OBSERVED SANITARY RISKS AND WATER QUALITY PARAMETERS INDICATING FAECAL CONTAMINATION IN URBAN AND PERI-URBAN GROUNDWATER SOURCES, GREATER ACCRA, GHANA.

BY

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DECLARATION

I, KAFUI AWO SESHIE-DOE, declare that this study is my original work carried out under the supervision of Dr. Mawuli Dzodzomenyo at the Department of Biological, Environmental and Occupational Health, and that apart from the literature review that have been duly acknowledged in-here, this work has never been presented either whole or in part by anyone to any institution or school for the award of any other course or degree qualifications.

I also reaffirm that all sources of materials used and consulted in the course of this study have been duly acknowledged.

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DEDICATION

I dedicate this work to my late mother, Mrs. Cecilia Ami Doe (Kexodu), and all family and friends who have complete faith in me and supported me. My mother would have been proud to see what I have accomplished. I am grateful for all she did for me and shaped me into the person I am today. Thank you, mother, for being a role model in fighting for one’s dream and accomplishing it.
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ABSTRACT

Introduction: Rapid population growth and urbanization has significantly resulted in higher demand on groundwater resources in urban and peri-urban areas. However, anthropogenic activities and poor protection of groundwater, are potential sources of contamination posing health risks. To access the faecal contamination pathway to determine the quality of groundwater, the World Health Organization (WHO) developed a sanitary risk inspection protocol to identify potential risks and hazards. The study therefore sought to assess the relationship between observed sanitary risks and water quality parameters indicating faecal contamination in urban and peri-urban groundwater sources in Greater Accra, Ghana.

Method: The study used a descriptive cross – sectional study, that was carried out in 5 selected enumerations areas (EA) in the Greater Accra Region. After selecting the households with groundwater sources, hazards (sources of contamination) were identified and water samples taken for physico-chemical and bacteriological laboratory analysis, using international standard procedures. Statistical analysis of the results was carried out using SSPS version 22.

Results: The sources of contamination identified within the periphery of the groundwater sources were bath-houses, hen coups, piggery, pit latrines, polluted swamps, refuse dumps, septic tanks and urban storm drains. Nitrate levels ranged from 0.7mg/l to 19.7mg/l with a mean of 6.4mg/l. Chloride levels ranged from 35.43mg/l to 421.15mg/l with a mean of 121.24mg/l. Nitrite levels ranged from 0.002mg/l to 4.192mg/l with a mean of 0.23mg/l. Electrical conductivity ranged from 0.56mS/cm to 7.24mS/cm with a mean of 2.29mS/cm. Total coliforms counts ranged from non-detection to a maximum of 2400cfu/100ml with a mean of 50.8cfu/100ml, Faecal coliform counts ranged from non-detection to a maximum of 450cfu/100ml with a mean of 14.69cfu/100ml and E. coli counts ranged from non-detection to a maximum of 200cfu/100ml with a mean of 10.55cfu/100ml. Multiple regression model
used showed that faecal contamination pathways such as depth of groundwater and distance of groundwater from source of contamination were additional explanatory power used to predict faecal contamination of groundwater.

**Conclusion:** The findings of the study showed that there was a relationship between the modified observed sanitary risks and water quality parameters indicating faecal contamination of groundwater in urban and peri-urban areas in Greater Accra Region, Ghana.
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LIST OF ABBREVIATIONS

ANOVA: Analysis of Variance
APHA: American Public Health
CDC: Centre for Disease Control and Prevention
Cl⁻: Chloride
CFU: Coliform Forming Unit
EC: Electrical Conductivity/ Electroconductivity
E. coli: Escherichia coli
EMB: Eosin Methylene Blue
FC: Faecal Coliform
GSS: Ghana Statistical Service
GWC/ GWCL: Ghana Water Company/ Ghana Water Company Limited
MAC: Maximum Acceptable Concentration
mg/l: milligram per litre
ml: millilitre
mS/cm: millisiemen per centimetre
l: litre
N: Nitrogen
NaCl: Sodium Chloride
NGO: Non-Governmental Organization
NO₃⁻: Nitrate
NRC: National Research Council
PBS: Phosphate Buffered Saline
PC: Plate Count
PCA: Plate Count Agar
SD: Standard Deviation
SE: Standard Error
SMCL: Suggested Maximum Contaminant Level
SPSS: Statistical Package for Social Services
SRM: Standard Reference Material
TC: Total Coliform
USEPA: United States Environmental Protection Agency
VRB: Violet Red Bile
WHO: World Health Organization
1.0 INTRODUCTION

1.1 BACKGROUND

Around the world, 1.1 billion people depend on unsafe drinking water sources from lakes, rivers and open wells. Most live in Asia (20%) and sub-Saharan Africa (42%). It is also estimated that 2.4 billion people lack adequate sanitation worldwide (WHO/UNICEF, 2000).

The Government of Ghana has collaborated with institutions such as Community Water and Sanitation Agency and NGOs such as, World Vision International and many other faith-based organizations to construct hundreds of hand dug wells and boreholes annually throughout the country. This has made hand dug wells and boreholes values in many communities across Ghana (Issah, 2000).

Rapid population growth and urbanization has significantly resulted in higher demand on ground water resources. However, there are several anthropogenic sources of contamination that can compromise the quality of groundwater resources over time and when not adequately addressed can influence the physico-chemical and microbiological quality of water (Lee et al., 2002). Septic tanks and sewage systems for household wastewater that are poorly built, underground storage tanks that are abandoned or leaking, drains that discharge chemicals to groundwater and inappropriate disposal or storage of chemical waste around a water source all add up to contaminate water source (Arya et al., 2012).

In response to addressing the varied contamination pathways to groundwater sources, the World Health Organization (WHO) developed a sanitary risk inspection tool. Its application was predominant in rural settings in the past. Currently however, there is a need to evaluate and develop a sanitary risk inspection protocol for assessing faecal contamination pathways.
for urban and peri-urban groundwater sources to address the different sources of contamination found in these areas. Sanitary risk inspection and water quality assessment are essential elements in characterizing the microbiological safety of water and a well-conducted sanitary risk inspection can identify sources of microbiological hazard. Microbiological water quality data confirm the presence of hazards, and the two together allow an estimation of the risk of harm to consumers and other users. In assessing the faecal contamination pathway to determine the quality of groundwater, it is important to conduct an intensive sanitary risk inspection using the sanitary risk inspection protocol developed by WHO to identify potential contamination.

Over the past several decades, researches repeatedly have shown that sanitary facilities contribute significantly to degraded groundwater quality in shallow aquifers in urban and peri-urban areas. Indeed, improvement in hygiene and sanitation are contingent upon the availability of good water quality (Pickford et al., 1992). The WHO recommends that such sanitary facilities which pose a risk to water quality should be located at least 30m away from water sources (WHO, 2008).

Greater Accra Region, for well over a decade, has experienced rapid spatial development and increasing population (GSS, 2010). These factors have among others lead to increasing pressure on the demand for water resources. The Ghana Water Company Limited, the agency responsible for urban and peri-urban water supply, has been constantly unable to provide adequate water supply to most communities of Accra. In response to this, many households have privately constructed hand dug wells within their compounds or sites nearby to access groundwater for domestic use and in some cases for drinking. These households may have point source contamination hazards such as uncollected solid waste, broken sewage pipes,
blocked stormed drains and septic tanks and drainages whose leachate can directly and rapidly contaminate groundwater sited nearby. The failure to identify and inspect these pollution sources and follow inspection protocols developed by WHO can increase the risk of contaminants entering the groundwater source. Faecal coliforms, nitrates, chlorides and other contaminants are responsible for water-borne diarrhoeal diseases such as enteric fever and shigellosis (NRC, 1998).

1.2 PROBLEM STATEMENT

In developing countries, estimated 801,000 children under age 5 years, die yearly from ingesting contaminated water. Lack of safe drinking water supply, basic sanitation and poor hygienic practices are associated with high morbidity and mortality from excreta related diseases (CDC, 2016).

In Ghana, data collected by Community Water and Sanitation Agency (CWSA) and Ghana Water Company Limited (GWCL) indicated that, every year an average of 596,000 people need to gain access to an improved water supply (GWC, 2010).

Faecal contamination pathways from sanitary facilities such as uncollected solid waste, blocked storm drainage, broken sewerage pipes among others are significant possible anthropogenic contaminants sources that often compromise the quality of groundwater sources causing adverse health effects and disease outbreaks (Nkansah et al., 2010).

The WHO developed sanitary risk inspection tool to identify contamination hazards present around water sources (WHO/UNICEF, 2000). Although the tool has been used in a variety of studies in assessing rural ground water contamination hazards (Cronin et al., 2006; Howard et al., 2003), its utility as a predictor of contamination has been questioned (Luby et al., 2008).
One potential use of the tool is to determine the apparent relationship between faecal contamination of groundwater sources and observed contamination risks. Some sources of contamination found in urban and peri-urban areas are uncollected solid waste, blocked storm drains and broken sewerage pipes among several others which can potentially contaminate groundwater sources with faecal matter are not recorded in the existing WHO sanitary risk inspection forms as mentioned earlier. This creates a theory gap for investigation in order to modify the current sanitary risk inspection protocol by expanding the set of contaminants for evaluation and its possible adaptability for use in urban and peri-urban settlements.

The study is therefore necessary to understand sanitary risk facilities and its association with faecal contamination on water quality and subsequently assist in the future management of groundwater resources in urban and peri-urban communities. This will help to ascertain the levels of faecal contaminants and measures put in place in the protocol to protect ground water aquifer.
1.3 JUSTIFICATION

The availability of water in adequate quantity and quality is imperative for sustainable development. In Ghana, significant imbalance exists with regards to sustainable development particularly from a water and sanitation perspective. There is therefore the need to improve the health of humans through the consumption of quality water in order to reduce water related diseases. The study is necessary to provide adequate data and information on the relationship between identified hazards and faecal contamination to establish the microbiological quality. The study findings will help modify guidelines to continuously monitor faecal contamination in groundwater in urban and peri-urban areas where potential hazards are high. The study findings will also aid in modification and implementation of appropriate guidelines and policies to help in the proper designing, siting and management of sanitation systems that are potential hazards around groundwater sources in Ghana.

RESEARCH QUESTIONS

- Are there contamination sources found within the periphery of the groundwater sources that can impact on the water quality?
- To what extent can an observational checklist for recording potential faecal contamination sources at and immediately surrounding urban and peri-urban groundwater sources be modified?
- What is the relationship between the presence of hazards and contamination measured through faecal indicator bacterial counts in water sample.
1.4 OBJECTIVES OF THE STUDY

1.4.1 GENERAL OBJECTIVE

The objective of the study is to assess the relationship between observed sanitary risks and water quality parameters indicating faecal contamination in urban and peri-urban groundwater sources.

