AN INVESTIGATION INTO QUALITY OF WATER FROM PRIVATE HAND DUG WELLS SITED IN CLOSE PROXIMITY TO ON-SITE SANITATION SYSTEMS IN HOUSEHOLDS OF SMALL TOWNS: A CASE STUDY OF KINTAMPO MUNICIPALITY IN BRONG-AHAFO REGION, GHANA.

By

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DECLARATION

I hereby declare that except for reference to other people's work which have been dully cited, this thesis submitted to the School of Graduate studies, Kwame Nkrumah University of Science and Technology, Kumasi is the result of my own investigation, and has not been presented for any other degree elsewhere.

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ABSTRACT

The study investigated the quality of water from private Hand dug wells sited in close proximity to on-site sanitation systems in households of Kintampo municipality in Brong-Ahafo Region, Ghana. Kintampo town was zoned into five areas, based on the old (year 2000) electoral areas. Water samples were taken from 10 private hand dug wells. Samples were also taken from one borehole and one public stand pipe that supply water to the town. The samples were assessed for both the bacteriological and physicochemical parameters. The bacteriological parameters were: Total coliform, faecal coliform, and *E. coli*. The physicochemical parameters included: colour, turbidity, temperature, conductivity, pH, dissolved oxygen, total dissolved solids, total suspended solids, total hardness, iron, fluoride, chloride, calcium, sulphate and nitrate. All the 10 samples from the private hand dug wells tested positive to Total coliform count in the laboratory, whiles samples from the public stand pipe and borehole well showed negative total coliform result. However, all of the 10 samples together with the public stand pipe and borehole well indicated negative results for both faecal coliform and *E.coli*. None of the physicochemical parameters of the well waters were above the Ghana Standard Board and the WHO permissible and guided values, respectively. Physical characteristics such as temperature and colour of PHDWs were almost the same as that of the public stand pipe and the borehole. However, turbidity and conductivity were different from that of samples of the PHDWs and the public water supply. There were various variations with respect to the chemical parameters when the private hand dug wells (PHDWs) were compared to the public stand pipe and the borehole. Alkalinity, total hardness and calcium hardness levels were higher in public stand pipe than those of PHDWs and bore hole. Physicochemical

parameters: Temperature, Colour; alkalinity, Nitrite, Nitrate and Dissolved Oxygen showed significant seasonal variations. They all have p-values of 0.0001.

DEDICATION

The piece of work is dedicated to my late mother Obaapayin Yaa Pokua of blessed memory.

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LIST OF ABBREVIATIONS

APEC................... Advance Purification Engineering Corporation

APHA................... American Public Health Association

AWWA.................. American Water Works Association

CWSA.................. Community Water and Sanitation Agency

HWTS………… Household water Treatment and Safe storage

MCL..................... Maximum Contaminant Level

Methemoglobinemia: An altered form of haemoglobin that cannot bind oxygen produced by some poisons or genetic disorder

PHDW................... Private Hand Dug well

SMCL..................... Secondary Maximum Contaminant Level

UNEP................... United Nations Environment Programme

USEPA................ United States Environmental Protection Agency

USGS................... United States Geological Survey

WHO.................... World Health Organisation

CHAPTER ONE

1.0 INTRODUCTION

The provision of water and sanitation facilities are important public health measures that contribute significantly to the reduction in the disease burden of populations. The provision of such facilities is also critical to socio-economic development and has important equity implications as increasing numbers of international protocols and national policies emphasise the ‘rights-based’ approach to development (UNEP and WHO, 1996).

Peri-urban areas in developing countries are often densely populated with poor living standards and few or no connections to sewage networks or water pipes. A main part of the population have thus to rely on unsafe water supplies and poor sanitation facilities, resulting in severe health problems. Simple On-Site Sanitation (OSS) units e.g. pit latrines or pour flush latrines are a common solution for disposal of excreta in these settings. A high density of pit latrines is known to increase the risk of groundwater contamination and to pollute shallow wells or bore wells used for domestic/drinking purposes, particularly during seasons when the water table is high (ARGOSS, 2001).

Again, most peri-urban areas in Ghana, especially in Kintampo, often have to make provision for latrines in their houses as well as well water due to two important issues that are in the interest of public health. The first issue which is associated with the provision of latrines in homes is a matter of policy which addresses the problem of individuals defecating on open spaces, dumping sites and into black polyethylene bags and throwing the content into drains which end up into water bodies. The second issue which concerns water for domestic uses addresses the problem of inadequate or irregular water supply from public water supply system. House owners, therefore, are left with little or no option but to dig wells in their houses to augment, if not to replace the unpredicted public water supply (District Environmental Sanitation Strategy and Action Plans (DESSAP), 2011).

There are many challenges to improve access to drinking water and sanitation worldwide, and the two most important identified by the WHO are the rapid pace of urbanisation and the large number of rural people that lack basic sanitation and safe drinking water (Boqvist, 2008).

Kintampo community has very serious infrastructural and developmental problems due to over population. The community has numerous Government Departments, Institutions, and schools. The community is also a commercial centre and a tourist area. People come from all parts of the nation to trade and tourists as well come from all over the world to view the community's natural vegetation and natural water falls. Due to this overpopulation, some landlords have now turned their kitchens and latrines into bedrooms. In family houses, more than six (6) family members are lodging in a room including husband, wife and children causing serious health hazards to the people (Habitat for Humanity, Ghana, 2011). According to the outcome of a survey, about 14 communities in the Kintampo North Municipality confirmed using water from the hand dug wells for domestic purpose. This is so, for many residents in the district have access to shallow type of hand-dug wells in their own homes since it is relatively cheaper to construct (DESSAP, 2011). Even though the use of hand dug wells ranks third as far as source of domestic water uses is concerned, it also has its attendant problems of drying up in the dry seasons. Often the top parts of most hand dug wells are left unprotected; therefore, run-offs of rain trickle down the well, contaminating the water in the wells. Pit latrine (45.6%) is the predominant form of toilet system in the Kintampo township, bucket latrine (2.5%) was less common, and only a hand full had water closet toilet facility (Okechukwu *et al.*, 2012).

Negative health effects of poor water and sanitation and how this facilitates transmission of pathogens, either through the environment or as food borne transmission stresses the need for improvements in this area. To meet global development targets, improvements in water supply and sanitation are likely to focus on increasing sanitation coverage, and assessing the pollution risk to groundwater posed by on-site sanitation system is likely to become more important. Boqvist (2008), suggested the need for risk assessment to assess the spread of pathogens from on-site sanitation and the importance of aquatic reservoirs for pathogens, including faecal contamination of products used for human consumption

1.1 Problem statement

Groundwater remains one of the most important sources of water supply in rural communities and small towns in Ghana. Currently, over 90% of water provided for small towns for domestic use is extracted from groundwater sources (Community Water and Sanitation Agency (CWSA), 2008).There is growing concern that widespread use of on-site sanitation system will cause subsurface migration of contamination of groundwater ultimately resulting in disease transmission and environmental degradation.

