2.09590	7.17703	114	23.5	23.5	90.5	90.5	2.09552	7.17702	115	7.2	107.8	2.5	17.3	17.3
12	2.17767	7.22868	93	30	31.0	63	62.0	2.17755	7.22893	94	7.2	86.8	2.8	23.8	24.8
13	2.17832	7.22717	91	4.8	6.8	86.2	84.2	2.17823	7.22757	92	4.2	87.8	10.0	1..6	3.6
14	2.03307	7.17718	109	15	16.6	94	92.4	2.03317	7.17680	107	8.4	98.6	-8.3	4.6	6.2
15	2.03338	7.17892	105	19.5	20.6	85.5	84.4	2.03342	7.17862	106	9.5	96.5	2.2	11	12.1

Negative infiltration layer (-2.9 m) means that pit latrine depth is higher than well depth.
N= Northerns, E= Easterns, CE= Color Elevation, WSWL= Wet season Static Water Level, DSWL = Dry season Static Water Level, WSWLE = Wet season Static Water Level Elevation, DSWLE = Dry season Static Water Level Elevation, PLD = Pit Latrine Depth, PBE = Pit Bottom Elevation, WIL = Wet season Infiltration Layer, and DIL = Dry season Infiltration Layer.
Color Elevation= the distance of the Ground surface above the Sea level
Static Water Level (SWL) Elevation= the distance of the static water level above sea level.
Pit Bottom Elevation (PBE) = distance of the pit bottom above sea level
SWL Elevation - PBE= Infiltration Layer
Wells Color Elevation – SWL = SWL Elevation
Pit latrine Color Elevation – PLD=PBE
1= C62/4, 2=D77/3, 3=D382/3, 4= D369/3, 5=D156/3, 6= D306/3, 7= D78/3, 8= C31/3, 9= D45/3, 10= Nurses Quarters A, 11= Nurses Quarters B, 12= Susuanmu A, 13= Susuanmu B, 14= Saviour Mission A, and 15= Saviour Mission B

4.3 Influences of infiltration layer on groundwater contamination

The infiltration layer (layer between the bottom of pit latrine and water table) alone has little influence on the total coliform counts of the water. From table 4.6 below, the average total coliform counts of log 3.01, 2.40 and 2.62, were recorded for the ranges, 0.1-10.1, 10.2-20.2, and >20.2 respectively

Table 4.6: Comparison of Means of Microbial Counts in Relation to Infiltration layer (Dry season)

IL/m	Frequency	Log_{10} **Geo mean counts/100ml**		
		TC	FC	EC
0.1 - 10.1	9	3.01(0.64)	1.96(0.52)	2.08(0.30)
10.2 - 20.2	5	2.40(1.06)	1.67(0.41)	1.57(0.41)
Above 20.2	1	2.62(0.00)	0.00(0.00)	0.00(0.00)
Pr	Not applicable	0.419	0.008	<0.001

TC = total coliform, FC=faecal coliform, EC=enterococci,

Statistically the difference between the counts was not significant (p>0.05). With particular reference to faecal coliform, average counts recorded for the ranges of infiltration layers, 0.1-10.1, 10.2-20.2 and >20.2 meters were Log 1.96, 1.67 and 0.00 respectively. The difference between the counts was significant (p<0.05). However, Average enterococci (EC) counts of log 2.08, 1.57, and 0.00 were recorded for the ranges of infiltration layer of 0.1-10.1, 10.2-20.2 and >20.2 respectively. The difference between the counts was significant (p<0.05). EC = 0.12(PLD) – 0.09(SWL) + 2.37 as shown in Table 4.7

Results obtained in the wet season (Table 4.8) indicated that the average total coliform counts of log 4.09, 3.65, and 3.62 were recorded for infiltration layers with the ranges; -1-9, 10-20, and >20 respectively. The difference between the counts was not statistically significant ($p>0.05$). Similar trend was recorded for faecal coliform. For enterococci the average counts for the ranges, -1-9, 10-20, and >20 were log 2.52, 2.05, and 0.00 respectively. The differences between the counts was statistically significant ($p<0.05$).

Table 4.7: Multiple regression of static water level and pit latrine depth (infiltration layer) on microbial counts

Parameter	Coefficients	Standard error	Significance
Intercept	2.37	0.21	<0.001
SWL	-0.09	0.01	<0.001
PLD	0.12	0.04	0.0016

R = 0.91, P<0.001

EC = 0.12(PLD) – 0.09(SWL) + 2.37

EC = enterococci

PLD = pit latrine depth

SWL = static water level

Table 4.8 Microbial Counts in Relation to Infiltration Layer(Wet Season)

IL/m	Frequency	Log_{10} Geo mean counts/100ml		
		TC	FC	EC
-1 - 9	9	4.09(0.92)	2.55(1.05)	2.52(0.62)
10 - 20	5	3.65(1.63)	2.14(0.74)	2.05(0.82)
Above 20	1	3.62(0.00)	0.00(0.00)	0.00(0.00)
Pr	Not applicable	0.780	0.074	0.015

TC=total coliform, FC=faecal coliform, EC=enterococci,

4.4 Influences of topography of pit latrine on groundwater contamination

The topography of pit latrine and water sources (i.e. borehole / well) alone have a little influence on the microbial quality of the water (Table 4.9). This can further be explained from table 4.9

Table 4.9; Microbial Counts in Relation to Slope (Dry Season)

Slope/%	Frequency	Log_{10} Geo mean counts/100ml		
		TC	FC	EC
-10.9 - 0.9	6	2.54(0.67)	1.81(0.45)	1.81(0.41)
1 - 11	7	3.04(0.99)	1.70(0.92)	1.73(0.89)
Above 11	2	2.62(0.00)	1.62(0.00)	1.84(0.08)
Pr	Not applicable	0.547	0.933	0.968

TC=total coliform, FC=faecal coliform, EC=enterococci

There is no significant difference (p>0.05) in total coliform, faecal coliform and enterococci counts between waters sampled from sources located downhill or uphill to pit latrines.

Table 4.10: Microbial Counts in Relation to Slope(Wet Season)

Slope/%	Frequency	Log_{10} Geo mean counts/100ml		
		TC	EC	FC
-10.9 -0.9	6	3.70(0.94)	2.10(0.72)	2.12(0.50)
1 - 11	7	3.9(1.47)	2.30(1.53)	2.16(1.20)
Above 11	2	4.37 (0.00)	2.50(0.18)	2.64(0.79)
Pr	Not applicable	0.784	0.904	0.783

TC=total coliform, FC=faecal coliform, EC=enterococci,

Also, there is no significant difference (p>0.05) in all the counts of total coliform, feacal coliforms and enterococci between waters sampled from sources located downhill and uphill in the wet season despite the higher level of microbial counts in all samples collected in this season.

4.5 Lined and unlined pit latrines within the study area and groundwater contamination

Pit latrines 10 (Nurses quarters A) and 11 (Nurse quarters B) representing 13.0% of the selected pit latrines were lined (Table 4.11). The results obtained in the dry season indicated that average total coliform, faecal coliform and enterococci counts were log 1.41, 1.36 and 1.13 respectively recorded for wells within the proximity of these latrines. However, the rest of the pit latrines (13) were not lined. This number represents 87% of the total number of pit latrines. Water samples collected from wells within the proximity of these wells had average total coliform, faecal coliform and enterococci counts of log 3.00, 1.79 and 1.78 2.38 and 2.35 respectively. Table 4.12(wet season results) shows that the average microbial counts of log 2.00, 1.37 and 1.47 were recorded for total coliform, faecal coliform and enterococci respectively with reference to wells with corresponding lined pit latrines. Even so the average total coliform, faecal coliform and enterococci counts of log 4.21, 2.30 and 2.35 respectively were recorded for wells within the proximity of unlined pit latrines. The results indicates that samples collected from wells with corresponding lined pit latrines had lower microbial counts than samples with corresponding unlined pit latrines.