1.4.2 SPECIFIC OBJECTIVES

The specific objectives of the study include the following:

1) To assess the sources of contamination within the periphery of the groundwater sources.

2) To assess the relationship between the presence of sources of contamination and groundwater quality.

3) To assess the additional explanatory power (if any) in predicting faecal contamination from observing hazards specific to urban and peri-urban environments in addition to standard risk inspection checklist items.
1.5 CONCEPTUAL FRAMEWORK

Sources and factors promoting groundwater contamination

The threat that a sanitary facility poses to nearby groundwater sources, is dependent on a number of factors related to the environment. Understanding these factors is important to enable new systems to be constructed in a manner that will lessen their pollution threat, while allowing management to be concentrated in vulnerable areas. Distance of contaminants to surface and groundwater, soil type, density of septic tank, land topography and groundwater depth, broken sewerage pipes, refuse dumping sites, blocked storm drains and polluted swampy areas, are all factors.

Distance

Sanitary facilities sited close to underground water potentially contaminate these water sources. The World Health Organization proposes that watercourses such as wells be located at least 30m away from the nearest contamination source (Chukwurch, 2001).

Soil Type

Soil filters and attenuate pollutants. Sanitary facilities should be sited on the appropriate soil types to reduce contamination. Sand and sandy loam soil is appropriate for siting sanitary facilities (Cantor and Knox, 1985).
Slope

Slope controls hydrology as it affects percolation of water into the ground, water flow rates and pathways. Domestic wells are mostly sited up gradient from household on-site sanitation systems (Kinsley and Joy, 2005).

Depth

It is generally believed that the deeper you sink a well, the better the water quality. Efe (2008) stated that the longer the polluted water travels through the soil formation, the better (cleaner) it becomes. Agbede and Akpen (2008) in their study on the bacteriological and physico-chemical qualities of ground water in Makurdi metropolis floodplains (depth between 1.82meters and 7.43meters) found that all the ten wells studied were polluted with faecal bacteria.

Blocked stormed drains

With urban population growth, there is a rise in rain water runoff caused by paved surfaces. Some municipalities use storm water drainage wells to dispose of this additional runoff particularly if the area has a restricted sewer system. In areas where the water table is high, storm water drainage wells that communities use to control water during storm events pose a threat to groundwater (Nkansah et al., 2010).

Polluted swampy areas

Swampy areas usually have high water tables. When polluted with refuse, faecal matter, dead rodents and other contaminants, it is a source of groundwater source contamination. Some of these areas are found in urban and peri-urban communities.
Agricultural activities

Fertilizers, herbicides, insecticides, fungicides and pesticides applied to the lawn and gardens, contain hazardous chemicals that can travel through the soil and contaminate the ground water (Osiakwan, 2002).

Septic tanks and pit latrines

On-site sanitary facilities, such as pit latrines and septic tank systems are potential sources of many categories of contaminants including nitrate, bacteria and viruses from human waste and organic compounds. The particular concern to ground water quality is the pollution source is located close to and up gradient of drinking water wells (Issah, 2000)

Refuse Dumping

Uncollected solid waste in households or within the periphery of groundwater sources is a contamination hazard as contaminants stay in the soil and may leak with time into the groundwater source. Sometimes an old dumpsite may be used as reclaimed land and used for building houses. Wells sited in these lands may have contaminated ground water.

Receptacles used at wells

The condition of the receptacles such as buckets used for drawing water from the well may be a source of contamination, if they are dirty and if not kept in a clean storage area after use.

Unsanitary or cracked wellhead

If the well head is cracked and unsanitary, this is another source of contamination. Faecal matter and other contaminants can be introduced into well water if the wellhead is unsanitary, improperly covered well, cracked wellhead or poorly lined well.
Figure 1: CONCEPTUAL FRAMEWORK (Adapted from Source-Pathway-Receptor Framework Concept)

**SOURCE**

**Inspection hazards**
- Soak away septic tanks
- Blocked storm drains
- Broken sewerage pipes
- Receptacles used for drawing water
- Unsanitary or cracked wellhead
- Pit latrines (lined and unlined)
- Refuse dumping
- Agricultural activities

**PATHWAY**

**Factors influencing microbial quality of ground water**
- Distance
- Topography/ slope
- Soil type
- Depth of well

**CONTAMINATION INDICATORS**

**Water quality analysis**
- Physico-chemical parameters (Nitrates and chlorides)
- Microbiological parameters (Fecal coliforms-isolation of Escherichia coli (E. Coli), and Thermotolerant coliforms)

**RECEPTOR/CONSEQUENCE**

**Ground water contamination**
- Waterborne diseases
2.0 LITERATURE REVIEW

2.1 INTRODUCTION

This chapter looks at findings on the use of sanitary risk inspection checklist, a water management tool developed and recommended by the World Health Organization (WHO) to assess faecal contamination pathways of groundwater sources. It also looks at the importance of groundwater use and the sources of contamination to this vital water source and the pathways that promote its contamination. The chapter also addresses how groundwater is formed and its vulnerability to contamination from hazards identified in urban and peri-urban areas.

2.2 GROUNDWATER FORMATION AND SYSTEM

Groundwater is an important part of the natural water cycle, thus whenever it rains and snows, some of the water from the rain and melted snow flows onto land surface, into rivers, lakes and streams. A proportion of the melted snow and rain evaporate into the atmosphere and the rest soaks and moves into the ground via gravity (Clark et al., 1995). Plants and soil organisms use water that seeps into the soil, and the proportion left, further seeps into pores in the ground. This water moves downwards through the soil and cracks and fractures in rocks until it is intercepted by an impermeable layer of clay or rock. The water then accumulates on this layer filling up all available spaces until saturation. The top of the impermeable layer become the water table whiles the accumulated water becomes the groundwater. The void space in the soil and cracked and fractured rocks where the water accumulates and is stored above the impermeable layer of clay or rock is called an aquifer.

Porosity is the volume of open space that groundwater can be stored. It determines the amount of water that a rock or sediment can contain. Rounded coarse-grained sediments have higher porosity than fine-grained sediment. Sediments that are poorly sorted have low porosity because the fine-grained fragments fill in the spaces reducing pore space. Also
cemented sedimentary rocks have low porosity because cements fill up pore space. Igneous and metamorphic rocks that are highly fractured usually have high porosity.

The measure of the degree to which pore spaces are interconnected and the size of the interconnections is permeability. When the size of the interconnections is large water moves freely, thus sands are more permeable than clay and coarse-grained rocks are more permeable than fine-grained rocks. Good aquifers have high permeability and examples are highly fractured rocks and poorly cemented sands and gravels.

2.3 SOURCES OF GROUNDWATER IN URBAN AND PERIURBAN AREAS

Groundwater is a life-sustaining resource that supplies water to billions of people (Gleeson et al., 2012). Groundwater is usually of good microbiological quality due to its process of formation; thus, it is preferred for drinking and domestic use as treatment is usually limited to disinfection or no treatment at all. Building of groundwater systems may however provide a direct pathway for contamination of groundwater, therefore construction should be appropriately planned and carried out (ARGOSS, 2001).

The main sources of groundwater used in urban and peri-urban areas are dug wells, boreholes (tube wells) and springs.

**Dug wells** are wells that are hand dug with a relatively shallow depth and are of large diameter. Water is drawn from the well using a receptacle or bucket with a rope tied onto it. Some wells are fitted with hand pumps.

**Boreholes**, also sometimes referred to as tube wells, are holes that are drilled with a narrow diameter and may be shallow or deep in depth. They may be fitted with a hand pump or an electric submersible pump to abstract water. Boreholes are usually protected from pollution, however when constructed with simple hand drilling methods, risk of contamination increases.
2.4 RISK OF CONTAMINATION: Source-Pathway-Receptor Concept

Groundwater supplies risk being contaminated by on-site sanitation. A source of contamination and a pathway which provides the route for contamination of groundwater supplies (receptor) must exist in the source-pathway-receptor concept (ARGOSS, 2001).

Sources of contamination are present and widespread, including on-site sanitation, in the natural environment. Pathways that allow water to move from these sources to the receptor can be aquifer pathway or localized pathway.

**Aquifer pathway** occur naturally in the subsurface from cracks in the soil and rock.

**Localized pathway** are man-made pathways that occur as a result of the design and construction of the receptor (groundwater supplies).

Risk of contamination of groundwater supplies (receptor) can be reduced by removing the source of contamination or minimizing the levels of contaminants that are produced; increasing the time for water to move from the source to the receptor and reducing man-made pathways (ARGOSS, 2001).

### 2.4.1 AQUIFER VULNERABILITY TO POLLUTION

The concentration of many contaminants which include harmful microorganisms are reduced as water moves through the ground using natural processes. Aquifers get filled from surface waters and from rain and melted snow which filters through the unsaturated zone (the area immediately below the land surface containing open spaces). Where aquifers take in water are known as recharge areas and where groundwater flows to the land surface are known as discharge areas. Water moves from recharge areas which are high elevation areas to low elevation areas of discharge through the saturated zone (the area underlying the unsaturated zone, in which all the pores and fractures are filled with water). The top of the saturated zone is the water table.
Vulnerability of an aquifer to pollution comprises the intrinsic properties of the strata separating a saturated aquifer from the land surface which determine the sensitivity of that aquifer to being adversely affected by pollution loads applied at the land surface (Chilton, 2006). All aquifers in the long term are vulnerable to persistent pollutants. Aquifer vulnerability is classified as follows:

- **Extreme** – vulnerable to most water pollutants with relatively rapid impact in many pollution scenarios
- **High** – vulnerable to many pollutants, except those highly absorbed and/or readily transformed, in many pollution scenarios
- **Moderate** – vulnerable to some pollutants, but only when continuously discharged or leached
- **Low** – Only vulnerable to the most persistent pollutants in the long term, when continuously and widely discharged or leached
- **Negligible** – Confining beds are present and prevent any significant vertical groundwater flow

Sensitivity of an aquifer is how well it is protected from infiltrating contamination. A highly sensitive aquifer has little or no protection whereas one with low sensitivity is well protected. Sensitivity is based on physical characteristics of an aquifer, the overlying geologic materials and the chemical characteristics of a specific contaminant.