In the 1960s to 1980s, the Kintampo town was endowed with many public latrines and since drinking water sources was a challenge, most houses decided to dig hand dug wells in their houses. Due to rapid population growth in the town recently, the public latrines cannot serve the inhabitants. Consequently, indiscriminate defecation became rampant in the community. In this light, all house owners are mandated by the Municipal Assembly to provide latrines in their houses. House owners therefore have little option as to how far to separate the well from the latrine even if they are to consider the expected 20 m and above distance between the well and latrine, a standard that has been set by the Kintampo Municipal Assembly. This resulted in situations where the well-pit latrine distance in some cases, are as short as 6 metres posing a risk of groundwater contamination by these pit latrines. Another concern is that even though Kintampo has a high dependency on groundwater as a source of drinking water supply, only the public water-supply systems currently require the routine monitoring and treatment of their systems for microbiological contaminants and physicochemical parameters. Protection and maintenance of private household-supply wells is not regulated and many house owners do not see this as their responsibility. In addition, the Municipal Assembly currently has no well-construction requirements.

The greatest risk from microbes in water is associated with consumption of drinking-water that is contaminated with human and animal excreta, although other sources and routes of exposure may also be significant (WHO, 2008).Previous studies conducted in and around Kintampo examined largely the bacterial load of well water without attempting to identify and quantify the potential risk factors associated with on-site sanitation in close proximity to the wells. This study therefore investigated the risks to health posed by groundwater pollution from on-site sanitation (particularly pit latrines) and attempts to consider it in the light of realistic alternative solutions to the water and sanitation problems of the Kintampo municipality.

1.2. Objective

The main objective of the study was to assess the quality of water from private hand dug wells sited in close proximity to on-site sanitation systems in households at Kintampo.

The specific objectives to achieve the purpose of this work were to:

- Assess the sanitary conditions to the well water supply.
- Determine the microbial populations (Total coliforms, faecal coliforms and *E. coli*) of the water from the private hand dug wells and the public water supply system.
- Measure the physicochemical parameters: pH, temperature, conductivity, total solids (TS), total suspended solids (TSS), total dissolved solids (TDS), turbidity, nitrate (NO_3^-), sulphate (SO_4^{2-}), phosphate (PO_4^{3-}), dissolved oxygen (DO) of the well water samples.
- Assess the seasonal influence in water quality of wells sited in close proximity to on-site sanitation

1.3. Hypothesis

1. The mean levels of bacteriological components in the water from the hand dug wells and the public water supply system in Kintampo are significantly different from one another.

2. The average levels of physicochemical component in the water from the hand dug wells and the public water supply system in Kintampo are significantly different from one another.

3. There is significant seasonal influence in well water quality of private hand dug wells sited in close proximity to on-site sanitation in Kintampo during the dry and wet seasons.

CHAPTER TWO

LITERATURE REVIEW

2.1Groundwater Supply and Sanitation Choices

One of the most dependent sources of water supply in most peri-urban and rural communities has been groundwater. And there is no doubt that sanitation choice of interest for such communities is on-site sanitation (AGROSS, 2001).

2.1.1. Groundwater supplies

It is well known that, in its natural state, groundwater is usually of good microbiological quality and as a result is often the preferred source of drinking water supply as treatment is limited to disinfection. In the case of rural and peri-urban supplies, groundwater supplies are usually untreated (AGROSS, 2001). It is well established that the principal forms of groundwater supply used for drinking water are as follows:

- Boreholes (also known as tube wells)—These are narrow-diameter, drilled holes that can be shallow or deep, and use a hand pump or motorized or electric submersible pump to abstract water. Boreholes are often easier to protect from pollution than other groundwater supplies.
- Dug wells—these are usually dug by hand and are typically of large diameter and of relatively shallow depth. These may be fitted with a hand pump or some other form of improved water collection or buckets and ropes utilized. Dug wells are susceptible to contamination, especially where they are shallow and/or uncovered.
- Springs—these may occur where groundwater discharges at the surface. They are generally protected by constructing a spring box around the eye of the

spring and may feed piped systems by gravity. Springs can be susceptible to contamination and great care needs to be taken to protect the supply (ARGOSS, 2001).

2.1.2 Types of sanitation and their choices

Sanitation facilities may be water-borne or dry. The British Geological Survey (BGS) commissioned report (AGROSS, 2001) on the guidelines for assessing the risk to groundwater from on-site sanitation indicated that there are many different forms of sanitation ranging from conventional and modified sewerage, to water-borne on-site systems such as septic tanks, aqua privies and pour-flush latrines to dry systems which are generally different forms of pit latrines, some of which may include urine separation. The technical team of BGS added that the choice of sanitation system is based partly on availability of water, but also on cultural reasons and anal cleansing methods. Sanitation systems according to British Geological Survey commissioned report (AGROSS, 2001) can be divided into two principal categories:

Off-site methods—these are different forms of sewerage where faecal and household wastes are carried away from the household. No treatment occurs at the household and the waste must be taken to a treatment plant before discharge into the environment.

On-site methods— include septic tanks and all forms of pit latrines. In these systems the wastes are stored at the point of disposal and usually undergo some degree of decomposition on site. On-site systems either require periodic emptying or construction of new facilities once they fill up. On-site systems often represent a significant hazard to groundwater because faecal matter accumulates in one place and leaching of contaminants into the subsurface environment may occur. Septic tanks typically hold the solid component of wastes in a sealed tank where the matter decomposes anaerobically. Liquid effluent is usually discharged into a soak-away pit. In well-designed septic tanks, the solid matter does not represent a significant hazard, but the soak-away pits may cause both microbiological and chemical contamination. The liquid part of the waste in a pit latrine that infiltrates into the soil is called the hydraulic load. Where hydraulic loads are high and exceed natural attenuation potential in the sub-surface this may lead to direct contamination of groundwater supplies (ARGOSS, 2001).

Pit latrines are usually not sealed, although sealed pits may be used in urban areas or in areas of high water-table (AGROSS, 2001). In most pit latrine designs, the liquid part of the waste is allowed to infiltrate into the soil, although some pour-flush latrine designs provide a soak away. This infiltration of wastes (often containing micro-organisms and nitrogen, the latter may be oxidized to nitrate) represents an additional hazard to groundwater, particularly as this frequently occurs at some depth in the subsurface and thus by-passes the soil (AGROSS, 2001).

The choice of sanitation technology depends on many economic, technical and social issues and each type of technology has advantages and disadvantages. For instance pit latrines generally are the cheapest form of sanitation and can be easily constructed at a household level. In rural areas and most small towns in Ghana, they often represent the only viable sanitation option given the low-level of water supply service. In many small towns and peri-urban areas pit latrines may also be commonly used and may represent a greater hazard as the numbers and densities of pit latrines increase the potential for groundwater pollution. Pit latrine designs can be improved to reduce such risks (ARGOSS, 2001).

2.2. Groundwater Quality

No drinking water is truly pure. Instead, water contains minerals and other substances dissolved from the surrounding rocks and environment (Brian, 2012). Water quality is a widely used term which has different meanings to different users. A user may define water quality in terms of its physical, chemical, and biological characteristics by which he/she evaluates the acceptability of the water. Water for domestic activities like drinking, cooking, and washing must be microbiologically safe, free from undesirable substances, not coloured, and with desirable taste. Water in this state can be said to be potable since its consumption may not lead to any health problems (Appiah and Momende, 2010).