Table 4.11: Comparison of microbial counts in relation to lined and unlined pit latrines (Dry Season)

TYPE	FREQUENCY	Log_{10} Geo mean counts/100ml		
		TC	FC	EC
Lined	3	1.41(0.07)	1.36(0.00)	1.13(0.04)
Unlined	13	2.99(0.62)	1.79(0.71)	1.87(0.62)
Pr	Not Applicable	0.04	0.419	0.125

Table 4.12; Comparison of means of microbial counts in relation to lined and unlined pit latrine (Wet Season)

TYPE	FREQUENCY	Log_{10} Geo mean counts/100ml		
		TC	FC	EC
Lined	2	2.00(0.88)	1.37(0.01)	1.47(0.02)
Unlined	13	4.21(0.86)	2.38(1.12)	2.35(0.94)
Pr	Not Applicable	0.05	0.24	0.22

4.6 The use of water from wells

Five respondents from each sampling site were interviewed. This brings the total number of respondents to 75. Sixty five respondents representing 86.7% from the 15 locations use water from the wells for the following purposes: drinking, cooking, washing and bathing. These are people from the locations other than Nurses Quarters A and B but 10 (13.3%) out of the 75 respondents use the water from the wells for bathing, cooking, washing and not for drinking. These are people from Nurses Quarters A and B.

Table 4.13; Uses of Water from Wells and their Locations

Domestic use of Well water	Locations of wells														
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
Drinking	√	√	√	√	√	√	√	√	√			√	√	√	√
Cooking	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√
Washing	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√
Bathing	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√

1= C62/4, 2=D77/3, 3=D382/3, 4= D369/3, 5=D156/3, 6= D306/3, 7= D78/3, 8= C31/3, 9= D45/3, 10= Nurses Quarters A, 11= Nurses Quarters B, 12= Susuanmu A, 13= Susuanmu B, 14= Saviour Mission, and 15= Saviour Mission B

4.7 Incidence of diarrhoea related diseases in the study area

From the responses of the respondents, it was observed that out of the 75 (100%) respondents, 60 (80%) of them indicated intermittent cases on diarrhoea related disease. These are people from locations apart from Susuanmu A, Nurses Quarters A and B. This means that, 15 (20%) of them did not record any case on diarrhoea related diseases. It was observed that Susuanmu A, Nurses Quarters A, and Nurses Quarters B are the locations characterized by lower microbial counts compared to the rest of the locations which recorded cases on diarrhoea related diseases.

4.8 Treatment of water from wells

It is observed that 70(93.3%) of the respondents drink water from the wells without any treatment. This means that only 5(6.7%) of the respondents have their water treated before drinking. The respondents from this location (Susuanmu A) indicated that the chlorination of the water in this well was the sole responsibility of Newmont Ghana, which is intermittently done. Table 4.2 shows that the average total coliform, faecal coliform and enterococci counts of this location were log 2.62, 0.00 and 0.00 respectively for the dry season. However, this Table 4.2 recorded an average of total coliform, faecal coliform and enterococci counts of log 3.62, 0.00 and 0.00 respectively for the wet season. This location had the lowest microbial counts for faecal coliform and enterococci in both seasons.

CHAPTER FIVE

DISCUSSION, CONCLUSION AND RECOMMENDATION

5.1 DISCUSSION

5.1.1 Contamination of Groundwater

This study reveals that all water collected from the 15 sampling sites were contaminated with Total Coliforms, Faecal Coliforms and Enterococci with the exception of Susuanmu A which recorded only Total Coliforms. The presence of these organisms is an indication that water within the wells from the study area, except Susuanmu A have come into contact with animal or human faeces. These bacteria are used as indicators of possible sewage contamination because they are commonly found in human faeces. Although they are generally not harmful themselves, they indicate the possible presence of pathogenic (disease causing) bacteria, viruses and prokaryotes that lives in human and animal digestive systems. Therefore their presence in the sampled water from the selected wells suggests that pathogenic micro-organisms might also be present, and drinking or ingesting water from these sources might be a health risk. Water should have a value of 0CFU/100 ml in order for it to be considered safe for human consumption (WHO guidelines, 2004).

Powell *et al*, (2003) demonstrated that microbial contaminants (both bacterial and viral) derived from sewage can penetrate up to the depth of 90 m in some aquifers. These included indicator organisms such as total coliform, faecal coliforms and entrocoocci which were detected in the samples collected.

The pit latrines were the main sources of faecal pollution observed.The Pit latrines might therefore be the main contributing factors to the contamination of these wells.

5.1.2 Lateral distance between wells and pit latrines and groundwater contamination

The results of this study (Table 4.2) indicates that the lateral distances between the pit Latrines and the wells in the sample areas were below the national guideline for constructing pit latrines. Ghana MWRWH (2010) guideline limit for Constructing pit latrines is 50 m.

From the microbial test performed, the results from both seasons indicated that there are not much variation between the lateral distance and the total and faecal coliform counts in water. However, the differences between the enterococci counts were statistically significant. The enterocci might be a better human faecal indicator than the other coliforms considered in this study .Total and fecal coliform bacterial indicators often do not indicate the persistence of pathogens .Total and fecal coliforms can readily be isolated in tropical Waters from areas far removed from human activity and thus are not adequate indicators of Fecal contamination and human health risks. Enterococci enable a better assessment of fecal contamination and public health risks

In the work of Fattal *et al* (1987), to determine the organism that can indicate faecal contamination stated that, of the indicators (facal coliform, enterococci and *Escherichia coli*) enterococci were the most predictive indicator for enteric disease symptoms. In the Words of Kay *et al* (1994), compared to the other indicators (total coliform, faecal coliform), enterococci are the best indicator of gastrointestinal symptoms. The enterococci might therefore be a more better faecal determinant than the total and faecal coliforms. It was generally observed that water samples which were in close proximity to the pit latrines had higher microbial counts (Table 4.2). Sudgen (2006) stated that, the further the horizontal distance the pathogen had to travel from point of entry into the water table to the water point, the longer it is retained and the more likely the pathogen will die. He summarised this by saying, the greater the distance between the latrine and the water point, the lower the risk of contamination. Sudgen (2006) further stated that, if the time taken for a pathogen to be transferred to the water point is large, the pathogen would have died off and that the water would no longer be a threat to public health.

Kimani-Murage and Ngidu (2003), in their attempt to explain the impact of proximity of a pit latrine to a well state that where the distance between well and pit latrine is not adequate, micro-organisms can migrate from the latrine to the water. They went on to say that where the pit latrine and wells co-exist, the commonly used guideline is that there should be at least 15m from the pit latrine. Sugden (2006), Kimani-Murage and Ngindu (2003) spoke as if the individual effect of lateral / horizontal distance between a pit latrine and a ground water source (well) has a direct variation on the microbial quality of the groundwater. However from the findings of this study, the individual effect of the lateral distances on the microbial quality of groundwater was seen to be that of synergy with factors such as: climate, infiltration layer, slope of land etc.