A shallow, unconsolidated aquifer made up of sand and gravel is highly sensitive to contamination because of the physical characteristics; it allows for rapid infiltration of recharge which leaves little time for the contaminants to degrade naturally before reaching the aquifer. A deep, confined aquifer made up of layered basalt has low sensitivity to contamination, as infiltrating recharge takes a long time to reach the aquifer, allowing contaminants to degrade or lessen.
With geologic conditions, fractured rocks tend to conduct recharge quicker than unfractured rocks. Also, dissolution of limestone rock terrain by groundwater forms karst which are usually caves and sinkholes with rapid underground drainage. Having many conduits connecting the surface and subsurface, karst terrain is a very sensitive aquifer.

Silt and clay form impermeable layers, which provide a physical barrier above the aquifer, thus making it less sensitive to contamination (Driscoll, 1987).

2.5 SOURCES OF GROUNDWATER CONTAMINATION

Faecal matter is common in the environment in developing countries and this increases the risk of contamination of groundwater systems. On-site sanitation systems contribute largely to faecal matter contamination, but other sources of sanitation are refuse pits and solid waste dumps, household wastewater, storm drains and animals.

2.5.1 TYPES OF SANITATION FACILITIES

According to a joint WHO and UNICEF report on water, sanitation and hygiene, improved sanitation facilities are important as they hygienically separate human excreta from human contact. About 1.1 billion people globally practice open defecation (WHO, 2012).

Sanitation facilities may be dry or water-borne. Choosing a sanitation facility is based on the availability of water and cultural activities such as anal cleansing methods. There are two principal categories of sanitation systems. These are off-site sanitation and on-site sanitation. **Off-site** methods are different forms of sewerage where household and faecal waste are carried away from the household to a treatment plant and treated before discharge into the environment. These methods are found in urban areas because space constraints limit on-site methods. Conventional sewerage which is an off-site method, is very costly and requires water supply to function properly in-house. However, with higher population densities like those found in urban areas, cost is cheaper with modified sewerage. This method also
includes water-borne systems like septic tanks, pour-flush latrines and aqua privies (ARGOSS, 2001).

Leaking sewers from broken or damaged sewer pipes contaminate groundwater by increasing microbiological and nitrate levels. Often times when sewage is poorly treated before discharged into the environment, it contaminates groundwater. Some treatment plants with waste stabilization ponds may leach chemical and microbiological contaminants into groundwater (ARGOSS, 2001).

**On-site** methods include all forms of pit latrines and septic tanks. Waste is stored at the point of disposal and allowed to undergo some form of decomposition on-site. Once the sanitation facilities fill up, periodic emptying is required or construction of new facilities. These methods are hazards to groundwater since faecal matter accumulates in one place, leaching contaminants into the subsurface environment.

Septic tanks are widely used in urban areas and are sealed tanks that hold the solid component of waste and the liquid effluent is discharged into a soak away pit which is the part of this sanitation facility that poses the risk of chemical and microbiological contamination.

With pit latrines, the liquid effluent of the waste infiltrates into the soil and this is called hydraulic load. When hydraulic loads exceed the natural attenuation potential in the subsurface this may lead to contamination of groundwater supplies. With pour-flush latrines some are designed with a soak away. Pit latrines are a cheap form of sanitation and easy to construct. They are usually used in peri-urban areas, but pose a great risk of contamination to groundwater, when the numbers and densities of the pit latrines increase (ARGOSS, 2001).

Verstraeten et al., (2005) used several tracers including nitrogen and boron isotopes and observed that sand point domestic wells within 30m of a septic system and less than 14m deep in a shallow aquifer were the most vulnerable to contamination from septic effluent.
2.5.2 OTHER TYPES OF SANITATION SOURCES

As mentioned earlier aside from off-site and on-site sanitation facilities, there are other sanitation sources that are pose a risk of groundwater contamination. These include solid waste/refuse dumps, polluted stagnant surface water such as polluted swamps, household wastewater, animal enclosures and free-range animals and blocked urban storm drains.

**Solid waste and refuse dumps**

With the high population density in urban areas, where proper human excreta disposal is insufficient or absent to meet the population’s needs, excreta is usually dumped off at solid waste sites. If the faeces located up-gradient of groundwater supply, there is high contamination risk. Also, rainfall can carry the faecal contamination directly into groundwater sources if the dug wells are not properly constructed. If the well head has cracks and the walls of the well are not properly sealed, this allows direct seepage of contaminated rain run-off water into the well water.

Valenzuela et al., (2009) suggested that the most important factors affecting well vulnerability to bacterial contamination were those related to the well itself, construction and site management whilst its usage and maintenance is also crucial. Faecal contamination from solid waste, which affects microbiological quality of groundwater sources, is likely to be localized. Improperly managed solid waste is also a source of nitrate which is a chemical contaminant of groundwater.

**Household waste water**

Household waste water incudes domestic waste from washing, cooking, car washing and other anthropogenic activities as well as sullage (sewage). Most of this waste water is discharged directly into open ditches. Sullage usually contains a large percentage of faecal indicator bacteria and other pathogens, thus if not disposed of properly causes groundwater
contamination. Also, the chemicals from detergents used in washing can cause contamination of groundwater.

**Polluted swamps or stagnant surface water**

When an area is swampy the water table is usually high, thus when the swamp is polluted with human and animal excreta, refuse and other contaminants, it poses a major risk of directly contaminating groundwater. Pools of stagnant water in densely populated area with poor sanitation practices usually collect faecal matter from household sullage and animals walking around leaving their excreta in the environment. This also contaminates groundwater through infiltration of the sources when it rains (ARGOSS, 2001).

**Animal enclosures and free-range animals**

Animal faeces in the environment is a hazard to groundwater contamination. Free-range animals’ faeces are usually found in the environment, and as mentioned earlier may collect in stagnant surface water of may be carried by rain waters directly into a poor managed and maintained groundwater supply (ARGOSS, 2001). Animals in an enclosed area like a piggery, is a serious source of groundwater contamination, as large volumes of waste produced may build up over time. This has an impact on nitrate contaminating groundwater more than faecal contamination with harmful microbiological organisms.

**Blocked urban storm drains**

Sercu et al., (2009) did a study and found out that apart from urban storm drains being a source of high human faecal contamination to watershed areas in three urban southern Californian areas during the rainy season, it was also a source of high human faecal contamination during the dry season. With rapid urban growth, urban storm drains are constructed to take in run-off water during the rainy seasons to prevent floods. However, as shown in the study they are also a source of human faecal contamination as sewer water from
various sources are channeled into these storm drains and faecal matter from the environment are also carried by run-off waters into these storm drains. When the storm drains are also blocked with refuse and sewer water, when it rains the contents overflow onto the surface and eventually contaminating groundwater sources through seepage.

2.6 SOME FACTORS PROMOTING GROUNDWATER CONTAMINATION FROM SOME HAZARDS

Researching and understanding the factors that promote contamination of groundwater supplies is important to enable new systems to be built in a manner that will lessen their pollution threat. This should make water and sanitation companies construct and manage proper sanitation systems in vulnerable areas that have these factors that promote pollution. These factors include; distance to surface water and groundwater supplies, soil type, slope or topography of the land, the depth of the groundwater source and design and construction of groundwater supplies.

2.6.1 DISTANCE TO SURFACE WATER AND GROUNDWATER SUPPLIES

On-site sanitary systems such as pit latrines and septic tanks near groundwater supplies, water channels, and watercourses pose a greater risk than those further away. There is controversy in literature surrounding minimum setback distances because a variety of other factors can influence the potential of on-site sanitation systems to pollute groundwater sources. A study done in Ireland showed that sanitary systems should not be built within 400m of any surface watercourse (Clark et al., 1995) and Canter and Knox (1985) suggest a minimum distance of 30m from open watercourses is suitable. The WHO proposes that boreholes should be sited at least 30m away from septic tanks (Chukwurch, 2001). In urban areas, the risk of contamination to groundwater supplies increases when the distance between the on-site sanitation system and water source is less than 10m (ARGOSS, 2001).
2.6.2 TYPE OF SOIL

It is essential that on-site sanitation systems are located on suitable soil types. On-site sanitation systems rely on the surrounding soil to filter and attenuate pollutants (Morgenstern, 2005). On-site sanitation systems should be located on well drained sandy loams, with good filtration. The sanitation system should be constructed at least 90 cm above the highest water table level to prevent surface break-out (Canter and Knox, 1985). Kinsley and Joy (2005) used estimating hydraulic conductivity from superficial geology maps as a technique to rank the risk associated with soil types.

2.6.3 SLOPE OR TOPOGRAPHY OF THE LAND

Slope is a major control on hydrology as it affects percolation, water pathways and flow (Canter and Knox, 1985). Domestic wells are mostly sited up gradient from the household on-site sanitation systems (Kingsley and Joy, 2005) and at a specified minimum distance or depth to reduce potential groundwater quality problems. Canter and Knox (1985) suggest that sanitation systems should not be constructed on slopes with a gradient greater than 20%.

2.6.4 DEPTH OF GROUNDWATER SOURCE

One of the ways to attenuate microbiological and chemical contaminants in groundwater sources is prolonging the time water travels from the surface to the aquifer which is ideally more than 50 days. Twenty-five to fifty days poses a low risk of contamination (ARGOSS, 2001). Thus, the deeper a well or borehole is dug, the lower the risk of contamination. Also, if the water table is high making access to the groundwater shallow the risk of contamination is high. However, some studies dispute these general findings. Eni et al., (2011) conducted a study on the influence of aquifer depth on microbial parameters of borehole water in Calabar Metropolis, Nigeria. The results indicated that the deepest depth of 50m still showed a value of 6 cfu/100ml and 4 cfu/100ml for faecal coliforms and total coliforms in the dry season. Efe (2008) stated that the longer the polluted water travels through the soil formation the better
(cleaner) it becomes. Essien (1996) stated that shallow wells close to sites that are contaminated will invariably be contaminated with the contaminating substances if they are less than 15m deep. Agbede and Akpen (2008) in their study on the bacteriological and physico-chemical qualities of ground water in Makurdi metropolis floodplains (depth between 1.82 and 7.43m) found that all the ten wells studied were polluted with faecal bacteria, while the wells outside the floodplain were polluted with non-faecal bacteria. The ideal depth suggested for reducing contamination risk is that dug wells should be more than 10m and boreholes more than 30m.

2.6.5 DESIGN AND CONSTRUCTION OF GROUNDWATER SUPPLIES

When groundwater supplies are not designed and constructed properly it promotes contamination to groundwater sources. The infrastructure also need to undergo proper maintenance and protection to ensure reduced contamination.