According to Kortatsi (1994), the quality of groundwater is generally good for multipurpose use except for the presence of low pH (3.5-6.0) waters, high level of iron, manganese and fluoride in certain localities as well as high mineralization with Total Dissolved Solids (TDS) in the range 2000-14584 mg/l. Low pH waters are found mainly in the forest zones of southern Ghana. About30% of all boreholes in Ghana has iron problems (Kortatsi, 1994).The quality of groundwater is generally perceived to be good. However, the occurrence of high levels of minerals including metal compounds, especially iron and manganese in most of these groundwater sources has been identified as a challenge limiting the extent to which the resource can be exploited. About 40% of drilled wells with high iron levels have been abandoned by user communities while about 60% are used marginally for purposes other than drinking, cooking, and laundry (CWSA, 2008).

The quality of water expected from a hand-dug well or borehole will vary according to the type of water raising system employed. Water raised from a hand-dug well with a hand pump can be expected to contain fewer bacteria than one fitted with a bucket and windlass. However, the bucket and windlass is less likely to malfunction, and is cheaper to maintain than a hand pump (Morgan, 1990). Again, there are three routes by which the water in a well may become contaminated. These include: through the wellhead, lining, or water entering the intake (Appiah and Momende, 2010).

Generally, the closer the groundwater is to the surface, the more influential is the effect of heavy rain in carrying bacteria and other organisms through the soil into it. Poorly made concrete apron and water run-off can crack, and will allow leakage of waste water from the surface back into the well to contaminate it. Buckets and ropes which are used to raise the water, and often lie around the unhygienic rim of the well also pollute the water. Generally, shallow wells are less than 15 m deep (Appiah and Momende, 2010). Currently, the most practical approach to the problem of improving and maintaining the quality of water delivered in rural water supply schemes is not to impose a set standard, but to insist on adequate measures of sanitary protection which significantly improve the quality of water (Appiah and Momende, 2010).

2.3 Factors Influencing Groundwater Quality

2.3.1. Geology of groundwater

2.3.1.1 Nature of aquifer

The underground reservoir that permits significant quantities of water to be abstracted in it is known as an aquifer. The ground above the aquifer through which the infiltration percolated is referred to as the unsaturated zone. The level to which the ground is fully saturated is known as the water table. Although there are many types of rocks that permit significant quantities of water to be abstracted (aquifer), these can be summarized into a number of broad groups that takes into account not only the rock type but also the environment in which the rocks were formed (ARGOSS, 2001). The first of these broad groups of aquifer formation is the unconsolidated aquifers. These aquifers are rarely simple systems; they are typically layered, with permeable layers of sands and gravel separated by less permeable layers of clay or silt, producing complex groundwater flow patterns. Groundwater in these aquifers is naturally of excellent microbiological quality; natural filtration produces clear, colourless water, free from microbial contamination and thus requiring minimal treatment. However, this may not be the case at shallow (ARGOSS, 2001).

The second to consider is the consolidated sedimentary aquifers. This include; the consolidated sediments and the recent coastal limestone. The Consolidated sediments are younger sandstones which usually retain a primary porosity (the porosity between grains) and are typically of low-moderate permeability. In older, more-cemented formations, the primary porosity is virtually absent and it is the secondary (fracture) porosity which provides the aquifer permeability and storage. The vulnerability to pollution of consolidated sedimentary aquifers is greatly increased by the development of secondary permeability, especially in the karst limestone where particularly rapid water movement along fractures is possible.

Another important formation of the consolidated sedimentary aquifer is recent coastal limestone. These formations can form important aquifers. Their permeability is often dominated by fracturing and is, as a consequence, high, producing rapid groundwater movement with velocities frequently in excess of 100m/d. The high infiltration capacity of these rocks often eliminates surface runoff and very often groundwater is the only available source of water supply in these environments (ARGOSS, 2001). These characteristics have important implications for groundwater quality. Water movement from the soil to the water-table is often via fractures and is so rapid that even filtration and removal of micro-organisms within the unsaturated zone is not effective. Consequently these formations are extremely vulnerable to widespread pollution. In addition, as these coastal aquifers are usually underlain by seawater often at shallow depths, excessive abstraction, may induce seawater up coning and contamination of fresh water (ARGOSS, 2001).

The third aquifer group is the weathered basement aquifers. Over large areas of Africa and parts of Asia, groundwater occurs in basement rock aquifers. These aquifers are often ancient crystalline rocks with little or no primary porosity e.g. granite. In some cases the basement rock is covered by an extensive and relatively deep weathered clayey layer of low permeability. Below this the rock becomes progressively harder until fresh fractured basement rock is reached. Where the deeply weathered low permeability layer is both extensive and deep, the aquifer can be considered to have relatively low pollution vulnerability. However, there are other areas where the weathered layer is of variable thickness and basement rock can occur at the ground surface. Such aquifer environments are more vulnerable to pollution because of the likelihood of fractures extending close to ground surface (ARGOSS, 2001).

The quality of groundwater may be affected by the source rock, soil composition, or overlaying superficial deposits. Chemical reactions between ions in the water and minerals in associated rocks also play a role in this regard. The rate of movement of groundwater and human activity within the catchment basin may also affect the water quality (Appiah and Momende, 2010).

The rocks underlying the Kintampo North Municipal form part of the "Voltain formation" which covers about two – fifths (2/5) of the surface area of Ghana and about 80% of the District's land surface. It is represented by white-grey quartzitic and feldspathic sandstones of variable grainsize ranging from fine-grained to grits, locally interbeded with shales (Bozhko, 2008). Rocks belonging to this formation are mainly sedimentary and because of their relatively high solubility, coupled with their great abundance in the earth's crust produce the major soluble constituents of groundwater. Sodium and calcium are commonly added cations; bicarbonates and sulphates are corresponding anions (Appiah and Momende, 2010).

Certain chemicals can be linked to igneous, metamorphic, and sedimentary rocks.

The regions in Ghana most vulnerable to high fluoride concentrations are the arid zones of the north and areas where bedrock geology is dominated by granite and some Birimian rocks. Marked variations in fluoride concentration with depth were observed in groundwater from the problem areas of Bolgatanga (e.g. the Bongo granite). Shallow groundwater from dug wells had significantly lower concentrations of fluoride than borehole waters as a result of dilution (Appiah and Momende, 2010).

2.3.1.2 Aquifer vulnerability to pollution and risks to groundwater supplies

According to the British Geological Survey commissioned report (ARGOSS, 2001) the term aquifer pollution vulnerability is used to represent the intrinsic characteristics of the aquifer which determine whether it is likely to be affected by an imposed contaminant load. Vulnerability assessment is based on the likely travel time for water to move from the ground surface to the water-table – the greater the travel time the greater the opportunity for contaminant attenuation. As water moves through the ground, natural processes reduce (or attenuate) the concentration of many contaminants including harmful microorganisms. The degree to which attenuation occurs is dependent on the type of soil and rock, the types of contaminant and the associated activity.