5.1.3 Depth of pit latrine and Static Water Level (Infiltration Layer) and ground water contamination

From Tables 4.2 and 4.5, the results revealed that there is no relationship between pit latrine depth and microbial quality of groundwater.

It can be deduced from this research that higher pit latrine depth does not always suggest groundwater contamination. Ranjana and Weerasinghe (2010) indicated that the E coli and Coliform (bacterial) contaminations depend on latrine pit depth (latrine pits are constructed above and below the groundwater level), among other factors. One can study the effect of the depth of pit latrine on groundwater contamination when it is related to the water table. The risk of groundwater being contaminated by pit latrines is increased where: the base of the pit occurs near the water table (DWAF, South Africa, 2004).Using the multiple regression analysis (Table 4.7), it was deduced that, EC (Enterococci) count=0.12(PLD) - 0.09(SWL) + 2.37. Considering the equation it can be inferred that EC has a direct relation with PLD but an inverse variation with SWL. This can be explained in that, increasing PLD brings the pit bottom closed to the water table. In this case the coliforms take lesser time to reach the groundwater and hence higher rate of contamination. Also Increasing SWL sends the water table far away from the pit bottom and therefore the colifoms take much time to reach the water table, thus, decreasing the rate of the contamination. In short it can be said that under constant conditions coliform level increases with increasing pit depth and decreasing SWL.

The infiltration layer was taken to be the layer from the pit latrine bottom to the water table. This was calculated by subtracting pit latrines bottom elevation from static water elevations. The relation EC (Enterococci) =0.12(PLD)-0.09(SWL) +2.37 also holds for the infiltration layer. Increasing PLD means decreasing the vertical distant (infiltration layer) from the bottom of the pit latrine to the water table and increasing SWL has to do with increasing the infiltration layer. From the results in both seasons, the difference between the microbial counts was significant in relation to infiltration layer. The farther the water that contains pathogens has to travel to the water table, the more tortuous its route, and the longer it is retained. This additional time allows for greater numbers of pathogens to die off naturally (Sugden 2006). Care is needed when assessing this factor to consider the higher water table level in the wet season and not just the dry season water levels. This is to say that, the greater the distance between the base of the pit and the water table, the lower the risk of contamination. Coliforms enter into the groundwater system through infiltration. This indicates that the thicker the infiltration layer, the lower the effect of the coliforms. From the tables and contour map, it can be seen that areas with thicker infiltration layer and also the well and pit latrine on very less steep slope recorded no or less faecal coliform and enterococci. This can be seen for nurses' quarters A and B and Susuanmu A.

Susuanmu B is an area with small infiltration layer and recorded the highest EC and FC because the slope between the well and pit latrine was higher (10%) as seen in the Table 4.5 It can be said that slope and infiltration layer thickness play an important role to the presence of coliform in the groundwater systems in the area.

5.1.5 Season and Pit Latrine Groundwater Contamination

In this research results were recorded for both the dry and the rainin seasons. There was no much difference between the pattern of results obtained in the dry and that of the raining seasons except that higher microbial counts were obtained in the raining season (Table 4.1). These differences between the microbial counts in both seasons were statistically significant ($P<0.05$).The higher microbial counts in the wet season can be attributed to the rise in the water table, decreasing the infiltration layer and bringing the water very closed to the bottom of the pit latrines and also the fact that micro-organisms use water as a medium of migration. In the words of Bartram *et al*, (2003) available evidence suggests that dry and low flush pit latrines have high climate resilience because there is significant adaptive capacity through change in design. Where the environment is getting drier, the groundwater level declined, pit latrines will be highly resilient because of an increasing potential for the attenuation or death of pathogens. Where rainfall leads to rising groundwater level, flooding of pit and contamination of groundwater can occur. This has often been given a satisfaction for not installing latrine where groundwater is used as a drinking water source. The risk might increase in an environment that is getting wetter. In an environment where the soil is getting wetter, low flush system are more likely than dry latrines to cause groundwater contamination because of the use of water, even small quantities can significantly increase pathogens breakthrough (Pedley *et al*, 2006). This risk may be compounded in a situation where groundwater levels are rising.

One of the factors that might be attributed to the higher microbial counts in the raining season is higher concentration of liquid in the pits. This is in support of Sugden (2006) who stated that majority of disease causing organisms (pathogens) lack the property to propel themselves through the environment in which they live and those that can are not capable of traveling very great distances. Instead pathogens are carried from one point to another within the medium in which they live and in the case of water point contamination from pit latrines this is the liquid that accumulates in the pit. Sugden (2006) stated further that the smaller the amount of liquid in the pit the lower the risk of water point contamination. This can be explained in that the water serves as a medium through which the microbial contaminants move.

5.1.6 Influence of topography and wells on microbial quality of groundwater

The individual effect of topography of pit latrines and wells has little influence on the microbial quality of groundwater. One will expect that contents of pit latrines located uphill seep into the groundwater thereby contaminating it. This assertion is affected by other factors such as climate, infiltration layer, lateral separation between the pit latrines and the wells etc. From the tables (4.6 4.8 and 4.5) and the contour map(fig.4.1), it can be seen that areas with thicker infiltration layer and also the well and pit latrine on the less steep slope recorded no or less faecal coliform and enterococci. This can be seen from nurses' quarters A and B and Susuanmu A.

Susuanmu B is an area with higher elevation (10%) between the well and the pit latrine (Table 4.5). This area recorded the highest EC and FC because the infiltration layer between the bottom of the pit latrine and the static water level was small (1.6 m).The lateral separation here is 10 m. It can be said that, the combined effect of elevation, infiltration layer thickness and lateral separation plays an important role to the presence of coliform in the groundwater systems in the area.

According to Sugden(2006),the rule that water flows down hill holds true for the vast majority of groundwater, although there are exceptions, From Tables, 4.9 and 4.10 it is observed that there is no correlation between the microbial counts and the slope of land when treated as individual factor.

It is made clear that there are other factors such as pit latrine depth and static water level (infiltration layer), lateral distance, climate etc, which combine with the topography to have impact on pit latrine groundwater contamination. Steeper slope in a situation where pit latrine is placed uphill to a well does not always suggest shorter infiltration layer between the bottom of the pit latrine and the water table or shorter lateral separation between the well and the pit latrine. It will therefore not make sense to conclude that slope increases with increasing microbial counts or the converse without taking other factors into consideration.

5.1.7 Lined and Unlined Pit Latrines

It is observed from this study that water samples from wells with nearby lined pit latrines had lower microbial counts. The lower microbial counts recorded for samples from wells of nearby lined pit latrines(Nurses Quarters A and Nurses Quarters B) can be attributed to barriers at the bottoms of those pit latrines which acted as the factor to prevent smooth contact of microorganisms with the ground water. Studies made by Franceys *et al*, (1992) showed that pollution of groundwater from a pit latrine can be reduced by constructing an artificial sand barrier around the pit to create a schmutzdecke filter effect.

5.1.8 Treatment and the use of water from selected wells

This study reveals that 70 (93.3%) out of the 75 (100%) of the respondents said they drink the water without boiling or subjecting them to any other form of treatment. However, the

93.3% of the selected wells tested positive for faecal coliform and enterococci. People who live at where those wells are sited are exposed to health risk. It must be stated that 87.3% of the selected wells are used for drinking whilst 100% are used for washing, bathing and cooking .This means that a larger number of people within those vicinities are exposed to the pathogens associated with those faecal indicators. USEPA (1986) in an attempt to explain the pathogenicity associated with faecal indicators states that members of the two bacterial groups, coliform and faecal streptocci are used as indictors of possible sewage contamination because they are commonly found in human and animal faeces.