**Dug wells** are highly vulnerable to contamination because often it is difficult to properly line the top layers making it impermeable to contamination. Using a proper cement seal between the dug ground and the top two rings prevents contamination through the rings. The cement seal also provides structural stability. If the dug well is fitted with a handpump, it should have a non-return valve to prevent contamination. To protect the wellhead from direct contamination, the apron around the wellhead should extend at least 1.5m and should not be cracked or damaged. Also, the wellhead should be raised at least 0.3m and have a cover slab that is not cracked. If there is a handpump there should be no ponding between the apron and casing, and there should be no ponding of water on the apron. The floor of the apron should be sloped away from the wellhead (ARGOSS, 2001).

The immediate area of the well should be fenced to prevent animals accessing the area of the well. There should be a proper drainage channel for waste water to drain away from the well.
Boreholes should have a proper cement seal of at least 5m thick around the casing to the top of the intake screen to prevent localized contamination of groundwater. If the above specification cannot be achieved the cement seal should be at least 2m to 3m below the ground surface. Boreholes should ideally be sunk more than 30m deep and a screen placed as deep as possible. Good quality casing materials should be used and thread joints screwed. All precautions that need to be taken with the apron is similar to that of the apron for a dug well. Should also have a non-return valve at the base of the rising ain of the pump to prevent contamination from water used in priming (ARGOSS, 2001). There should also be a fence around the borehole to prevent animals from gaining access there and leaving faecal matter.

2.7 INDICATORS OF GROUNDWATER CONTAMINATION

There are chemical and microbiological indicators of groundwater contamination. The contaminants of importance are nitrate and chloride. Microbiological indicators of importance are bacteria that indicate faecal contamination of water. These are principally *Escherichia coli* (*E. coli*) and thermotolerant coliforms (faecal coliforms). The presence of these indicator bacteria means that there has been recent contamination of the groundwater source from sources of faecal matter in the environment. Their absence means that the contamination risk is low (ARGOSS, 2001). There are limitations with bacterial indicators because there are other pathogens like protozoa and viruses which make water unsafe and cause disease outbreaks.

2.7.1 CHEMICAL INDICATORS

Nitrate

Nitrate is the most common form of nitrogen found in water. It is a chemical compound of one-part nitrogen and three parts oxygen that is designated by the symbol NO$_3^-$ . In water, nitrate has no taste or scent and can only be detected through a chemical test. According to
WHO drinking-water quality, the Maximum Acceptable Concentration (MAC) for nitrate in drinking water. For laboratory tests reported as nitrate-nitrogen (NO₃⁻-N), the amount of nitrogen present in nitrate as the MAC is 10 mg/l.

There are natural and anthropogenic sources of nitrate that lead to the contamination of groundwater. Some anthropogenic sources are waste loading from on-site sanitation systems, household waste and agricultural activities, such as large livestock rearing. Industrial wastes related to food processing, cleaning detergents, and some sites that handle accidental spills of nitrogenous materials are some anthropogenic sources (Iserman, 1977). Naturally nitrates found in aerobic environments are stable, thus accumulate and persist in the longer term.

During nitrification, bacteria oxidize amines from organic matter to nitrite and nitrate.

In anaerobic environments, the stable form of nitrogen is ammonium which is a health hazard (ARGOSS, 2001). Ammonia is produced by the breakdown of organic sources of nitrogen; being a major constituent of proteins and nucleic acids. Urban wastewaters contain large amounts of organic wastes, thus a high ammonia concentration.

Urban sources of nitrate may have a high impact on groundwater quality because of the high concentration of potential sources in a smaller area than agricultural land (Wakida, 2008). According Wakida (2008) the rapid growth of urban population in developing countries leads to unplanned settlements where limited pit latrines or septic tanks are the only options available for sewage disposal. The mobility of nitrogen with respect to groundwater is related to chemical properties that affect the ease of transport with water and adsorption to soil particles. Nitrate (NO₃⁻) is the most mobile form of nitrogen because of its high solubility and negative charge.

**Chloride**

Chloride (Cl⁻) is one of the major anions found in water and is generally combined with calcium, magnesium or sodium. Since almost all chloride salts are highly soluble in water,
the chloride content ranges from 10 to 100 mg/l. Sea water contains over 30,000mg/l as sodium chloride (NaCl). The suggested maximum contaminant level (SMCL) for chloride is 250mg/l which is due strictly to the objectionable salty taste produced in drinking water (USEPA, 1994). Chloride is associated with the corrosion of piping systems. The corrosion rate and the iron dissolved into the water from piping increases as the NaCl content of the water is increased. Department of Natural Health and welfare (1978), reported that chloride in surface and groundwater may result from both natural and anthropogenic sources such as, run off containing salts, sea water intrusion in areas close to the sea, the use of mineral fertilizers in farming, septic tank effluent, industrial leachate and intensive irrigation drainage. Chloride is not harmful to humans at low concentrations but its effects depend on the associated cations present in the water such as calcium, sodium, potassium and magnesium. In a research study conducted on groundwater from open wells in the vicinity of a cement factory at Akporkloe in south eastern Ghana, the amount of chloride ions found in the water samples were between 87.97 and 5142.1 mg/l with a mean of 1348.18 mg/l which was five times higher than the WHO permissible safe limit of 250 mg/l. The higher levels were attributed to the natural geochemistry of the area (Addo et al., 2012).

2.7.2 MICROBIOLOGICAL INDICATORS

As stated earlier there are three categories of microbiological pathogens. Protozoa, viruses and bacteria. Bacterial pathogens that contaminate groundwater are usually from human and animal faecal sources. Bacterial pathogens must be consumed in large number to cause infection and the symptoms tend to be severe. Natural processes of filtration usually attenuate the bacterial load as they are susceptible to these processes. The bacterial indicators human and animal faeces are *Escherichia coli, Vibrio cholerae, Salmonella typhi, Campylobacter jejuni* and *Shigellae* spp (ARGOSS 2001).
2.7.3 ELECTRICAL CONDUCTIVITY

Electrical conductivity is the ability of a solution to conduct electrical current as a result of the total dissolved ions such as sodium (Na\(^+\)) and chloride (Cl\(^-\)) in water. The WHO guideline limit of electroconductivity in drinking water is 2.5mS/cm (millisiemen per centimeter). Values higher than the recommended level means that the dissolved ions in the groundwater source are too high for human consumption.

2.8 CONSEQUENCES OF GROUNDWATER CONTAMINATION

The bacterial pathogens that contaminate groundwater from human and animal faecal sources usually cause infectious diarrhoeal diseases such as typhoid fever (enteric fever), dysentery, cholera and shigellosis.

Nitrate is considered relatively non-toxic, but at high nitrate concentrations in drinking water, it is a health concern. It can harm infants by reducing the ability of blood to transport oxygen. In babies, especially those under six months old, methaemoglobinamena, commonly called blue-baby syndrome od infantile cyanosis, can result from oxygen deprivation caused by drinking water with high levels of nitrate. It can also occur in adults with methaemoglobinemia reductase enzyme deficiency. Methaemoglobin is probably formed in the intestinal tract of an infant when bacteria convert the nitrate ion to nitrite ion (Comly, 1987). One nitrite molecule then reacts with two molecules of haemoglobin to form methaemoglobin. In acid mediums, such as the stomach, the reaction occurs quite rapidly. This altered form of blood protein prevents the blood cells from absorbing oxygen which leads to slow suffocation of the infant which may lead to death (Gustafson, 1993).

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

2.9 SANITARY INSPECTION CHECKLIST

This is a checklist that is used as an assessment and monitoring tool for potential sources of hazards that may contaminate groundwater supply. The sanitary inspection recommended to follow a systematic standardized approach, by WHO and other organizations. The sanitary inspection checklist is designed for different groundwater supply systems such as boreholes (tube wells), dug wells and springs. It comprises a limited number of questions related to pathways and indirect ways groundwater supply can be contaminated. It is used in identifying which are the most important factors that promote contamination. Each question has a yes/no answer; when the answer is to a question is ‘yes’ it means a sanitary risk is present and when the answer is ‘no’ it means that no risk is present. For scoring, one point is given to a ‘yes’ response to a question and zero points awarded when the response is ‘no’. The overall total score is calculated (a summation of the points awarded), and provides a measure of the vulnerability of groundwater supply to contamination and the operation and maintenance of the water supply system (ARGOSS, 2001).

Howard et al., (2003) used a sanitary inspection checklist in their study of risk factors contributing to microbiological contamination of shallow groundwater in Kampala, Uganda and the results showed a strong correlation between median risk score and median thermotolerant coliform and faecal streptococci presence, showing that the sanitary inspection checklist is a useful tool in indicating microbial contamination.
3.0 METHODOLOGY

3.1 RESEARCH DESIGN

The study was a descriptive cross-sectional study with laboratory component assessing water quality, that was carried out in 5 selected enumerations areas (EA) in the Greater Accra Region using the 2010 census data from the Ghana statistical service (GSS).

3.2 STUDY AREAS

The selected enumeration areas were Sapeiman, a peri-urban area in Ga West District, Medie, a peri-urban area in Ga West District, Akweteyman in the Achimota area found in urban Accra Metropolis, La in the La Estates area also found in urban Accra and Ampomah village a peri-urban area in the Adentan municipality in Ga East District.

A reconnaissance survey was embarked upon in all the enumeration areas. The enumeration areas studied were selected based on high population densities with greater than 10% of the households in these areas using wells as the main water source (Population Census, 2010).

The purpose of the on-site visit was to identify and evaluate all existing and potential sources of microbiological contamination sources that could affect the safe use of the ground water sources in the area. Attention was paid to the presence of sewerage disposal facilities, including septic tanks; broken sewerage pipes, leaking sewerage from broken pipes, storm drain water, polluted swampy areas and agricultural runoff which are hazards for faecal contamination into water sources.
Figure 3.1: Map of Districts in Greater Accra  
Source: Ghana Statistical Service, 2010

Figure 2.2: Faecal indicator bacterial counts sampled from groundwater sources found in the different 5 enumeration areas. (Bubble Scatter plot)
3.3 SAMPLING METHOD

Households that have wells were identified using snowball sampling or chain referral technique. The snowball sampling technique was appropriate to the study and it involved asking participants with a well in the household to lead the researcher to locate other households with wells until a chain of households with well water or groundwater sources were identified and selected for the study.

3.3.1 SAMPLE SIZE DETERMINATION

The sample size of 54 wells was determined based on a least squares regression of overall sanitary risk score, that is count of visible sources of contaminants observed using the sanitary risk inspection checklist and on E. coli counts in well water samples. Based on similar work done in Kenya (Wright et al, 2012), Cohen’s F² of 0.15 for such a model was assumed. With power of 0.8 and alpha=0.05, a minimum sample size of 54 wells was calculated for a regression model with a single covariate, using an online Cohen’s F² sample size calculation tool found at the following website: www.danielsoper.com/statcalc/formulas.aspx?id=1. However, at the end of the study a total of 62 groundwater sources were sampled. This included 58 shallow dug wells and 4 boreholes.