2.3.2. On-site sanitation systems

On-site sanitation systems, which include septic tanks and all forms of pit latrine, store wastes at the point of disposal. Septic tanks typically hold the solids compartment of wastes in a sealed tank where the matter decomposes anaerobically; the liquid effluent is usually discharged into a soak-away. Pit latrines are generally not sealed and are usually only appropriate where the level of water table is low (communal or yard) and minimal liquid volumes are generated (ARGOSS, 2001).

Whilst the absence of water and sanitation facilities is associated with high rates of disease incidence and infant mortality rates, improvements in sanitation need to be integrated and properly planned; otherwise one unanticipated outcome may be the contamination of drinking water by faecal matter derived from on-site sanitation (ARGOSS, 2001).The principal hazard from on-site sanitation is the risk of transmission of pathogenic micro-organisms. Concentrations of nitrate in excess of the WHO (2008) guideline limit can give rise to methemoglobinemia (or blue-baby syndrome) (Appiah and Momende, 2010). In some geological settings elevated groundwater concentrations of some trace elements e.g. arsenic, fluorine, manganese can pose a health hazard (Appiah and Momende, 2010).

On-site sanitation systems naturally raise a concern about the pollution of groundwater. Van Ryneveld *et al.*, (1997), wrote that pollution from on-site sanitation is influenced by a variety of complex factors namely:

- Varying subsurface conditions: - In addition to the variety of subsurface soils encountered, within any soil the most critical distinction is between the saturated and the unsaturated zone. Sudhakar (2011) also wrote that unsaturated zone is most important line of defence against faecal pollution of aquifer as it is less permeable

- Varying contaminants:- Different contaminants have different characteristics (e.g. mobility and persistence) which are affected differently by conditions in the subsurface and
- Varying mechanisms of movement through different materials and which vary with scale. Bacteria travel depends on velocity of groundwater flow. During travel, fraction die or retained (adsorbed or screened) on soil matrix. The key factors for removal of bacteria and viruses from groundwater are effluent residence time between contamination source and point of water abstraction. The probable survival time for coliforms in anaerobic groundwater environment is 4-7 days (Sudhakar, 2011).

2.3.3. Impact of poor solid waste management on groundwater quality

The leachate produced by waste disposal sites contains a large amount of substances which are likely to contaminate groundwater. A study conducted in India to look at the impact of poor solid waste management on groundwater has revealed that the groundwater quality does not conform to the drinking water quality standards as per Bureau of Indian Standards (Vansanthi,2008). The effects of dumping activity on groundwater appeared most clearly as high concentrations of total dissolved solids, electrical conductivity, total hardness, chlorides, chemical oxygen demand, nitrates and sulphates. Leachate collected from the site showed presence of heavy metals (Vansanthi, 2008).

2.4. Arrangements of on-site sanitation systems & groundwater sources

According to Odai and Dugbantey (2003), in Ghana there is no law governing the arrangement of on-site sanitation and groundwater tapping points in a private compound. In most urban and peri-urban communities residential areas usually share common walls. Due to lack of sewerage and water supply systems in these areas, the residents tend to depend on groundwater resources for their water supply, and on-site sanitation for disposal of excreta. In some arrangements, there is only a wall separating a hand-dug well in one compound from an on-site sanitation system in another. This may be a major source of health risks as these two technologies are usually developed hand-in-hand. Odai and Dugbantey (2003) added that even the psychological effect of the closeness of the two necessities of peri-urban and rural residences is so conflicting that some have ceased using their hand-dug wells as a source of their water supply. The authors stressed that there is therefore the need to increase the lateral separation between pollution source on-site sanitation (OSS) and groundwater supply to reduce the risk of faecal pollution. A plan view of a typical setting in the study of risk assessment of water supply from onsite Sanitation Systems (OSS) proposed by Odai and Dugbantey (2003) has been presented in Appendix C.

2.5. Effect of distance from pollution source on groundwater quality

Available literature maintains that increased lateral separation between pollution source and groundwater supply reduces the risk of faecal pollution. Hence, the farther a groundwater supply is from the pollution source the less the risk of pollution (ARGOSS, 2001). Odai and Dugbantey (2003) studied the concentration of selected contaminants in relation to the distances between the groundwater supplies and the on-site sanitation systems. The contaminants analysed were faecal coliform, nitrate, and chloride because they are key indicators of the presence of faecal pollution. The results were that: the levels of faecal coliform were highest in the wells at distances 25m and46m, respectively from on-site sanitation. The well at a distance of 49m away from a pit latrine, was however, less polluted. With respect to nitrate and chloride, they found that the trend for concentration of the three contaminants was similar: the closer the well to pollution sources the higher the levels of concentration of the three contaminants. Odai and Dugbantey (2003) therefore concluded that the pollution levels in groundwater sources depend on distance between the groundwater supplies and the pit latrines. They also indicated that because the latrines and groundwater supplies were located in different communities with varying soil types, it is likely that the low levels of contaminant levels at some distances may be due to the soil types. Their second speculation was that there may be ingress of faecal coliform into the well through the openings.

2.6. Risk of contamination of groundwater supplies by on-site sanitation

The British Geological Survey commissioned report (ARGOSS, 2001) proposed that the risk of contamination of groundwater supplies by on-site sanitation uses the concept of source –pathway-receptor. For a risk to a receptor (in this case a groundwater supply) to exist both a source of contamination and a pathway must be present (the pathway provides the means or route for contamination to reach the receptor). In the natural environment, sources of contamination are always present and usually widespread, including on-site sanitation. Pathways that allow water to move from these sources to the receptor can be subdivided into:

- Aquifer pathway -Pathways that occur naturally in the subsurface due to openings and cracks in the soil and rock.
- Localized pathway –That is man-made pathways that occur as a consequence of the design and construction of the receptor (in this case the well).

The ARGOSS (2001) indicated that, many contaminants, especially micro-organisms, can be rendered harmless or reduced to low numbers/concentrations by natural processes provided there is sufficient time. Reducing the risk (to the receptor) can be achieved by: removing the source of contamination or reducing the levels of contaminants that are produced; increasing the time for water to travel from the source to the receptor; and minimizing man-made pathways such as increasing the lateral distance between a well and pit latrine. The soil is the most biologically active layer and is where contaminant attenuation is greatest. However, biological communities also typically develop around the active parts of the pit and contain predatory micro-organisms capable of removing pathogens. This may help limit the risk of contaminant movement to deeper layers to some degree (Sudhakar, 2011).

2.7. Measuring Water Quality

Water can be tested for thousands of possible elements or agents, but only about 100 are covered by most drinking water standards. With respect to private wells, the standards of the US Environmental Protection Agency (USEPA) according to Brian (2012) have been divided into the following categories: microbiological, inorganic (IOCs), secondary contaminants, volatile organic chemicals (VOCs), and synthetic organic chemicals (SOCs), and radio-nuclides, i.e., radio-active substances. The Ghana Standard Board (GSB) and Ghana Water Company (GWC) have adopted the WHO water quality guidelines categorization. For drinking water, it may include the following parameters: microbiological (Total coliform, faecal coliform and E *coli*) and physicochemical (temperature, colour, and turbidity, and dissolved oxygen level, concentration of organic and inorganic compounds (Appiah and Momende, 2010).