5.2 Conclusion

Total coliforms, faecal coliform and enterococci were found to be impacting negatively on groundwater quality. Apart from Susanmu B none of the sample gave OCFU/100 limit. All the selected wells tested positive for total coliform whilst 93.3% of the wells tested positive for faecal coliform and enterococci. The enterococci was found to be a better human faecal indicator than the other coliforms. According to WHO guidelines (2004), water should have a value of 0CF/100ml in order for that water to be considered safe for human consumption.

The presence of indicator coliforms in the wells indicate that the water in the wells have come into contact with faeces from humans or other cold blooded animals. Generally, the results of this work show that pit latrines were the major sources of groundwater contamination; however, there may be other sources. These sources include open air defecation, run-off water, and unhygienic human practices at the wells' sites, among others. The findings of this research indicated that the microbial counts vary inversely as the infiltration layer (between the bottom of the pit latrine and the static water level) and the lateral separation between pit latrines and the wells. The results have also shown that faecal contamination of the wells increases with increasing pit latrine depth and decreasing static water level. It was also found that all the sample areas did not satisfy the country's guideline, MWRWH (2010) for lateral separation between a pit latrine and a well which is 50m.However for the infiltration layer, only D382/3,D45/3 and D45/3 and Susuanmu B did not fall within the recommended thickness of MWRWH (2010) which is 2m.Amoung all the factors considered in this research, the lateral separation and the infiltration layer were seen to have the greatest impact on pit latrine groundwater contamination

5.3 Recommendations

In the attempt to reduce the risk of groundwater contamination, the following methods must be employed:

- Increase lateral separation distances between the latrines and the water point
- Move water points much higher than the latrines
- Increase vertical separation between bottom of pit and water table by using shallower pits or vaults latrines
- Treat groundwater supplies or encourage the use of the home water treatment
- Basic treatment of water at the community or household level by chemical disinfection using chlorine, filtration-using simple household filters, and boiling should be promoted.
- Raised or lined pit latrines and other low-cost technologies could be considered as an alternative to unlined pit latrines, because they minimize the risk of releasing pit latrine effluent flow across the infiltration layer
- The results of this study also suggest that tap water may be safe, but additional sampling is needed. The Ideal intervention in the long-run may therefore be the provision of adequate pipe borne water to all the dwellers of the research area.

REFERENCES

Ampofo, K. (1996) National biogas resource assessment. Ministry of Energy; Accra, Ghana. Retrieved on 18/07/2011, from http://www.medwelljournals.com/ref.php?

Anon (1996) Waterborne Pathogens Kill 10m-20m People A Year: World Water Environment Engine. Retrieved On 17/07/2011 from Http://Projects.Itu/Luisa%20Alres/Bibliografia

Archives: District Health Directorate (2007,2008,2009,2010,2011), Diarrhoea related diseases, Tano North District, Brong Ahafo Region, Ghana

Archives (2010), Tano North District Assembly, Brong Ahafo Region, Ghana

ARGOSS (2001), Guidelines for Accessing the Risk to Groundwater from On-Site Sanitation. British Geological survey Commission Report, CR/01/142. Pp .97; United Kingdom.

Bartram, J., Corrales, L., Davison, A., Deere, D., Drury, D., Gordon, B., Howard, G., Rinehold, A. & Stevens, M. (2010), Water Safety Plan Manual: Step-by-Step Risk Management for Drinking-Water Suppliers. World Health Organization, Geneva.

Bartram, J., Cotruvo J., Exner M., Fricker, C., and Glasmacher, A. (2003), Heterotrophic Plate Counts and Drinking-Water Safety, the Significance of HPCs for Water Quality and Human Health. IWA Publishing, London.

Bouma, J. Ziebell, W.A., Walker, W.G. Olcutt, P.G., McCoy, E. and Hole F.D., (1972), "Soil Absorption of Septic Tank Effluent", *Extension Circular No. 20, University of Wisconsin*, Madison.

Brandberg B. (1997), Latrine Building: A Handbook for Implementing the Sampler System; Retrieved On 10/06/11 From Http;//Scholar Search.Google.Com/Scholar?Q=Brandberg+B.+(1997)+Latrine+Building&H/=En& As-Sat=O&.

Brown, K.W., Slowey J.F. & Wolf, H.W. (1977), "Vertical Separation: A Review of Available Scientific Literature and a Listing from Fifteen other States. Washington State Department of Health; Environmental Health Programs. Retrieved from www.doh.wa.gov.ehp/ts/uw/vert.sep.

Brown, K.W., J.F. Slowey & H.W. Wolf, 1979. "The Movement of Salts, Nutrients, Fecal Coliform and Virus Below Septic Leach Fields in Three Soils", *Home Sewage Treatment*, American Society of Agricultural Engineers Publication 5-77, St. Joseph, MI.

Caldwell, E.L. and L.W. Parr, (1937), "Ground Water Pollution and the Bored Hole Latrine", *J. Infectious Disease* 61:148-183.

Caldwell, E.L., (1937), "Pollution from Pit Latrines When an Impervious Structure Closely Underlies the Flow", *J. Infectious Diseases* 61:269-288.

Caldwell, E.L., (1938a), "Pollution Flow from a Pit Latrine when Permeable Soils of Considerable Depth Exist Below the Pit", *J. Infectious Diseases* 62:225-258.

Caldwell, E.L., (1938b), "Studies in Subsoil Pollution in Relation to Possible Contamination of Ground Water from Human Excreta Deposited in Experimental Latrines", *J. Infectious Diseases* 62:273-292.

Cambell, D. T. and Stanley. J.C. (1963). Experimental and Quasi – Experimental Designs for Research on Teaching. Chicago. Rand McNally

Centers for Disease Control and Prevention (CDC) 1994. Addressing Emerging Infectious Disease Threats: A Strategy for the United States. Atlanta, GA: U.S. Department of Health and Human Services. Retrieved from http://www.cdc.gov. on 13/06/2011.

Chapelle F.H. (1993), Bacterial And Their Effects On Ground-Water Quality Retrieved On 13/06/11 From http://mi.water.usgs.gov/h2oqual/GWBactHOWeb.html

Chapelle, F.H. (1993), Ground-water Microbiology and Geochemistry; John Wiley and Sons, New York.

Chave P., Howard G., Schijven, J., Appleyard S., Fladere F., and Schimon W. (2006), Groundwater Protection Zones in Protecting Groundwater for Health: Managing the Quality of Drinking-Water Source; (ed. O. Schimoll, G. Howard, J. Chillton and I. Chorus), Pp.456-492. World Health Organization, Geneva.

Chenje, M., Sola, L. And Paleczny D. (Editors) (1998), The State of Zimbabwe's Environment 1998. Government of the Republic Of Zimbabwe, Ministries Of Mines, Environment And Tourism, Harare, Zimbabwe. Retrieved on 19/06/2011 from Http://Www.Bscw.Ihe.N//Pub/Bscw.Cgi/D2606459/Dziwairo.Paf.

Chidavaenzi; M., Bradley M., Jere M. and Nhandara C. (1999), Pit Latrine Effluent Infiltration into Groundwater. The Epworth Case Study, Water Science and Technology Journal 1999.