3.4 DATA PROCESSING AND ANALYSIS

Raw data collected for the bacteriological and physico-chemical parameters was entered into Microsoft excel version 2010. SPSS version 22 was used to produce the means, maximum and minimum ranges for the various parameters and frequencies used in the data for the water quality. Analysis of variance (ANOVA) was used to test for the significant difference between the sources of groundwater contamination identified against the water quality parameters measured in the water samples taken from the wells. Pearson’s product moment correlation analysis was carried out to establish the degree of relationship between
microbiological counts in water samples and the identified sanitary risk contamination sources. Multiple regression model was used to predict faecal contamination using contamination pathways. The dependent variables were the water quality parameters and the independent variables were the sources of contamination nearest the groundwater source, as well as the contamination pathways such as depth of groundwater source and distance of groundwater source from nearest source of contamination to the groundwater source.

3.5 SELECTION CRITERIA

All households that had wells and had at least one of the sources of contamination present among the sanitary risk inspection protocol checklist under investigation was used for the study.

3.6 TOOLS FOR DATA COLLECTION

A modified sanitary risk inspection checklist was used during the field survey in households with groundwater sources to identify the sources of contamination available and those not available in the checklist also recorded to inform the need for modification of the toolkit.

The geographical locations of the hand dug wells and sanitary facility distances that cause the contamination was determined using global positioning system (GPS) device (Model, GARMIN eTrex 10). This was a confirmatory measure in addition to taking distances with a tape measure on the field.
3.7 WATER SAMPLING PROCEDURES

For water assessment regarding the suitability of water for human consumption and other domestic purposes, careful sampling and sample handling procedures were undertaken. Strict measures were adhered to in order to avoid any external influences that could affect the loss of quality of the water sample during sampling, handling, transportation and preservation at the laboratory. Precautions were taken to prevent duplication of bacteria in the water samples, by putting the bottles containing the water samples on ice in an ice chest and transported immediately to the laboratory after each day’s activities. Water samples for bacteriological analysis was put in sterilized glass bottles with plastic caps.

Polyethylene bottles of 500ml capacity with a plastic cap were used for collecting the water samples. The bottles were pretreated by washing with acetone to get rid of organic substances such as grease and fat residues. Detergents were then used to wash each bottle and rinsed with de-ionized water. The sampling bottles were then soaked in 1.0M nitric acid solution for 24 hours. The bottles were finally rinsed three times with distilled water before transporting them to the site for water sampling. These bottles contained the water samples for chemical analysis at the laboratory.

At the site, groundwater was used to rinse the sampling bottle thoroughly and was discarded, before the bottle filled was filled again with the groundwater to be analyzed. A clean small plastic bucket was introduced into the well/borehole with the help of a rope and the water was drawn out and poured into the sample bottle. At each sampling site, the groundwater sample was fetched into the clean plastic bucket for in-situ measurements such as pH, as the chemistry of water is sensitive to environmental changes. The bucket was cleaned with rubbing alcohol and with distilled water after completion of each water sample drawn from the well or borehole.
3.8 WATER QUALITY PARAMETERS MEASURED

The parameters measured as indicators for faecal pollution were chemical parameters such as nitrates and chlorides. Thermotolerant coliforms, faecal coliform with the isolation of *Escherichia coli*, were the bacteriological parameters measured.

The processes outlined in the standard methods for the examination of water and wastewater and the examination of water for pollution control, were used for the water quality analysis of the chemical and bacteriological variables carried out on water samples collected from wells and boreholes (APHA, 1998).

Bacteriological and chemical analysis was done at ECOLAB at the University of Ghana, Legon.

3.8.1 BACTERIOLOGICAL ANALYSIS

Phosphate buffered saline (PBS) was the diluent used making serial dilutions of the water samples taken for bacteriology before culturing them in media for growth. PBS is isotonic with a neutral pH of 7.4 and non-toxic to most cells. 900 microlitres was pipetted aseptically into nine sterile plastic locking microcentrifuge tubes to make the dilutions for each water sample taken on the field. The 1st microcentrifuge tube served as the control tube. 100 microlitres of the water sample was added to the 1st microcentrifuge tube to make a 10^-1 dilution. The contents were then swirled gently. A fresh sterile micropipette tip was used to pipette 100 microlitres of the contents in the 1st microcentrifuge tube was taken and added to the 2nd microcentrifuge tube to make a dilution of 10^-2 which was also gently swirled. Again 100 microlitres of the contents of the 2nd microcentrifuge tube was aseptically added to the 3rd microcentrifuge tube and the contents swirled gently. This process continued until 100 microlitres of the 10^-9 dilution (which is a mixture of 900 microlitres of PBS and 100 microlitres of the 10^-7 dilution) was added to the 9th and last microcentrifuge tube to make a dilution of 10^-9.
Plate count for total viable microbes

With a fresh sterile micropipette tip, using a pipette, 100 microlitres of each dilution was pipetted into respective labeled sterilized petri-dishes. Plate count agar (PCA) was used to culture total viable microorganisms such as bacteria, yeast and mold cells (plate count-PC). The agar was prepared according to the manufacturer’s instruction, autoclaved for 45 minutes and allowed to cool to about 45°C. The pour plate method was used by pouring 2ml of the sterilized plate count agar (PCA) onto the serial dilutions of the water samples in the respective labeled petri dishes. The petri dishes were then swirled gently to thoroughly mix the water samples with the PCA to facilitate distribution of the water sample throughout the medium. The petri dishes were covered and allowed to solidify. The petri dishes were then incubated at 37°C for 24-48 hours. After the 48hours the petri dishes were removed from the incubator and the colonies were counted using a colony counting chamber (Gallen Kamp, UK) and recorded in coliform forming units per 100ml (cfu/100ml). Plates showing counts between 30-300 a colony were selected and their total colony forming unit per 100ml was calculated by multiplying the count by the dilution factor.

Total coliforms

For total coliforms (TC), Violet red bile (VRB) was used. The agar was also prepared according to the manufacturer’s instruction and autoclaved. the same procedure was followed as was done with the PCA. Pour plate technique was used by pouring the agar onto a fresh set of the serial dilutions of the water samples which were already pipetted into labelled sterile petri dishes. After completion of the procedure the petri dishes were incubated at 37°C for 24-48 hours. The colonies were counted with the colony counting chamber.
**Faecal coliforms**

For faecal coliforms (FC), Eosin methylene blue (EMB) was used. After preparing the agar according to manufacturer’s instructions, the same procedures were repeated as was done with PCA and VRB. This time the sterile petri dishes containing the EMB agar with the various dilutions of the water samples were incubated at 44°C for 24-48 hours and the colonies were counted with the colony counting chamber.

**Escherichia coli**

For *Escherichia coli* (*E. coli*), CHROMOCULT agar was used. The agar was prepared using the manufacturer’s instructions. Again, the same procedures were repeated as done with the other media. The petri dishes upon completion of the procedures were incubated at 37°C for 24-48 hours and the colonies were counted with the colony counting chamber.

### 3.8.2 PHYSICO-CHEMICAL ANALYSIS

The nitrogen-nitrate level was determined using Nitrate Powder Pillows in a direct reading with HACH spectrophotometer Model DR. 2010. Chloride concentration was determined by the Silver Nitrate method titrimetrically.

Electrical conductivity was assessed using a portable handheld water quality meter, model (HANNA H1 98129).

### 3.9 QUALITY ASSURANCES

Proper quality assurance procedures and precautions was taken to ensure the reliability of the results. The water samples were carefully handled to avoid any external influences that could contaminate the samples. Triplicate water samples were determined during laboratory analysis and the results were presented as means. Equipment used was properly cleaned with deionized water, and was used throughout the study. Spectrophotometric analysis of chemicals like nitrates and chlorides, reagent blank determinations were used to correct the instrument readings. For validation of the analytical procedure, repeated analysis of the
samples against internationally certified/standard reference material (SRM-1570) of National Institute of Standard and Technology will be used.

3.10 ETHICAL CONSIDERATIONS

3.10.1 APPROVAL FROM ETHICAL REVIEW BOARD

Ethical clearance was already obtained from Noguchi Memorial Institute for Medical Research, Institutional Review Board (No. 106/15-16), for the bigger research project of which this research is a part of.

3.10.2 INFORMED WRITTEN CONSENT

Consent was sought from owners of the wells or landlords of households having wells, before water sample collection.

3.10.3 SAFETY MEASURES

Risk of harm to research team members was minimized by the use of disposable gloves, sanitizing and washing hands with alcohol before and after taking samples. Fresh pairs of disposable gloves were used following successive sampling of the wells for water. The plastic bucket used for water sampling was sterilized with alcohol, then distilled water after successive sampling of the well. The meter used for measuring depth and distance was also sterilized.
**4.0 RESULTS**

**4.1 INTRODUCTION**

A total of 62 groundwater sources (58 dug wells and 4 boreholes) were sampled in the 5 enumeration areas of the study.

**Table 4.1: Summary of types of groundwater sources found in the 5 enumeration areas**

<table>
<thead>
<tr>
<th>Area Sampled</th>
<th>No. of Dug wells (n=58)</th>
<th>No. of Boreholes (n=4)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sapeiman (Ga West)</td>
<td>14</td>
<td>0</td>
</tr>
<tr>
<td>Medie (Ga West)</td>
<td>6</td>
<td>1</td>
</tr>
<tr>
<td>Akweteyman (Accra)</td>
<td>20</td>
<td>0</td>
</tr>
<tr>
<td>La (Accra)</td>
<td>10</td>
<td>0</td>
</tr>
<tr>
<td>Ampomah village</td>
<td>8</td>
<td>3</td>
</tr>
</tbody>
</table>

**4.2 DESCRIPTIVE SUMMARY**

**4.2.1 SOURCES OF CONTAMINATION IDENTIFIED NEAR GROUNDWATER**

**Figure 4.1**: Nearest identified sources of contamination to groundwater from all study sites. (Bar chart)

The graph is showing the frequency of the categories of the nearest identified sources of contamination to the 62 different groundwater sources sampled. In all, there were 15 bathhouses within 30metres of the groundwater sources. Two hen coups were identified as source
of contamination found nearest to 2 different groundwater sources. Twelve pit latrines within 30 metres of the groundwater sources, were the nearest source of contamination identified.