Appiah and Momende, (2010), cited the drinking water quality guidelines as determined by WHO in 2006 and Ghana standards Board (GSB) and Ghana Water Company (GWC) in 2006. This has been presented in Table 1. These guidelines were set mainly for health reasons. However, the guidelines also take into consideration the psychological effect and aesthetic aspect associated with drinking water, for example the objection of the water due to colour or odour or turbidity.

Table 1: Drinking Water Quality Guidelines for the WHO and GSB/GWC

Parameter	WHO	GSB/GWC
Colour	0-15 Hz	0- 15 colour unit
Turbidity	5 NTU	5 NTU
pH	6.5-8.5	6.5-8.5
Total Dissolved Solids	1000 mg/l	1000 mg/l
Iron	0.3 mg/l	0.3 mg/l
Fluoride	1.5 mg/l	1.5 mg/l
Chloride	250 mg/l	250 mg/l
Total Hardness	500 mg/l	500 mg/l
Sulphate	250 mg/l	250 mg/l
Nitrate	50 mg/l	50 mg/l
Faecal coliform	0/100 ml	Negative
E. coli	0/100 ml	Negative

(Source: WHO, 2006; GSB, 2006)

2.7.1. Microbiological Parameters

The microbiological agents in water can include bacteria, protozoan, and viruses. The microbiological contaminants are classified as primary drinking water standards, because of specific health concerns and the spread of disease. Because the cost for testing for specific microbiological agents may be cost prohibitive, most drinking water standards use coliform bacteria as an indicator of contamination (Brian, 2012).The World Health Organization (2008) has defined coliforms as any rod-shaped, non-spore-forming, gram-negative bacteria capable of growth in the presence of bile salts or other surface-active agents. Continuing, the definition states that coliforms are cytochrome-oxidase negative and able to ferment lactose at either 35 or 37 °C with the production of acid, gas, and aldehyde within 24 to 48 hours. The total coliform group is the most inclusive indicator classification and contamination indicated by the presence of total coliforms is indicative of inadequate disinfection of drinking water (Hach, 2000).

Total Coliform-These bacteria can be easily tested by certified laboratories and can be used as an indicator of the microbiological quality of your water. If these bacteria are not present in your water, i.e., a result of Absent or < 1 colony per 100 ml, this should be interpreted to mean that it is not likely that the water contains a microbiological agent that may pose a health problem. If the bacteria are present in your water, i.e., a result of Present or 1 or more colonies per 100 ml, this should be interpreted to mean that it is more likely that the water contains a microbiological agent that may pose a health problem and that some action is needed (Brian, 2012).

Faecal Coliform - This is a sub-group of total coliform bacteria which are more typically found in the waste of warm-blooded animals, but which can be found in non-mammals and insects. Faecal coliform bacteria should not be present in your drinking water and a suitable result would be Absent or < 1 colony per 100 ml. Appiah and Momende (2010) reported that, all the hand-dug wells in Kintampo were contaminated by faecal coliform.

Escherichia coli (E.coli.)- This is a bacterial strain that is most commonly found in humans and animals. The best coliform indicator of faecal contamination from human and animal waste is *E. coli*. In human and animal faeces, 90 to 100% of the coliform organisms isolated are *E. coli*. In sewage and contaminated water samples, the percentage drops to 59%.The presence of this group of bacteria would suggest the source is a human or mammalian waste source and a suitable result would be Absent or < 1 colony per 100 ml (American Public Health Association, 1992).

Brian (2012), wrote that if the results suggest that total coliform bacteria, faecal coliform, and/or *E.coli* are present this would mean that it is more likely that a pathogen is present in your drinking water. A fourth, production of hydrogen sulphide, has recently been recommended and used (Center for Disease Control and Prevention, 2010).

2.7.2. Physicochemical parameter

Colour

The U.S. Environmental Protection Agency (USEPA) standard for color is 15 color units. This is the level on the colour scale where individuals tend to be able to detect a visual change in the appearance or tint of the water. Colour can be indicative of elevated levels of dissolved organic material like tannins, corrosion by-product, and foaming agents (Brian, 2012). Colour in drinking water may affect aesthetics, and can be rejected by consumers. It is determined using a spectrophotometer (Hach, 2000). Appiah and Momende (2010) reported that the colour of 28 of the wells studied in Kintampo had values between 3.7 and 6.3 colour units, which were below that for the treated water with colour of 8.0 colour units in the town.

Turbidity

Turbidity in water is caused by the presence of particulate matter such as clay, silt, colloidal particles, and microorganisms. Turbidity is the measure of the water's ability to scatter and absorb light. High turbidity levels can reduce the efficiency of disinfection by creating a disinfection demand. The particles may also provide absorption sites for toxic substances in the water. Although it does not adversely affect human health, turbidity is an important parameter in that it can protect microorganisms from disinfection effects, can stimulate bacteria growth and indicates problems with treatment processes (WHO, 2004).Turbidity is measured in Nephelometric Turbidity Units (NTU), using a turbidity meter (USEPA, 1995). For effective disinfection, median turbidity should be below 0.1 NTU although turbidity of less than 5NTU is usually acceptable to consumers (WHO, 2004). Appiah and Momende (2010) recorded turbidity range of 0.4 to 23.5NTU in groundwater in Kintampo Municipality.

Temperature

Depending on whether temperature is high or low, may affect other parameters including conductivity and dissolved minerals. It affects the reaction rates and solubility levels of chemicals present in water. It is determined using Temperature meter (Hach, 2000). Cool water is generally more palatable than warm water. Appiah and Momende (2010) reported that temperature range of between 26.5 and 28.5 °C was recorded for the water of hand-dug wells in Kintampo.

Conductivity

Conductivity is a measure of the water's ability to conduct electric current. It is directly related to the total dissolved salt content of the water. This is so because the salts dissociate into positive and negative ions and can conduct electric current proportional to their concentration. It is recorded in micro Siemens per centimetre (μS/cm) using a conductivity meter (Hach, 2000).Human activities may influence conductivity. Sewage and farm runoff can raise conductivity due to the presence of nitrate and phosphate. Runoff from roads can also carry salt and other materials that contribute ions to water. WHO (2006) recommended level for conductivity is 300μS/cm for drinking water. (Appiah and Momende, 2010), reported a conductivity range of between 420 µS/cm to 5180 µS/cm (with a mean of 1737.1 µS/cm), on groundwater in Kintampo.