Cogger, C.G., (1988), "On-site Septic Systems: The Risk of Groundwater Contamination", *J. Environmental Health*, 51:12-16.

Crane, S.R. and Moore J. A (1984), Bacterial Pollution of Groundwater; A Review. Department of Agricultural Engineering, Oregon State University, U.S.A. Water, Air and Soil Pollution 22, No 1 Reidel Publishing Company.

Dua, A.A (2006), Groundwater Contamination in Ghana. CSIR Water Research Institute, Accra, Ghana Published by Taylor and Francis Group plc. , London, UK. Retrieved from http;//www.crcnetbase.com/doi/abs/10.12011 on 26/06/11.

DWAF, (2004),Guidelines On Protecting Groundwater From Contamination, Department Of Water Affairs and Forestry Directorate Information Programmes

Fong T.T., Mansfield M.S., Wilson D.L, Schwab D.J., Molloy S.L., And Rose J.B. (2007), Massive Microbiological Contamination Association With A Waterborne Outbreak In Lake Eric, South Bass Ilsland, Ohio: Research Retrieved On 16/06/11 From Http://Www.Glerl.Noaa.Gov/Pubs/Fulltext/2007

Fattal, B., E. Peleg-Olevsky, T. Agursky, and H.I. Shuval. 1987. The association between seawater pollution as measured by bacterial indicators and morbidity among bathers at Mediterranean bathing beaches of Israel. *Chemosphere* 16:565-570.

Fourie. A. B. and Vanrynelveld M.B (1997), A Strategy for evaluation the environmental Impact of Onsite Sanitation System. Department of Civil Engineering, University of the Witwatersrand; Water SA Vol. 23 No.4

Franceys, R., Pickford, J. and Reed, R. A. (1992), A guide to the development of on-site sanitation, WHO, Geneva.

Fyfe W.S. (1996), The Biosphere Is Going Deep; Science 273,448. Retrieved on 11/06/11 from Http://Faculty.Washington.Edu/Dcatling/Astbi0502

Gay, R. L. (1992). Educational Research fundamentals for the consumer (2nd Ed). N.Y.; Harper Collins

Geldreich W.S. (1996), Microbiological Quality Of Source Waters For Water Supply; in G.A. M Ofesters (Ed) Drinking Water Microbiology: Progress and Recent Developments; Springer-Verlag, New York Pp.3-31.

Geldreich, E.E. (1990), Microbiological quality of source waters for water supply; G. A. McFeters (ed.) Drinking Water Microbiology: Progress and Recent Developments. Springer-Verlag, New York pp. 3-31.

Gerba, C.P., (1984), "Microorganisms as Groundwater Tracers", In: Groundwater Pollution Microbiology; G. Bitton and C.P. Gerba, eds. John Wiley & Sons, New York. pp. 225-234.

Goyal P., Li H., Regener E. And Sadri F. (1984) Sea Food Safety; Retrieved on 10/06/11 From Http://Www.Thecookinginn.Comlseasafe.Htm/

Hagedorn, C., D.T. Hansen, and G.H. Simonson, (1978), "Survival and Movement of Fecal Indicator Bacteria in Soil under Conditions of Saturated Flow"; *J. Environmental Quality* 7:55-59.

Hagedorn, C., E.L. McCoy, and T.M. Rahe, (1981), "The Potential for Ground Water Contamination from Septic Effluents"; *J. Environmental Quality* 10:1-8.

Hansel M.J., and R.E. Machmeier, (1980), "Onsite Wastewater Treatment on Problem Soils"; *Journal of Water Pollution Control Federation*, 52(3):548-558.

Hornsby A.G (2003), How Contaminants Reach Groundwater; Paper Sl143 Retrieved on 11/06/11 from Http:Lledis-:Fas-Ufl.Edu/Ss194.

Howard K.W.F(2002), Current Problems of Hydrology in Urban Areas; Urban Agglomerases and Industrial Centres Journal pp 1-15

Keswick, B.H. and C.P. Gerba, (1980), "Viruses in Groundwater", *Environmental Science Technology* 14:1290-1297.

Kay, D., J.M. Fleisher, R.L. Salmon, F. Jones, M.D. Wyer, A.F. Godfree, Z. Zelenauch-Jacqotte, and R. Shore. 1994. Predicting likelihood of gastroenteritis from sea bathing: Results from randomised exposure. *The Lancet* 344(October 1):905-909.

Kimani-Murage E. and Ngindu A.M (2003), Quality of Water the Slum Dwellers Use: the Case of a Korgan Slum; Urban Health Journal, 2007 Nov; 84(6):829-38, Retrieved on 10/06/11 from http://www.ncbi.nlm-n;h-gov/pubmed/17551841.

Lance, J.C. and C.P. Gerba, (1980), "Virus Movement in Soil during Saturated and Unsaturated Flow"; *Applied Environmental Microbiology* 47:335-337.

Lance, J.C., Gerba C.P., and Melnick, J.L., (1976), "Virus Movement in Soil Columns Flooded with Secondary Sewage Effluent"; *Applied Environmental Microbiology* 32:520-526.

Lance, S. C. and Gerba C. P., (1984), Virus Movement in Soil during Saturated and Unsaturated Flow; Appl. Environ. Microbial, 47:335-337.

Lewis J., Foster S., and Diasar B.S (1980), The Risk of Groundwater Pollution by On-Site Sanitation in Developing Countries; International Reference Center for Waste Disposal (Ircwd-Now Sandec) Report No. 01/82.

Love D., (2006) – Groundwater Pollution in Africa; Edited by Youngxin Xu and Brent Usher. Retrieved on 19/06/11 from http://www.crcnetbase.com/doi/abs/10.1201

Lufthyg. S. V. W. B (2000), Pit Latrine Effluent Infiltration into Groundwater; The Epworth Case Study Article. Retrieved On 28/05/2011from Httpi//Www.Ncbi.N/M.Nih. Gov/ Pubmed//084 28

Madsen E.L and Ghiorse W.C. (1993), Bacterial and Their Effects on Ground-Water Quality; Retrieved on 10/06/11 from Http:Mi;Water.Usgs.Gov/H2oqual/Gwbacthoweb.Htm/

Magaritz M., Amiel A.J., Ronen D., and Wells M. C, (1990), Distribution of Metals in a Polluted Aquifer; Contaminant Hydrology Journal v.5 pp 333-347

Magdoff, F.R., Keeney, D.R., Bouma J. and Ziebell, W.A., (1974), "Columns Representing Mound-Type Disposal of Septic Tank Effluent: II. Nutrient Transformations and Bacterial Populations"; *J. Environmental Quality* 3:228-234.

Mcdonald, D., Ahmed K.M., Islam M.S., Lawrence A. and Khandker, Z. (1999), Pit Latrines: A Source or Contamination In Peri-Urban Dhaka?; Water Lines 17(3), 6-8. Retrieved on 06/07/11 from http://practicalaction.org/waterlines-index.

Moe, C.L., Cogger C.G. , and Sobsey, M.D., (1984), "Viral and Bacterial Contamination of Groundwater by On-site Wastewater Treatment Systems in Sandy Coastal Soils"; Proceedings, Second International Conference on Groundwater Quality Research, University Center for Water Research, Oklahoma State University Stillwater.