There was 1 piggery as the nearest source of contamination and 3 polluted swamps identified as the source of contamination nearest groundwater sources. Two areas of refuse dumping within 30 metres of the groundwater source, were identified. For the septic tank category as the nearest source of contamination to groundwater source, 16 were identified and for the urban storm drain category as the nearest contamination source to groundwater, 11 were identified.

4.3 WATER QUALITY PARAMETERS

Table 4.2: Summary of laboratory results of water samples taken from all study sites

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Mean</th>
<th>SD</th>
<th>Minimum</th>
<th>Maximum</th>
<th>WHO guideline</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Physio-chemical</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Nitrate (mg/l)</td>
<td>6.4</td>
<td>3.67</td>
<td>0.7</td>
<td>19.7</td>
<td>10</td>
</tr>
<tr>
<td>Chloride (mg/l)</td>
<td>121.24</td>
<td>75.82</td>
<td>35.43</td>
<td>421.15</td>
<td>250</td>
</tr>
<tr>
<td>Nitrite (mg/l)</td>
<td>0.23</td>
<td>0.54</td>
<td>0.002</td>
<td>4.192</td>
<td>1</td>
</tr>
<tr>
<td>EC (mS/cm)</td>
<td>2.29</td>
<td>1.48</td>
<td>0.56</td>
<td>7.24</td>
<td>2.5</td>
</tr>
<tr>
<td><strong>Bacteriological</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>E. coli (cfu/100ml)</td>
<td>10.55</td>
<td>29.99</td>
<td>0</td>
<td>200</td>
<td>0</td>
</tr>
<tr>
<td>Faecal coliforms</td>
<td>14.69</td>
<td>59.75</td>
<td>0</td>
<td>450</td>
<td>0</td>
</tr>
<tr>
<td>Total coliforms</td>
<td>50.8</td>
<td>304.52</td>
<td>0</td>
<td>2400</td>
<td>0</td>
</tr>
</tbody>
</table>

EC = Electroconductivity, SD = Standard Deviation, WHO = World Health Organization
4.3.1 RELATIONSHIP BETWEEN SOURCES OF CONTAMINATION AND WATER QUALITY PARAMETERS MEASURED IN GROUNDWATER SAMPLES

Table 4.3: Nearest identified sources of contamination and mean concentrations of physico-chemical parameters found in groundwater sampled

<table>
<thead>
<tr>
<th>Nearest source of contamination</th>
<th>Frequency (n=62)</th>
<th>Nitrate (mg/l) Mean</th>
<th>Chloride (mg/l) Mean</th>
<th>Nitrite (mg/l) Mean</th>
<th>EC (mS/cm) Mean</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bathhouse</td>
<td>15</td>
<td>7.66</td>
<td>128.69</td>
<td>0.47</td>
<td>1.90</td>
</tr>
<tr>
<td>Hen coup</td>
<td>2</td>
<td>3.95</td>
<td>86.14</td>
<td>0.22</td>
<td>1.36</td>
</tr>
<tr>
<td>Latrine &lt;30m</td>
<td>12</td>
<td>9.1</td>
<td>143.39</td>
<td>0.01</td>
<td>2.23</td>
</tr>
<tr>
<td>Piggery</td>
<td>1</td>
<td>3.2</td>
<td>79.76</td>
<td>0.18</td>
<td>7.24</td>
</tr>
<tr>
<td>Polluted swamp</td>
<td>3</td>
<td>5.3</td>
<td>76.93</td>
<td>0.26</td>
<td>1.68</td>
</tr>
<tr>
<td>Refuse dump &lt;30m</td>
<td>2</td>
<td>5.8</td>
<td>78.17</td>
<td>0.02</td>
<td>1.05</td>
</tr>
<tr>
<td>Septic tank</td>
<td>16</td>
<td>5.01</td>
<td>103.74</td>
<td>0.17</td>
<td>3.02</td>
</tr>
<tr>
<td>Storm drain</td>
<td>11</td>
<td>4.93</td>
<td>142.43</td>
<td>0.17</td>
<td>1.96</td>
</tr>
</tbody>
</table>

**Nitrate**

The mean nitrate concentration of the water samples ranged from a minimum of 3.2 mg/l from the piggery, which was the nearest source of contamination, to a maximum level of 9.1 mg/l from pit latrine source of contamination. (Table 4.3). However, all the mean levels of nitrate analyzed from the water samples taken from the groundwater sources with the identified nearest sources of contamination, fell with the WHO maximum allowed concentration of 10mg/l. Statistical analysis using one-way (ANOVA) at 95% confidence interval, showed that the mean nitrate concentrations were not statistically significant among the various sources of contamination identified (p-value=0.488).

**Chloride**

Table 4.3 shows the mean concentrations of chloride in the water samples taken from groundwater sources with the nearest source of contamination identified within the periphery of the groundwater source. The mean concentrations of the water sample ranged from a
minimum of 76.93 mg/l (polluted swamp) to a maximum of 143.39 mg/l (pit latrine). One-way ANOVA at 95% confidence interval showed that the chloride concentrations of the water sample were not statistically significant among the identified contamination hazards (p-value= 0.835). Again, all the mean concentrations of chloride analyzed were within the WHO suggested maximum concentration level of 250mg/l for drinking water.

**Electrical Conductivity**

The mean concentrations electrical conductivity of the water samples taken from the groundwater sources with the nearest source of contamination identified within the periphery of the water source ranged from a minimum of 1.05mS/cm (refuse dump) to a maximum of 7.24mS/cm (piggery). One-way ANOVA at 95% confidence interval, showed that the conductivity differed significantly among the contamination sources (p-value=0.04). However, when the Bonferroni pair wise multiple comparison test was used to compare the means, it showed that, there were no statistically significant differences in conductivity concentrations among water sampled from groundwater away from pit latrine, storm drain and septic tank contamination sources (p-value=0.504). There were also no differences in conductivity among water sampled away from bathhouse, hen coup, polluted swamp and refuse dump contamination source.
Figure 4.2: Geographical distribution of Electroconductivity results of water samples taken from groundwater sources in enumeration areas. (Bubble Scatter plot)

**Nitrite**

In Figure 4.3, the geographical distribution of nitrite results from the water samples taken from the groundwater sources in the 5 different enumeration areas is presented. The size of the spheres in each area represents the amount of nitrite found in the groundwater sources in each site. The mean nitrite concentration ranged from a minimum of 0.02mg/l from the refuse dump nearest source of contamination, to a maximum of 0.47mg/l from the bath-house source of contamination (Table 4.3). One-way ANOVA at 95% confidence interval, showed there was no significant difference among the various source of contamination identified (p-value=0.855).
Figure 4.3: Geographical distribution of Nitrite results of water samples taken from groundwater sources in enumeration areas. (Bubble Scatter plot)

Table 4.4: Nearest identified sources of contamination and mean concentrations of bacteriological parameters found in groundwater sampled

<table>
<thead>
<tr>
<th>Nearest source of contamination</th>
<th>Frequency (n=62)</th>
<th>E. coli (cfu/ml) Mean</th>
<th>Faecal coliforms (cfu/ml) Mean</th>
<th>Total coliforms (cfu/ml) Mean</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bathhouse</td>
<td>15</td>
<td>13.33</td>
<td>16.67</td>
<td>28.13</td>
</tr>
<tr>
<td>Hen coup</td>
<td>2</td>
<td>0</td>
<td>1</td>
<td>2.5</td>
</tr>
<tr>
<td>Latrine &lt;30m</td>
<td>12</td>
<td>23</td>
<td>42.83</td>
<td>209.58</td>
</tr>
<tr>
<td>Piggery</td>
<td>1</td>
<td>1</td>
<td>0</td>
<td>1</td>
</tr>
<tr>
<td>Polluted swamp</td>
<td>3</td>
<td>32</td>
<td>29</td>
<td>15.67</td>
</tr>
<tr>
<td>Refuse dump &lt;30m</td>
<td>2</td>
<td>2</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Septic tank</td>
<td>16</td>
<td>1.8</td>
<td>0.8</td>
<td>3.69</td>
</tr>
<tr>
<td>Storm drain</td>
<td>11</td>
<td>4.36</td>
<td>4.09</td>
<td>9.18</td>
</tr>
</tbody>
</table>
**Total Coliform (TC)**

The mean total coliform counts of the groundwater samples analyzed, ranged from a minimum of non-detection at the refuse dump source of contamination to a maximum of 209.58 cfu/100ml from the pit latrine source of contamination. (Table 4.4). Statistical analysis using One-way ANOVA at 95% confidence interval, showed that the total coliform count of the groundwater samples did not differ significantly among the various sources contamination identified nearest to the water source (p-value=0.793).

**Faecal Coliforms (FC)**

The mean faecal coliform counts of the groundwater samples analyzed, ranged from a minimum of non-detection at both the refuse dump and the piggery contamination sources nearest to the groundwater source, to a maximum of 42.8 cfu/100ml from pit latrine contamination source (Figure 4.3.6). One-way ANOVA at 95% confidence interval, showed that the total coliform count of the water samples differed significantly among the various contamination hazards (p-value=0.032). The Bonferroni pair wise multiple comparison showed that, there were no significant differences in faecal coliform counts among water sampled away from latrine and polluted swamp but were however different from the other contamination sources (Table 4.4).

**Escherichia coli (E. coli)**

The mean E. coli counts of the groundwater samples analyzed, ranged from a minimum of non-detection from the hen coup source of contamination, to a maximum of 32 cfu/100ml from the polluted swamp source of contamination (Table 4.4). One-way ANOVA at 95% confidence interval showed that the E. coli count of the water samples did not differ significantly among the various contamination hazards (p-value=0.06).
4.3.2 CORRELATION OF BACTERIOLOGICAL PARAMETERS

To investigate the association, the direction and strength of the bacteriological parameters of the water sample, Pearson’s product moment correlation coefficient was used. Considerable numbers of significant positive correlation were observed between the following variables; Plate count and faecal coliform (r=0.933, p-value <0.01), plate count and total coliform (r=0.989, p-value <0.01), Faecal and total coliform (r=0.957, p-value < 0.01), Faecal and E. coli (r=0.953, p-value <0.01). The entire correlation matrix is as shown in Table 4.5.

Table 4.5: Correlation matrix of faecal indicator bacteriological parameters of the water samples.