The pH

It is the measure of acidity or alkalinity of the water. The pH of most drinking water lies within the range of 6.5 – 8.5 (WHO, 2004). Usually it has no direct impact on consumers and it is one of the most important operational water quality parameters (WHO, 2006). The usual pH for fresh water aquatic system is 6 to 9.Waters around this pH range is an indicator of existence of biological life in them as most of living organisms thrive in a quite narrow and critical pH range. The pH of water is related in several different ways to almost every other water quality parameter, as aqueous chemical equilibriums invariably involve hydrogen ions, (WHO, 2006).Water sample with low pH attributed to discharge of acidic water into these sources by agricultural and domestic activities. In fact, 98% of all world groundwater are dominated by Ca^{2+} and HCO_3^- due to limestone weathering in the catchments and under groundwater beds (Brian, 2012). (Appiah and Momende, 2010), reported that all the hand-dug wells they studied in Kintampo had pH values range of 5.5 to 6.5 which did not conform to the WHO and Ghana Standard Board pH range of 6.5-8.5.

Though pH has no direct effect on the human health, all the biochemical reactions are sensitive to variation of pH. For most reactions as well as for human beings, pH value of 7.0 is considered as the best and ideal. Depending on the pH and sometimes the temperature of water, metals may dissolve into ions. It is determined using a pH meter.

Dissolved oxygen

Dissolved oxygen (DO) is the amount of molecular oxygen dissolved in water. The amount of dissolved oxygen in water depends on temperature, degree of turbulence, light penetration, and turbidity. It also depends on chemical and biochemical reactions such as photosynthesis, respiration, and decomposition. It can be measured on the field using a DO meter (Hach, 2000). It is measured in milligram per litre (mg/l). Appiah and Momende (2010) reported that all the hand-dug wells they studied in Kintampo had concentration of dissolved oxygen of the water samples ranged from 2.6-5.5 mg/l. They concluded that higher dissolved molecular oxygen in water gives it a good taste and it may be the preferred choice by consumers.

Total Dissolved Solids (TDS)

Total Dissolved Solid (TDS) is a measure of the total amount of dissolved substances in the water sample. It is not a direct measure of a specific element or contaminant. An elevated TDS may be associated with an elevated water hardness, chemical deposits, corrosion by-products, staining, or salty bitter tastes. If the TDS content of the water is high, the primary recommendation would be to test the water for additional parameters, such as: total hardness, iron, manganese, sodium, chloride, sulphate, alkalinity, and nitrate, to determine the nature of the water quality problem.

In natural waters, salts are chemical compounds which comprise of anions such as carbonates, chlorides, sulphates and nitrates (primarily in ground water), and cations such as potassium, magnesium, calcium and sodium. It originates from natural sources, sewage, urban run-off, and industrial waste water. Its concentration in water varies considerably in different geological regions owing to differences in the solubility of minerals. It is measured in milligram per litre (mg/l) (Hach, 2000; WHO, 2006).

The TDS test is an indicator of the potential for water quality problems (Brain, 2012). According to Appiah and Momende (2010) the total dissolved solids of the water from the hand-dug wells in Kintampo ranged from 48-533 mg/l, which is far below the maximum value of 1000 mg/l recommended by the WHO and GSB. According to WHO (2006), there has not been any deleterious physiological reactions occurring in persons consuming drinking water that have TDS values in excess of 1000mg/l. WHO, however, recommends the low level of the latter as a guideline value for TDS. Kempster *et al*. (1997) reported a critical TDS value of 2450 mg/l above which some long term health problems might be anticipated due to excessive concentrations of dissolved particles in drinking water.

Total Suspended Solids

Total Suspended Solids (TSS) can include algal matter or non-algal matter such as finely ground calcium carbonate particles from limestone. Depending on the source, these substances may impact any number of colours to the water. It is determined using a spectrophotometer (Hach, 2000).

Nitrate

Nitrate (NO_3^-) is water-soluble and is made up of nitrogen and oxygen. It is formed when nitrogen from ammonia or other sources combines with oxygenated water. Water naturally, contains less than 1 mg nitrate/nitrogen per litre and is not a major source of exposure. Higher levels indicate that the water has been contaminated. The USEPA, Minimum Concentration Level is 10 mg NO_3^-N/L for nitrate and 1 mg NO_2^- N/L for nitrite (Brian, 2012). The primary source of nitrate and nitrite would be agricultural runoff, poorly maintained septic systems, sewage disposal, and acid solutions in injection fluids, urban runoff, and natural deposits. In some wells, particularly drive-point wells or other shallow wells, nitrate may only be present during the spring or after a heavy rainfall when rapid infiltration of surface water occurs (Appiah and Momende, 2010). Because nitrate can move rapidly down through the soil into the groundwater, the presence of nitrate may provide an early warning of possible problems and can sometimes indicate the presence of other contaminants (Minnesota Department of Health, 2010). Due to potential toxicity and widespread occurrence in water, it is regulated and should not exceed 10 mg/l in drinking water (WHO, 2006). The primary concern for nitrate and nitrite is that infants less than 6 months are susceptible to blue-baby syndrome, which is potentially fatal if not treated. Blue-Baby Disease or methemoglonemia, is an effect in which haemoglobin is oxidized to methemoglobin, resulting in asphyxia. It is a serious condition that can cause brain damage or death. Infants up to three months of age are the most susceptible subpopulation with regard to nitrate. Appiah and Momende (2010), recorded nitrate concentration ranging from 0.01 to 3.24mg/l in groundwater studied in the Kintampo Municipality.

Iron

Iron occurs in groundwater in high concentrations in many places throughout Ghana. It is generally associated with acidic groundwater or anaerobic (oxygen-free) groundwater. The Secondary Maximum Contaminant Level (SMCL) for iron is 0.3 mg/l (Brian, 2012).

Iron in the water can be associated with a bitter/metallic taste, formation of sediment and yellow, red, and orange films, and discoloured clothing during washing (Brian, 2012). Staining of laundry and household fixtures can occur in waters with high iron concentration. Its concentration in water is determined using a spectrophotometer (Hach, 2000). Appiah and Momende (2010), reported in Kintampo that hand-dug wells had a mean concentration of iron of 0.17mg/l whiles the treated water of the Kintampo Water Supply System (KWSS) had a mean concentration of 0.29 mg/l. They concluded that the treated water may be more coloured than water from the hand-dug wells.

Fluoride

It occurs naturally in most soils and in many water supplies. A UV-Visible spectrophotometer is used to determine fluoride ion concentration in water (Craun *et al*., 2003). Appiah and Momende, (2010), mentioned that the fluoride concentration of the hand-dug well water samples from Kintampo was generally low, being between 0.01-0.03 mg/l. They added that the boreholes had higher values than the hand-dug wells, but they were still low, between 0.10-0.13 mg/l. These values are far below the maximum allowable concentration of 1.5 mg/l by WHO and Ghana Standard Board (GSB) and therefore acceptable. The Maximum Contaminant Level (MCL) for fluoride is 4 mg/L, but because of the potential for dental fluorosis, i.e., mottled or discoloured teeth, the USEPA has set a secondary standard of 2 mg/l (Brian, 2012). Elevated levels of fluoride have been shown to cause bone disease. Low levels of fluoride may help to prevent cavities in teeth (WHO, 2008).