Mtine M. (2010) Zambia Cholera Outbreaks; Web Article. Retrieved on 20/07/11 from Htt://Www.Flutracters.Co / Forum/Showthread.Php^T=139591

Muszkat, L. M., Magaritz and Ronen D., (1989), Organic Contaminants in Israeli Coastal aquifer; Environmental Quality and Ecosystem Stability .E.Spanier,1st ed. ISEEQS Publishers, Jerusalem v.1 1VA PP 471-477

MWRWH,(2010) ,Small Towns Sector Guidelines. Ghana Community Water and Sanitation Agency.PP 7.

Nsubaga F.B, Kansiime F. and Oket-Okumu J., (2004), Pollution of Protected Springs In Relation To High Aid Low Density Settlements In Kampala-Uganda; Physics And Chemistry Of The Earth 29, 1153-1159.

Nevondo T.S and Cloete, T. E (1999) Bacterial and Chemical Quality of Water Supply in the Pertig Village Settlement. Water SA 25(2), 215-220.Retrieved on 25/07/11 from http://muienr.mak.ac.ug/index.php?q=StaffResearchPublications

Odai S.N and Dugbantey D.D., (2003), Towards Pollution Reduction in Peri-Urban Water Supply: A Case Study of Ashanti Region in Ghana; Diffused Pollution Conference, Dublin 2003; Department of Civil Engineering, KNUST, Kumasi, Ghana. Retrieved on 26/07/11 from http://www.ucd.ie/dipcon/docs/there14/there14_19-DAF.

Parry-Jones S. (1999), On-Site Sanitation in Areas with a High Groundwater Table; Sandy Caimcross; Well Factsheet. Retrieved On 9/06/11 from http://www.lboro.ac.uk/well/resource/fact-sheets/fact-sheet-htm/

Pedley S. And Howard G., (1995), The Public Health Implications Of Microbiological Geology And Hydrology; May 1997; Vol. 30; No. 2; P.179-188;001:10-1144/GSL-QJEGH-1997.030.P2.10, Retrieved On 10/06/11 From Http://Qjegh.Geoscience World.Org/Cgi/Content/Abstreet/30/02//19.

Pedley S. Yates, M., Schijven, J.F., West, J., Howard, G., and Barrett, M., (2006), Pathogens; Health Relevanc, Transport and Attenuation. In: Schmoll O. *et al*, Eds. Protecting Groundwater for Health: Managing The Quality of Drinking Water Sources. Geneva, world health organization: 493-516. Retrieved from http://www.bvsde.paho.org/bvsacd/cd59/protecting/sect1-3.pdf on 25/07/11

Powell, K.L., Taylor, R.G., Cronin, A.A., Barrett, M.H., Pedley, S., Sellwood, J., Trowsdale, S.A. and Lerner, D.N., 2003. Microbial contamination of two urban sandstone aquifers in the UK. *Water Res.*, **37**, 339-352.

Ranjana Piyadasa, U. K and Weerasinghe K.D.N. ,(2010),Groundwater Quality Sustainability XXXVIII IAH Congress Krakow, University Of Silesia Press (2010)

Reneau, R.B., Hagadorn C. and Degen, M.J., (1989), “Fate and Transport of Biological Contaminants from On-site Disposal of Domestic Wastewater"; *J. Environ. Qual.* 18(2):135-144.

Reneau, R.B., Simon, J.J., and Degen, M.J., 1985. "Treatment by Onsite Systems"; *Proceedings of a Workshop on Utilization, Treatment and Disposal of Waste on Land*. Soil Science Society of America, Madison, WI. Dec. 6-7.

Romero, J.C., (1970), "The Movement of Viruses through Porous Media"; *Groundwater*, 8(4):37-48.

Rusinga F., (2004), Groundwater Protecting: Guidelines for Protecting Springs; Retrieved On 13/06/11 from http://www.bgs.ac.uk/sadc/searchResults.cfm?country_search=ZA&country=South%20Africa

Stewart, L.W. and Reneau, R.B.Jr., (1984), "Septic Tank Effluent Disposal Experiments Using Non-conventional Systems in Selected Coastal Plain Soils"; *Final Report to Virginia Dept. of Health*. Virginia Polytechnic Institute and State Univ., Blacksburg, VA.

Stewart, L. W. and R.B. Reneau, Jr., 1988. "Shallowly Placed, Low Pressure Distribution System to Treat Domestic Wastewater in Soils with Fluctuating High Water Tables.", *J. Environ. Qual*. 17(3):499-504.

Stiles, C. W., and Crohurst**.** H. R., (1923), The Principles Underlying the Movement of Bacillus Coli in Ground-water, with Resulting Pollution of Wells; Public Health Report 38:1350-1353.

Still, D.A. and Nash, S.R., (2002), Groundwater Contamination Due To Pit Latrires Located in a Sandy Aquifer; A Case Study from Maputaland; Retrived On 11/06/11 from http://www.ssw.info/sites/default/files/references-eattachments.

Sugden S., (2006), The Microbiological Contamination Of Water Supplies, Sandy Cairncross; Well Factsheet. Retrieved from http://www.lboro.ac.uk/well/resource/fact-sheets/fact-sheet-htm/contamination.htm on 9/06/11

Tyler, E.J., R. Laak, E. McCoy and S.S. Sandhu, (1977), "The Soil as a Treatment System"; *Home Sewage Treatment*, American Society of Agricultural Engineers Publication 5-77, St. Joseph, Michigan.

U.S.EPA, (1980), Design Manual - Onsite Wastewater Treatment and Disposal Systems; EPA 625/1-80-012. U.S.EPA, Washington D.C.

USEPA, (1986), Bacteriological Ambient Water Quality Criteria for Marine and Fresh Recreational Waters; EPA 440/5-84-002. U.S. Environmental Protection Agency, Office of Research and Development, Cincinnati, OH.

USEPA, (2001), Protocol for Developing Pathogen; TMDLs. U.S. Environmental Protection Agency, Washington, DC. pp: 132.

W.H.O (1996), Water and Public Health ; Retrieved On 29/07/2011 from Http://Www.Who.Inter/Water-Sanitation-Health /Dwq/Sol.Polf

weblite.org/humanure/glossary.html groundwater

WHO (1993), Guidelines for Drinking Water Quality; Recommendations, Vol.1, Second Ed. World Health Organization, Geneva. Retrieved from Http://Www.Jstage.Jst.Go.Jp/Article/Jwet/7/4/7_277/_Cit On 20/07/2011.

WHO/UNICEF, (2004), Joint Monitoring Programme for Water Supply and Sanitation; Meeting the MDG drinking water and sanitation target: a mid-term assessment of progress. Geneva, Switzerland.

Willman, B.P., Peterson, G.W., and Fritton, D.D., (1981), "Renovation of Septic Tank Effluent in Sand-Clay Mixtures", *J. Environmental Quality Journal vol.* 10 pp. 439-434.

Wood, W. W., and Petraitis, M. J., (1984), Origin and distribution of carbon dioxide in the unsaturated zone of the Southern High Plains; Water Resources Research Journal, v. 20, p. 1193–1208

Yates, M.V. and Yates, S.R, (1989), "Septic Tank Setback Distances: A Way to Minimize Virus Contamination of Drinking Water",; *Ground Water* 27(2):202-208.

Ziebell, W.A., Nero, D.H., Deininger, J.F., and McCoy, E., (1974), Use of Bacteria in Assessing Waste Treatment and Soil Disposal Systems." *Home Sewage Treatment*, American Society of Agricultural Engineers Publication Proc-175, St. Joseph, MI, p.58.