<table>
<thead>
<tr>
<th>Variable</th>
<th>Plate count</th>
<th>Faecal coliform</th>
<th>Total coliform</th>
<th>E. coli</th>
</tr>
</thead>
<tbody>
<tr>
<td>Plate count</td>
<td>1</td>
<td>0.933**</td>
<td>0.989**</td>
<td>0.820*</td>
</tr>
<tr>
<td>Faecal coliform</td>
<td>1</td>
<td>0.957**</td>
<td>0.953**</td>
<td></td>
</tr>
<tr>
<td>Total coliform</td>
<td>1</td>
<td>1</td>
<td>0.847*</td>
<td></td>
</tr>
<tr>
<td>E. coli</td>
<td></td>
<td></td>
<td></td>
<td>1</td>
</tr>
</tbody>
</table>

*Significant (p-value ≤0.05)
**Significant (p-value ≤0.01)

4.4 CONTAMINATION PATHWAYS AS THE ADDITIONAL EXPLANATORY POWER IN PREDICTING FAECAL CONTAMINATION

In order to predict the faecal contamination of groundwater sources using contamination pathways, faecal coliform counts were used as the dependent variable, while the depth of groundwater source (well or borehole), and distance of source of contamination from groundwater source, were used as independent variables. The variables were then fitted into a multiple regression model; the model is as shown below:

\[ Y_i = \beta_0 + X_1\beta_1 + X_2\beta_2 \]
Where,

\[ Y_i = \text{the dependent variable (Faecal coliform)} \]
\[ \beta_0 = \text{constant} \]
\[ X_1 = \text{depth of groundwater source} \]
\[ X_2 = \text{distance of contamination source from groundwater source} \]

The regression results revealed that the independent variables, the distance of the groundwater to the contamination source, and the depth of the groundwater significantly influenced the faecal contamination pathway of the groundwater sample \((F=8.47, p\text{-value}=0.03)\). The \(R^2\) given from the regression analysis is 0.625 which is approximately 63\%. Statistically, this is a good fit. It means that about 63\% of the total variation in the faecal contamination is attributed to or explained by the faecal contamination pathways, depth of groundwater source and distance from contamination source to the groundwater source. The unexplained variation is 37\%. This means that if there are other factors that can better explain the faecal contamination pathway, it is less than what is being explained by depth and distance. The values of the Durbin Watson and \(R^2\) are 1.82698 and 0.625 respectively. The value of the Durbin-Watson is greater than the value of the \(R^2\). That is 1.82698 > 0.625. This means that the regression results are rational, since there is an absence of autocorrelation. Multicollinearity was also absent after collinearity diagnostics was applied, since the variance inflation factor (VIF) were all less than 5. This makes the model for predicting the faecal contamination pathway valid and can be accepted as a good model.
Table 4.6: Regression results of faecal contamination pathway

<table>
<thead>
<tr>
<th>Variable</th>
<th>Adjusted Coefficients</th>
<th>SE</th>
<th>p-value</th>
<th>95%CI</th>
</tr>
</thead>
<tbody>
<tr>
<td>Constant</td>
<td>1.049</td>
<td>0.459</td>
<td>0.013*</td>
<td>0.23-1.865</td>
</tr>
<tr>
<td>Depth</td>
<td>-0.093</td>
<td>0.044</td>
<td>0.028*</td>
<td>-1.029-0.843</td>
</tr>
<tr>
<td>Distance</td>
<td>-0.068</td>
<td>0.324</td>
<td>0.024*</td>
<td>-0.158-0.02</td>
</tr>
</tbody>
</table>

*Significant (p-value ≤ 0.05); CI = Confidence Interval, SE = Standard Error

The estimated model for the faecal pathway is as represented;

FC = 1.049 − 0.093X1 − 0.068X2; This is an indication that, holding distance constant, a unit decrease in the depth of the water source will increase the faecal coliform counts by 9.3% or 0.093 cfu/100ml. Also, a unit decrease in distance to the water source will increase faecal contamination by 6.8% or 0.068 cfu/100ml, holding depth of groundwater source constant.

Below are graphical representations of E. coli as the faecal bacterial indicator analyzed from the groundwater sources sampled against contamination pathways.

Figure 4.4: Influence of depth of groundwater source on faecal contamination (Scatterplot)
As shown in the figure above, the *E. coli* counts decreased with increase in depth of the groundwater source.

![Distance and E.coli](image-url)

**Figure 4.5:** Influence of distance of groundwater source from faecal contamination (Scatterplot)

In the figure above, the *E. coli* counts were distributed more as the distance of the groundwater source decreases from the source of faecal contamination.
5.0 DISCUSSION

5.1 INTRODUCTION

The results of the study are discussed in this section in relation to the objectives and compared with other similar studies.

5.2 RELATIONSHIP BETWEEN CONTAMINATION SOURCES AND INDICATORS

5.2.1 PHYSICO-CHEMICAL PARAMETERS

Mean Nitrate levels recorded during the study from the water samples taken ranged from 3.2mg/l to 9.1mg/l among the eight contamination sources observed. These values fell within the WHO maximum contaminant level (MCL) of 10mg/l. The statistical analysis also showed that there was not much variation in the means of the nitrate levels among the different contamination sources identified. The presence of nitrate in water is an indication of faecal pollution. Nitrate has been used to characterize urban loading to groundwater from a range of sources including pit latrines (Cissé Faye et al., 2004; Tijani and Ondera 2005). Nitrate levels are usually not that high in shallow groundwater sources due to denitrification, thus if it is in high concentrations, it is mostly because of pollution from anthropogenic activities and animal waste. Studies by Gélinas et al., 1996; Mwendera et al., 2003 and Nkhuwa 2006, show that there is evidence of faecal contamination in low nitrate groundwater. Also, borehole mixing processes can cause dilution and overall low nitrate concentrations, while still having significant microbial contamination (Lapworth et al., 2017). The findings in this study compare with the studies.

The WHO permissible limit for chloride in drinking water is 250mg/l. The mean chloride levels recorded in the study from the water samples ranged from 76.93mg/l to 143.39mg/l among the contamination sources identified. These mean values fall within the permissible limit. Lagerstedt et al. (1994) and Cronin et al., (2006) have successfully used nitrate and...
chloride to fingerprint different sources of urban and peri-urban pollution of groundwaters in Sub-Saharan Africa.

The mean nitrite levels recorded in the study from the water samples taken ranged from 0 to 0.47mg/l among the contamination sources. These mean values also fell within the WHO maximum contaminant level of 1.0mg/l. Again, the statistical analysis showed that there was no significant difference in mean nitrite levels among the contamination sources.

Electrical conductivity is a commonly applied physical and chemical water quality indicator used in groundwater studies, often in combination with nitrate or microbiology. The mean electrical conductivity values of the water samples taken from ground water in the study ranged from 1.05mS/cm to 7.24mS/cm with an overall mean value of 2.29mS/cm. The WHO guideline limit for drinking water is 2.5mS/cm. Studies done by Tijani and Ondera (2005), recorded high EC (electroconductivity) values of greater than 1.0-2.0mS/cm for shallow dug wells with a depth of less than 10m, with corresponding high nitrate values, of the Ibadan metropolis in Nigeria. They attributed these values to contamination from household septic tanks and pit latrines, but had low EC recordings of less than 0.5mS/cm for deeper wells and boreholes (Tijani and Ondera, 2005). The findings in their study varied from the findings in this study with respect to the high EC values and corresponding high nitrate values they recorded.

5.2.2 BACTERIOLOGICAL PARAMETERS

Water is safe for human consumption, when coliform bacteria and E. coli in the water sample are at zero detection levels (WHO, 2004). The main source of pathogen contamination of water is human and animal faeces.

From the water samples collected and tested in the laboratory, the mean total coliform (TC) counts from the water samples taken ranged from levels of non-detection at both refuse dump contamination source to a maximum count of 209.58cfu/100ml from the pit latrine.
contamination source. Statistical analysis using ANOVA showed no significant difference in the mean TC counts among the contamination sources.

Mean faecal coliform (FC) counts ranged from non-detection at both piggery and refuse dump contamination sources and a maximum of 42.83cfu/100ml from the pit latrine contamination source. Statistical analysis using ANOVA, showed significant difference among the various contamination sources. Mean counts were highest from the pit latrine to polluted swamp to bathhouse and then to storm drain in a descending order. Septic tank, hen coup, piggery and refuse dumps had low levels between 0 and 0.8cfu/100ml. The piggery water sample was only 1 out of the 62 water samples thus attributing to the low levels. Refuse dumps were not major dumping sites. Most were small mounds of scattered waste dumping. The septic tanks may also have been well sealed owing to minimal counts recorded. The hen coups were also not of commercial size and not very many.

*Escherichia coli* (*E. coli*) mean counts from the water samples taken ranged from non-detection from the hen coup contamination source to a maximum mean count of 32cfu/100ml from the polluted swamp contamination source. All other contamination sources recorded levels of *E. coli* contamination ranging in descending order from polluted swamp, to pit latrine, to bathhouse, to storm drain, to refuse dump, to septic tank, to piggery, and then to hen coup at non-detection level.

When Pearson’s product moment correlation coefficient was used to show the association, direction and strength of the bacteriological parameters, the was a positive correlation observed between the different variables as shown in Table 4.5, in the results section. This means that there was faecal contamination in almost all the of the groundwater samples.

On-site sanitation in the form of pit latrines and septic tanks was the dominant cause of microbiological contamination of water sources in Sub-Saharan Africa (Lapworth et al, 2017). This finding is comparable to findings in our study. However, other sources of
contamination include open defecation (Nkhuwa 2006; Nyenje et al., 2013), which contribute to groundwater contamination.

5.3 ADDITIONAL PREDICTORY FACTORS OF GROUNDWATER CONTAMINATION

In the results section, faecal coliform counts were used as the dependent variable, while the depth of the groundwater, and the distance of the water source from the contamination source, were used as independent variables and fitted into a multiple regression model. The outcome of the regression results showed that the independent variables significantly influenced the faecal contamination pathway of the groundwater (p-value = 0.03). $R^2$ was 0.625, meaning approximately 63% of the total variation in faecal contamination is attributed by contamination pathways, depth of groundwater, and distance of the contamination source from the groundwater. The unexplained variation of 37% could be the nature of the soil and/or the topography and hydrogeology of the land. The regression model also indicated that holding distance constant, a unit decrease in the depth of the water source will increase the faecal coliform counts by 9.3% or 0.09cfu/100ml. Also, holding depth of groundwater constant, a unit decrease in distance to the groundwater source will increase faecal contamination by 6% or 0.06cfu/100ml. This model shows that there is additional explanatory power in predicting faecal contamination from observing hazards specific to urban and peri-urban environments in addition to standard risk inspection checklists and key factors include the depth of the groundwater and the distance of the source of contamination from the groundwater. Dzwairo et al., (2006) found faecal and total coliform greatly reduced beyond 5m from pit latrines in Zimbabwe. Still and Nash (2002), found faecal coliforms to be attenuated to less than 10cfu/ml after 1m in Maputaland, KwaZulu-Natal. These studies compare to findings in our study.
5.4 LIMITATION

The time allotted for data collected restricted water sampling to one season, though some water samples were taken in areas where it had rained the previous day. Ideally, a comparison of the sampling results during the different seasons, that is rainy and dry season would have been preferred.
6.0 CONCLUSION AND RECOMMENDATIONS

6.1 CONCLUSION

The findings of the study showed that there was a relationship between the modified observed sanitary risks and water quality parameters indicating faecal contamination of groundwater in urban and peri-urban areas in Greater Accra Region, Ghana.