Chloride

Chloride is present in all potable water supplies and in sewage usually as a metallic salt. The USEPA Secondary Maximum Contaminant Level (SMCL) and the WHO guideline value for chloride is 250 mg/l. The standard has been set because of potential aesthetic problems associated with the taste of the water and that elevated levels can facilitate the corrosion of piping and fixtures (Brian, 2012). Chlorides are found naturally in the environment, but elevated levels of chloride can also be associated with septic system effluent, storm water runoff, brine water, cleaning solutions, and other industrial solutions. Its concentration in water is determined using precipitation titration (Hach, 2000; WHO, 2006). Appiah and Momende (2010) reported that water from 29 of the hand-dug wells in Kintampo (96%) had chloride concentrations below 344 mg/l.

Total Hardness

Total hardness in water is caused by dissolved calcium and, to a lesser extent, magnesium salts. The hardness of the water is reported as the equivalent concentration of calcium carbonate ($CaCO_3$) per liter of water, but the actual test measures the calcium, magnesium, manganese, iron, and other multivalent positively charged ions. Individuals typically report aesthetic problems with the water when the total hardness is above 160 mg $CaCO_3$/l, but it is possible that corrosion problems could be associated with water with very low water hardness (Brain, 2012). Depending on pH and alkalinity, hardness above 200 mg/l can result in scale deposition, particularly on heating. It is determined by titration with EDTA (Ethylene diamine tetra-acetic acid) (WHO, 2006). Water with less than 75 mg/l $CaCO_3$ is considered to be soft and above 150 mg/l as hard. According to Appiah and Momende (2010) the total hardness of water from the hand-dug wells ranged from 38.7-259 mg/l. Most of the hand-dug wells had less than half of the WHO maximum permissible value of 500 mg/l.

Sulphate

According to USEPA (1995) the Secondary Maximum Contaminant Level for sulphate is 250 mg/l. At a level of 250 mg/l, sulphate can impart a bitter to salty taste to the water, but at a level of over 500 mg/l the sulfate can have a laxative effect (Brian, 2012).

Sulphate is found in natural waters in a wide range of concentrations. A Spectrophotometer is used to determined sulphate concentration in drinking water (Hach, 2000). Sulfates may also be associated with the presence of hydrogen sulfide or rotten egg odors to the water. A hydrogen sulfide odor could be caused by a combination of chemical or biological reactions. There is no specific drinking water standard for hydrogen sulfide, but there is a secondary drinking water standard for odor.

According to Appiah and Momende, (2010), only water from 9 hand-dug wells in Kintampo had traces of sulphate, and it ranged from 1.3-9.3 mg/l. This concentration may be considered insignificant in relation to the WHO and GSB maximum allowable concentration of 250 mg/l.

Phosphates

High concentration of phosphate in water bodies is an indication of pollution and largely responsible for eutrophication (Appiah and Momende, 2010).Phosphates are not toxic to people or animals unless they are present in very high levels. Digestive problems could occur from extremely high levels of phosphate (Brian, 2012). WHO (2006), set a maximum contaminant level at 0.3mg/l. Appreciably low concentration of phosphate were observed in earlier study done by Appiah and Momende, (2010), on groundwater in Kintampo which varied from 0.001 to 0.6 mg/l. Nkansa *et al.*(2010), also recorded concentration of phosphate ranging from <0.001 to 0.921mg/L in surface water in South Western Ghana. Phosphorus is normally low (< 1 mg/L) in clean potable water sources and usually not regulated (Nduka *et al*., 2008).

2.8. Health and Aesthetics

Water is a basic need for all life and good health. Water is used to prevent and treat diseases. It may be difficult to know if water is safe or not. Some of the things that cause health problems are easily noticed by looking at, or tasting the water. Others can be found by testing the water. Understanding what makes water unsafe and taking steps to protect water from contamination can prevent many problems from unsafe water. Therefore, health and aesthetics are the principal motivations for water treatment (Appiah and Momende, 2010).

2.8.1. Health

Microbial contamination

Many types of pathogens transmit infectious diseases. These have differing impacts on health and transmission routes may vary. The pathogens that cause infectious diarrhoeal diseases that can be transmitted through contaminated water are grouped into three principal types of organisms: bacteria, viruses and protozoa (or cysts). All these pathogens may be transmitted by other routes, including via contaminated hands, flies and animals. Helminths (or worms) are not included as their size makes them unlikely to be present in groundwater supplies unless there is a direct entry for surface water, in which case pathogens of other types will also be present and are likely to represent a greater risk to health. Bacterial pathogens cause some of the best known and most feared infectious diseases, such as cholera, typhoid and dysentery, which still cause massive outbreaks (or epidemics) of diarrhoeal disease and contribute to ongoing infections. Bacterial pathogens tend to have high infectious doses – i.e. a large number must be consumed in order to cause an infection

Chemical contaminations

The chemical contaminants of principal importance that are derived from on-site sanitation are nitrate and chloride. Each person excretes in the region of 4kg of nitrogen per year and under aerobic conditions it can be expected that a significant percentage of this nitrogen will be oxidised to form nitrate. The nitrogen loading from on-site sanitation in densely populated areas can be very large indeed. Nitrate is a health concern and WHO have set a Guideline Value of 50 mg/L as the safe level of nitrate where the likelihood of methemoglobinemia will be low. Chloride is of less concern for health, but affects the acceptability of the water and thus may result in use of alternative more microbiologically contaminated water. When assessing the potential risk of widespread contamination of groundwater by nitrate or chloride from on-site sanitation, the other possible sources should also be considered. Whilst quantifying the relative contribution from each source is likely to prove difficult, where potentially high nitrogen loadings are indicated, it would probably be worthwhile monitoring for nitrate in groundwater. Both nitrate and chloride may show significant seasonal fluctuations in shallow groundwater, although concentrations are expected to be more stable in deeper groundwater. Therefore, when assessing the risk of widespread nitrate or chloride contamination, it is important to recognise the possibility of seasonal peaks

Fluoride in drinking water reduces dental caries. However, over 20 mg/l of fluoride can result in nausea, diarrhoea, abdominal pains, headache, and dizziness. Some long term effects are dental and skeletal fluorosis (Craun *et al*., 2003). Also, it can have adverse effect on tooth enamel and may give rise to mild dental fluorosis at concentrations between 0.9-1.2 mg/l, depending on intake (WHO, 2006). A relationship has been postulated between the incidence of cardiovascular disease and the amount of hardness in water, or, conversely, a positive correlation with the degree of softness. Many investigators attribute a cardiovascular protective effect to the presence of calcium and magnesium (Craun *et al*., 2003). The degree of hardness in water may affect its acceptability to the consumer in terms of taste and scale deposition (WHO, 2006).

High concentrations of iron are not directly problematic for human health. It may cause indirect problems because of abandonment of affected water sources due to unpleasant odour and taste, in favour of surface waters which may be contaminated by harmful bacteria (Appiah and Momende, 2010). In individuals genetically susceptible to haemochromatosis, too much iron can be accumulated in the body, resulting in liver, pancreatic, and heart dysfunction and failure after long term exposure (APHA, 1992). Nitrate converted to nitrite in the body causes methemoglobinemia, especially in infants under one year of age (USEPA, 1995).