APPENDIX A

F-Test and ANOVA results for dry season

A1 - Comparism of means of microbial counts in relation to depth of pit latrines

Depth of latrine		Total Coliform	Faecal Coliform	Enteroccoci
1 - 4	Mean	3.1933	2.0667	2.2383
	N	6	6	6
	Std. Deviation	.71436	.58551	.22596
5 - 8	Mean	2.3229	1.3257	1.3457
	N	7	7	7
	Std. Deviation	.63649	.62404	.67722
9 - 12	Mean	3.1650	2.1650	1.8900
	N	2	2	2
	Std. Deviation	1.12430	.28991	.05657
Total	Mean	2.7833	1.7340	1.7753
	N	15	15	15
	Std. Deviation	.80314	.67280	.63329

A2 – ANOVA for microbial counts in relation to depth of pit latrines

			Sum of Squares	df	Mean Square	F	Sig.
TotalColiform * Depthoflaterine	Between Groups	(Combined)	2.784	2	1.392	2.674	.110
	Within Groups		6.246	12	.521		
	Total		9.031	14			
FaecalColiform * Depthoflaterine	Between Groups	(Combined)	2.202	2	1.101	3.196	.077
	Within Groups		4.135	12	.345		
	Total		6.337	14			
Enteroccoci * Depthoflaterine	Between Groups	(Combined)	2.605	2	1.302	5.191	.024
	Within Groups		3.010	12	.251		
	Total		5.615	14			

A3- Comparism of means of microbial counts in relation to depth of wells

Depth of well		Total Coliform	Faecal Coliform	Enterococci
1 - 10	Mean	3.2400	2.1560	2.2500
	N	5	5	5
	Std. Deviation	.78838	.60719	.25060
1- 10	Mean	2.9600	1.6200	2.1800
	N	1	1	1
	Std. Deviation	.	.	.
11 - 20	Mean	2.5660	1.7040	1.8020
	N	5	5	5
	Std. Deviation	.27070	.25667	.12174
Above 20	Mean	2.3500	1.2725	.8625
	N	4	4	4
	Std. Deviation	1.21617	.97281	.57622
Total	Mean	2.7593	1.7340	1.7260
	N	15	15	15
	Std. Deviation	.81368	.67280	.64901

A4 - ANOVA for microbial counts in relation to depth of wells

			Sum of Squares	df	Mean Square	F	Sig.
TotalColiform * Depthofwell	Between Groups	(Combined)	2.053	3	.684	1.043	.412
	Within Groups		7.217	11	.656		
	Total		9.269	14			
FaecalColiform * Depthofwell	Between Groups	(Combined)	1.760	3	.587	1.410	.292
	Within Groups		4.577	11	.416		
	Total		6.337	14			
Enterococci * Depthofwell	Between Groups	(Combined)	4.590	3	1.530	12.882	.001
	Within Groups		1.307	11	.119		
	Total		5.897	14			

A5 - ANOVA for microbial counts in relation to infiltration layer

			Sum of Squares	df	Mean Square	F	Sig.
TotalColiform * Infiltrationlayer	Between Groups	(Combined)	1.218	2	.609	.935	.419
	Within Groups		7.813	12	.651		
	Total		9.031	14			
FaecalColiform * Infiltrationlayer	Between Groups	(Combined)	3.508	2	1.754	7.439	.008
	Within Groups		2.829	12	.236		
	Total		6.337	14			
Enterococci * Infiltrationlayer	Between Groups	(Combined)	4.214	2	2.107	18.057	.000
	Within Groups		1.400	12	.117		
	Total		5.615	14			

A6 - ANOVA for microbial counts in relation to lateral distance

			Sum of Squares	df	Mean Square	F	Sig.
TotalColiform * LateralDistance	Between Groups	(Combined)	1.083	2	.541	.843	.454
	Within Groups		7.708	12	.642		
	Total		8.791	14			
FaecalColiform * LateralDistance	Between Groups	(Combined)	.912	2	.456	1.009	.394
	Within Groups		5.425	12	.452		
	Total		6.337	14			
Enterecocci * LateralDistance	Between Groups	(Combined)	2.308	2	1.154	4.177	.042
	Within Groups		3.315	12	.276		
	Total		5.623	14			

A7-Anova for microbial counts in relation to slope

			Sum of Squares	df	Mean Square	F	Sig.
TotalColiform * Slope1	Between Groups	(Combined)	.865	2	.432	.635	.547
	Within Groups		8.166	12	.680		
	Total		9.031	14			
FaecalColiform * Slope1	Between Groups	(Combined)	.073	2	.036	.069	.933
	Within Groups		6.265	12	.522		
	Total		6.337	14			
Enterococci * Slope1	Between Groups	(Combined)	.030	2	.015	.032	.968
	Within Groups		5.585	12	.465		
	Total		5.615	14			

A8 - ANOVA for microbial counts in relation to lined and unlined pit latrines

			Sum of Squares	df	Mean Square	F	Sig.
tc * type	Between Groups	(Combined)	4.352	1	4.352	12.095	.004
	Within Groups		4.678	13	.360		
	Total		9.031	14			
fc * type	Between Groups	(Combined)	.323	1	.323	.698	.419
	Within Groups		6.014	13	.463		
	Total		6.337	14			
ec * type	Between Groups	(Combined)	.961	1	.961	2.685	.125
	Within Groups		4.654	13	.358		
	Total		5.615	14			

APENDIX B

F-Test and ANOVA results for wet season

B1- Comparism of means of microbial counts in relation to depth of pit latrines

Depth of laterine		Total Coliform	Faecal Coliform	Enteroccoci
1 - 4	Mean	4.1450	2.7817	2.7483
	N	6	6	6
	Std. Deviation	1.00261	1.14419	.62761
5 - 8	Mean	3.6257	1.7229	1.7700
	N	7	7	7
	Std. Deviation	1.20870	1.01171	.98805
9 - 12	Mean	4.2300	2.4600	2.1150
	N	2	2	2
	Std. Deviation	1.79605	.70711	.16263
Total	Mean	3.9140	2.2447	2.2073
	N	15	15	15
	Std. Deviation	1.13765	1.09923	.88501

B2 - ANOVA for microbial counts in relation to depth of pit latrines

		Sum of Squares	Df	Mean Square	F	Sig.
Total Coliform * Depth of laterine	Between Groups (Combined)	1.102	2	.551	.388	.686
	Within Groups	17.018	12	1.418		
	Total	18.119	14			
Faecal Coliform * Depth of laterine	Between Groups (Combined)	3.729	2	1.864	1.697	.224
	Within Groups	13.187	12	1.099		
	Total	16.916	14			
Enteroccoci * Depth of laterine	Between Groups (Combined)	3.112	2	1.556	2.378	.135
	Within Groups	7.853	12	.654		
	Total	10.965	14			

B3 - Comparism of microbial counts depth of wells

Depthofwell		TotalColiform	FaecalColiform	Enterococci
1 - 10	Mean	4.1450	2.7817	2.7483
	N	6	6	6
	Std. Deviation	1.00261	1.14419	.62761
11 - 20	Mean	4.3700	2.3750	2.2817
	N	6	6	6
	Std. Deviation	.81773	.62481	.49632
Above 20	Mean	2.5400	.9100	.9767
	N	3	3	3
	Std. Deviation	1.12214	.78810	.84595
Total	Mean	3.9140	2.2447	2.2073
	N	15	15	15
	Std. Deviation	1.13765	1.09923	.88501