There were sources of contamination found within the periphery of the groundwater sources studied, with laboratory evidence of faecal contamination with faecal indicator bacterial counts and physico-chemical parameters.

Findings also showed that the depth of the groundwater source and distance of groundwater from the source of contamination were found as additional explanatory power in predicting faecal contamination of groundwater.

These all indicate that urban and peri-urban groundwater sources selected in Greater Accra, are polluted with faecal matter and pose health risks if these water sources are used for drinking and domestic purposes. Most of the groundwater sources were shallow making them vulnerable to pollution. Also, the high-density population in urban and peri-urban areas make siting of on-site sanitary facilities with recommended distances of greater than 30m away difficult, making groundwater vulnerable to faecal contamination.

6.2 RECOMMENDATIONS

Funding and investment for similar studies to be conducted in other urban and peri-urban areas in Ghana should be conducted for more data as evidence to protect and properly maintain groundwater sources, since it is the most widely used source of water for drinking and domestic use with lack of and infrequent supply of safe potable water.
On-site sanitation and waste management should also be improved to minimize faecal contamination of groundwater sources. Urban groundwater supplies should be properly lined and sealed to reduce contamination from nearby sited on-site sanitation systems. Dug well heads should be properly constructed and kept sanitary.

Wells and boreholes in urban and peri-urban areas should be dug and drilled by professionals who will know where to site and construct the groundwater supply system.
REFERENCES


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USEPA (1994). Sources of ground water contamination, Agricultural and Biological Engineering Department, Purdue University, Indiana.


APPENDICES

APPENDIX A: QUESTIONNAIRE (SANITARY RISK CHECKLIST)

ENHANCING UNDERSTANDING OF DOMESTIC GROUNDWATER QUALITY AND CONTAMINATION HAZARDS

INTRODUCTION:

This questionnaire seeks to get consent from groundwater source owners/managers from urban and peri-urban areas, and performing sanitary risk inspection of ground water sources to assist in understanding groundwater and contamination hazards in these areas

WELL SURVEY FORM

| Surveyor Name: ____________________________________________ |
| Date: ______/____/____ | Time: __________________ |
| (dd/mm/yy) | Area Name: ____________________________________________ |
| Enumeration Area No.: ____________________________________ |

1. Is it possible to take a sample from this water source?
   - Yes  □ No

2. If water source is not available for sampling, please select why
   □ Pump not working
   □ No water in the well
   □ Well not accessible
   □ Other (please specify) ____________________________________________
   (If water source is available, for sampling then: )

3. What is the name of the current well or water source owner/manager?

   Read out the participation information sheet and use the consent form to get consent from water source owner to participate in the study

4. Water source owner or manager
   □ Consents to participate  □ Does not consent  □ Not available for interview
   (if the water source owner or manager agrees to participate)
Sanitary Risk Inspection

Boreholes and shallow dug wells:

1. Does the cement floor extend less than 1.5 metres from the well?
   - Yes
   - No
   - Not known

2. Is there any ponding of water on the cement floor?
   - Yes
   - No

3. Are there any cracks or holes in the cement floor which could permit water to enter the well?
   - Yes
   - No

4. Is the pump loose where attached to the base, allowing water to enter the casing?
   - Yes
   - No
   - No pump

5. Is there any ponding beyond the cement floor within 3 metres of the well?
   - Yes
   - No

6. Is the drainage channel missing altogether, cracked, broken or in need of cleaning?
   - Yes
   - No

7. Do animals have access within 10 metres of the well?
   - Yes
   - No
   - Cannot observe

8. Is there an unbroken fence with no gaps around the well?
   - Yes
   - No
   - Cannot observe

9. Are there any latrines within 10 metres of the well?
   - Yes
   - No
   - Cannot observe

10. Are there any additional latrines situated within 30 metres of the well?
    - Yes
    - No
    - Cannot observe

11. Is the nearest latrine on higher ground than the well?
    - Yes
    - No
    - Cannot observe

12. Are there any open water sources within 20 metres of the borehole?
    - Yes
    - No
    - Cannot observe

13. Are there any uncapped wells within 30 metres of the well?
    - Yes
    - No
    - Cannot observe

14. Are there any waste dumps within 30 metres the well?
    - Yes
    - No
    - Cannot observe

15. Is the cover of the well unsanitary or is there no cover at all?
    - Yes
    - No

---

Well observations and measurements (Take these measurements and place water sample in icebox for transport to lab)

1. Well depth: _________ m
2. Electroconductivity reading: ________ mS/cm
3. Sample ID number: ________ [write on bottle as well as here]
4. Did it rain: today / yesterday [circle neither, one or both options]
16. Are there any cracks or holes on the cover of the well?

☐ Yes  ☐ No  ☐ Not applicable

17. Is the topography where the well is sited slanted?

☐ Yes  ☐ No

18. Are the walls of the well inadequately sealed at any point below ground level?

☐ Yes  ☐ No  ☐ Cannot observe

19. What is the nature of the soil where the well is sited?

☐ Sandy  ☐ Clayey  ☐ Loamy  ☐ Other(Specify)_____________________________________

20. Is the receptacle for drawing water from the well sanitary?

☐ Yes  ☐ No

_Urban Hazard Inspection Questions_

21. Are there any sewage pipes within 30 metres of the wells?

☐ Yes  ☐ No

a. If yes, are there any signs of damage to these sewage pipes or leakages from them?

☐ Yes  ☐ No

22. Are there any blocked urban storm drains within 30 metres of the well?

☐ Yes  ☐ No

23. What contaminants are floating in the waste water in the blocked urban storm drain?

☐ Faecal (“flying toilet”)  ☐ Diapers  ☐ Polythene  ☐ Kitchen waste  ☐ Algae  ☐ Dead rodents  ☐ Papers

24. What human activities can be observed within 30 m of the well?

☐ Washing of laundry  ☐ Car washing  ☐ Farming  ☐ Refuse dumping

25. Is there any scattered waste within 30 metres of the well?

☐ Yes  ☐ No
APPENDIX B: INFORMED CONSENT FORM

Title: Observed Sanitary Risks and Water Quality Parameters Indicating Faecal Contamination Pathways in urban and peri-urban groundwater sources in Greater Accra.

Principal Investigator: Kafui Awo Seshie-Doe  (Ghana School of Public Health)

Address: College of Health Sciences, School of Public Health, P.O. Box LG 13, University of Ghana Legon, Accra.

General Information about Research

The research study in which we are asking you to participate in aims to develop and test a simple observation checklist for identifying possible contamination hazards for groundwater. We plan to develop a checklist of hazards that could contaminate groundwater in urban areas and see if our checklist is linked to contaminated water when we test the wells. The study is funded by the Royal Society, a charity that funds scientific collaborations between UK and other countries. The study is a collaboration between the Ghana School of Public Health and the University of Southampton in the UK.

You have been chosen because you either own or manage a well we have selected at random from among the wells in your neighbourhood. If you take part we will visit you twice, now and again in the next few days. Right now, we will record the position of your well, take a water quality sample from it and look for possible contamination pathways at or near the well, and ask a few questions about the well. My colleague will visit you afterwards and look for the same possible contamination pathways. The process should take about 15 minutes.

Possible Risks and Discomforts

Taking part in the study will take about 15 minutes of your time. There is also a possibility of unintentionally contaminating your well during water collection sampling as we move between different wells. We will however visits after each well visit, using disposable gloves when taking samples and sterilizing our well depth metre between visits to different households.
Possible Benefits

You will be given a hand sanitizer for participating in the study, to thank you for the time spent answering our questions and allowing water samples to be taken from the well. If any potential contamination pathways and hazards are identified, you will be provided with suggestions for stopping the contamination via that route. A general overview of groundwater quality in our study sites will be fed back via the local Municipal/District Assembly’s Environmental Health Officer or authorities of the Community Water and Sanitation Agency. The checklist of hazards created in this study for inspecting wells, will hopefully be a simple tool that people can use to make urban well water safe to use.

Confidentiality

Participation in the study will be kept confidential. The study will comply with both the 2012 Ghana Data Protection Act and the 1998 UK Data Protection Act. The information about you will be protected to the best of our ability. Your name will not be in any of the reports. Some staff and students at the Ghana School of Public Health may sometimes look at the research records. If you have no objection an anonymous version of the data collected will be available to other researchers and for educational purposes here in Ghana.

Voluntary Participation and Right to Leave the Research

You have the choice to take part in the study or not, and you are completely free to make your decision. You can choose to leave the study at any time, without causing any problems or your legal rights being affected.

Contacts for Additional Information

If you have any further questions about the study, you can contact the Ghana School of Public Health as follows:

Dr. Mawuli Dzodzomenyo

School of Public Health,

University of Ghana, Legon.

Tel: 020-837-6845
Your rights as a Participant

This research has been reviewed and approved by the Institutional Review Board of Noguchi Memorial Institute for Medical Research (NMIMR-IRB). If you have any questions about your rights as a research participant, you can contact the IRB Office between the hours of 8am-5pm through the landline 0302916438 or email addresses: nirb@noguchi.mimcom.org
VOLUNTEER AGREEMENT

The above document describing the benefits, risks and procedures for the research title ‘Evaluation of Sanitary Risk Inspection Protocol to Assess Faecal Contamination Pathways in urban and peri-urban groundwater sources in Greater Accra’, has been read and explained to me. I have been given an opportunity to have any questions about the research answered to my satisfaction. I agree to participate as a volunteer.

_______________________  ____________________________________________
Date  Name and signature or mark of volunteer

If volunteers cannot read the form themselves, a witness must sign here:

I was present while the benefits, risks and procedures were read to the volunteer. All questions were answered and the volunteer has agreed to take part in the research.

_______________________  ____________________________________________
Date  Name and signature of witness

I certify that the nature and purpose, the potential benefits, and possible risks associated with participating in this research have been explained to the above individual.

_______________________  ____________________________________________
Date  Name and Signature of Person Who Obtained Consent