B4 - ANOVA for microbial counts in relation to depth of wells

		Sum of Squares	df	Mean Square	F	Sig.
Total Coliform * Depth of well	Between Groups (Combined)	7.231	2	3.616	3.985 E0	.047
	Within Groups	10.888	12	.907		
	Total	18.119	14			
Faecal Coliform * Depth of well	Between Groups (Combined)	7.176	2	3.588	4.421 E0	.036
	Within Groups	9.740	12	.812		
	Total	16.916	14			
Enterococci * Depth of well	Between Groups (Combined)	6.333	2	3.166	8.202 E0	.006
	Within Groups	4.632	12	.386		
	Total	10.965	14			

B5 – ANOVA for microbial counts in relation to infiltration layer

			Sum of Squares	df	Mean Square	F	Sig.
T0talColifom * Infiltrationlayer	Between Groups	(Combined)	.733	2	.367	.253	.780
	Within Groups		17.386	12	1.449		
	Total		18.119	14			
FaecalColifor * Infiltrationlayer	Between Groups	(Combined)	5.945	2	2.972	3.251	.074
	Within Groups		10.972	12	.914		
	Total		16.916	14			
Enterococci * Infiltrationlayer	Between Groups	(Combined)	5.842	2	2.921	6.272	.015
	Within Groups		5.123	11	.466		
	Total		10.965	13			

B6- ANOVA for microbial counts in relation to lateral distance

			Sum of Squares	df	Mean Square	F	Sig.
Total Coliform * Lateraldistance	Between Groups	(Combined)	3.088	2	1.544	1.233	.326
	Within Groups		15.031	12	1.253		
	Total		18.119	14			
Faecal Coliform * Lateral Distance	Between Groups	(Combined)	4.125	2	2.062	1.933	.187
	Within Groups		12.806	12	1.067		
	Total		16.931	14			
Enterococci * Lateral Distance	Between Groups	(Combined)	4.778	2	2.389	4.633	.032
	Within Groups		6.188	12	.516		
	Total		10.965	14			

B7 - ANOVA for microbial counts in relation to slope

ANOVA Table

			Sum of Squares	df	Mean Square	F	Sig.
TotalColiform * Slope1	Between Groups	(Combined)	.721	2	.361	.249	.784
	Within Groups		17.398	12	1.450		
	Total		18.119	14			
FaecalColiform * Slope1	Between Groups	(Combined)	.282	2	.141	.102	.904
	Within Groups		16.634	12	1.386		
	Total		16.916	14			
Enterococci * Slope1	Between Groups	(Combined)	.438	2	.219	.249	.783
	Within Groups		10.528	12	.877		
	Total		10.965	14			

B8-ANOVA for microbial counts in relation to lined and unlined pit latrine

			Sum of Squares	df	Mean Square	F	Sig.
tc * type	Between Groups	(Combined)	8.454	1	8.454	11.371	.005
	Within Groups		9.665	13	.743		
	Total		18.119	14			
fc * type	Between Groups	(Combined)	1.786	1	1.786	1.534	.237
	Within Groups		15.130	13	1.164		
	Total		16.916	14			
ec * type	Between Groups	(Combined)	1.372	1	1.372	1.679	.218
	Within Groups		10.620	13	.817		
	Total		11.992	14			

APENDIX C

Other Tests on Microbial counts

T-test on differences between dry and wet seasons microbial counts

Sample	Size	Mean	Variance	Standard deviation	Standard error of mean	Probability
EC wet-ECdry	15	0.4320	0.1488	0.3857	0.09959	<0.001
FCwet-FCdry	15	0.5107	0.3327	0.5768	0.1489	<0.004
TCwet-TCdry	15	1.131	0.2769	0.5262	0.1359	<0.001

Multiple regression of static water level and pit latrine depth (infiltration layer) on microbial counts

SUMMARY OUTPUT

Regression Statistics	
Multiple R	0.913296
R Square	0.834109
Adjusted R Square	0.806461
Standard Error	0.278604
Observations	15

ANOVA

	df	*SS*	*MS*	*F*	*Significance F*
Regression	2	4.683333	2.341666	30.16833	2.08E-05
Residual	12	0.93144	0.07762		
Total	14	5.614773			

	Coefficients	*Standard Error*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*	*Lower 95.0%*	*Upper 95.0%*
Intercept	2.365241	0.208576	11.33992	9.06E-08	1.910792	2.81969	1.910792	2.81969
X Variable 1	-0.09139	0.012923	-7.07235	1.3E-05	-0.11955	-0.06324	-0.11955	-0.06324
X Variable 2	0.119175	0.042624	2.795921	0.016166	0.026304	0.212045	0.026304	0.212045

Variable1= static water level (SWL)
Variable2= pit latrine depth (PLD)
EC = 0.12(PLD) – 0.09(SWL) +2.36
EC = enterococci

KWAME NKRUMAH UNIVERSITY OF SCIENCE AND TECHNOLOGY

DEPARTMENT OF THEOLOGICAL AND APPLIED BIOLOGY

QUESTIONNAIR FOR RESPONDENTS ON IMPACT OF PIT LATRINE ON GROUND WATER

A research is being conducted to assess the impact of pit latrine on groundwater. I have the honour to select you to participate in this research by responding candidly to items on this questionnaire. The responses will be confidentially treated and used for the purpose for which it is intended.

Please tick (√) the box of the appropriate response you select. You may write in the space provided where necessary. Thank you for your co-operation.

Section A: Demography of respondent

1. Sex :
   Male ☐
   Female ☐
2. In what age range do you fall?
   18-23 ☐
   24-29 ☐
   30-35 ☐
   36-41 ☐
   42-47 ☐
   Above 47 ☐
3. For how long have you stayed in this household/vicinity?
   Under 3 years ☐
   4-6 years ☐
   6-8 years ☐
   Over 8 years ☐

4. What is your status in this house/ vicinity?

   Tenant ☐

   Landlord ☐

   Assemblyman ☐

   Pit latrine/ land-dug well constructor ☐

Section B: Source of domestic water

5. What is the major source of domestic water used in this household/ vicinity?

   Well ☐

   Bore hole ☐

   River / Stream ☐

   Tap ☐

   Any other? Specify…………

6. State the site of your domestic water sources

   House of residence ☐

   Outside house of residence ☐

   Any other? Specify……………….

7. How do you describe the distance the source of the domestic water the nearby pit latrine?

   Far ☐

   Near ☐

   Any other? Specify…………………………..

8. State the depth the pit latrine was constructed

   < 5m ☐

   5-10m ☐

   11-21m ☐

   Any other specify………………….

Section C: Treatment of domestic water

9. How is water from well / bore hole treated before use?

   Boiling ☐

   No boiling ☐

   Any other specify…………………….

Section D: Report on diarrhea related disease in household/ vicinity

10. How many reports on diarrhea related disease have been recorded in this household/ vicinity

None ☐

1-5 ☐

6-11 ☐

12-17 ☐

Any other specify……………….

Section E: Perception of possible source of domestic water contamination

11. Is there any source of your domestic water contamination?

Yes ☐

No ☐

If yes, describe the source of contamination…………………………….

12. Section F: The use of water from household well/bore hole in the vicinity

Bathing ☐

Cooking ☐

Washing of clothes ☐

Washing of utensils ☐

Any other? Specify

Section G: The Topographic relation between the well/ bore hole

13. What is the topographic relationship between the well and the pit latrine?

Pit latrine is up hill ☐

Pit latrine is down hill ☐