High concentrations of sulphate in drinking water may cause transitory diarrhoea (USEPA, 1995). At high sulphate levels (above 600 mg/l), bottle-fed infants develop diarrhoea. Adults living in areas having high sulphate concentrations in their drinking water easily adjust, with no ill effects. Sulphate may impact taste at levels above 300-400 mg/L (Craun*et al*., 2003).

2.8.2 Aesthetic

In addition to health issues, consumer satisfaction and confidence are also important. Aesthetic components of drinking water quality include taste, odour, turbidity, colour, mineralization, hardness, and staining. Taste problems in water derive in part from salts (Total Dissolved Solids) and the presence of specific metals, such as iron, copper, manganese and zinc. Specific salts may be more significant in terms of taste, notably magnesium chloride and magnesium bicarbonate. Concentrations of chloride above 250 mg/L may give water a salty taste. The presence of turbidity increases the apparent, but not true colour of water (Craun*et al.*, 2003).

E. coli cause diarrhoea that ranges from mild and non-bloody to highly bloody, which is indistinguishable from haemorrhagic colitis. Between 2-7% of cases can develop the potentially fatal haemolytic uraemic syndrome, which is characterized by acute renal failure and haemolytic anaemia. It is an important cause of diarrhoea in developing countries, especially in children (WHO, 2006).

2.9 Groundwater Management

Managing peri-urban or rural water quality is a significant challenge due to its site-specific nature and the typically inadequate financial and human resource available to address problems. Microbial health risks remain one of the major challenges. The most commonly detected problem of rural private wells is the occurrence of total coliform bacteria and other disease causing microbes. These may result from faecal matter coming from poorly constructed and poorly sited latrines and septic tanks, refuse dumps, and animal farms. Another problem is pesticide and nitrate infiltration from farmlands (Craun *et al*.,2003) Appiah and Momende(2010), therefore made this recommendation after assessing the water quality in Kintampo; the health officials in Kintampo Municipality should embark on a health education programme to educate the people on sanitary protection of all water sources, including appropriate setting of latrines.

As part of the solution to the lateral separation between pollution source (on-site sanitation) and groundwater supply to reduce the risk of faecal pollution, Odai and Dugbantey (2003), recommended that, the proposed arrangement demands that within the same compound, the longest distance possible should be provided between hand-dug wells and on-site sanitation. Also, houses having common walls should concentrate the development of on-site sanitation at the corner of their shared fence walls, while hand-dug wells are placed at the diagonal. It is therefore necessary that town planning agencies should enforce this ideal phenomenon.

Clasen *et al.*,(2006), indicated that water treatment at the point of use has become a favoured choice among donors and implementing agencies as an immediate, cost effective alternative to conventional treatment at the source. A number of low cost, simple and effective technologies are being promoted. Household water treatment and safe storage (HWTS) is an inexpensive alternative, which can immediately protect health. It is estimated for every $1 invested in household water treatment, there would be a return of $60 in terms of lives saved and diseases reduction (WHO, 2006). Experience with household water treatment is growing but low rates of adoption have been reported in many cases. There is relatively little information available about the potential uptake and sustainability of such interventions (Clasen, 2005).

Groundwater management is by nature localized. However, it can be planned simultaneously at the local, regional, and national levels. In addition to public policy and regulation, there is a range of technical tools available to assist in groundwater quality management. The best tool is accurate and adequate information. Major components of an information system needed for groundwater management decisions are hydrology, water extraction and use patterns, potential contamination sources and characteristics, and population patterns (Craun *et al*., 2003).

Most people are willing to pay a reasonable price for safe drinking water. However, in most places, water that people need for drinking is sold at a price they cannot afford. Whether water is managed by the community, government, private companies, or a partnership of these groups, the people who need water most must have a say in how it is priced, distributed, and used. They have to understand how to protect, store, and treat water. The community must be motivated to change what does not work, and to make these changes through community organization and action (Conant, 2005). Constructing individual water supply wells is always cost-effective where groundwater is abundant and of suitable quality. Where natural groundwater quality is exceptionally poor or where supplies are insufficient, the most costly option of piping treated water from a centralized source is a solution to provide suitable water (Craun *et al*., 2003).

It is sometimes assumed that if people do not accept a protected source, the answer is education. Often it is not a question of people not knowing that the protected source is healthier, for instance, but whether they are prepared to make the effort to change. In this kind of situation, the only answer is for the water agency to be willing to meet people's actual requirements as far as possible. For example, providing water sources as close as the contaminated ones, and not much more salty, hard, or otherwise objectionable. Where this is not possible, the difficulty should be discussed with them with the view of arriving at an agreed solution, instead of treating their concerns as a manifestation of ignorance and backwardness (Damme and White, 1984).

Documentation of all aspects of drinking-water quality management is essential. Documents should describe activities that are undertaken and how procedures are performed. Drinking water supply policy should normally outline the requirements for protection of sources and resources, the need for appropriate treatment, preventive maintenance within distribution systems and requirements to support and maintain water safety (WHO, 2006).

CHAPTER THREE

MATERIALS AND METHODS

3.1. Background of study area

Kintampo Municipality is strategically located at the centre as of Ghana shown in Appendix D (Ministry of Local Government and Rural Development and Maks, 2006). Kintampo is the capital of the municipality. The population of Kintampo town is 28,000 with 13,000 males and 15,000 females (Habitat for Humanity Ghana, 2011). Kintampo is composed mainly of Brong's, with other tribes like Dagares, Konkonbas, Mo, Dagombas, Fantes and Ewes who have migrated to the Town, from other Regions of Ghana to help in farming activities. The predominant mother tongue spoken is Brong. Kintampo lies in the Savannah zone of Ghana and is blessed with 2 main rainy seasons for effective farming activities. There are no hills in this part of Ghana. The land is gentle sloping, with a few streams flowing across. The Kintampo area has two-rainfall patterns, the major season (April to July) and the minor season (September to November)(Habitat for Humanity Ghana, 2011). There is a dry spell in August, which divides the two rainfall seasons and a major dry season, which starts, from November extending into March the following year. There is a lot of sunshine in the area. Temperature range is between 25 and 34 degrees Celsius while rainfall amounts are between 1, 200 mm and 1, 400 mm. The dry harmattan winds blow over the area during the major dry season when hazy dusty conditions prevail. The vegetation is wet grassland with a few patches of ‘wooded savanna’ found around sources of water.

A greater part of Kintampo lands are put to farming activities (Habitat for Humanity Ghana, 2011). The community is also a commercial centre and a tourism area. People come from all parts of the nation to trade and tourists as well come from all over the world to view the community's natural vegetation and natural waterfalls.

The community is not able to meet the challenge of housing due to over population. Due to this overpopulation, some landlords have now turned their kitchens to bedrooms (Habitat for Humanity Ghana, 2011). The map of Kintampo Township capturing important sites have been shown Appendix E (Appiah and Momende, 2010). And the satellite map of Kintampo where various sampling points have been imposed has been shown in Figure 1 (Goggle Map, 2012).

Figure 1: Satellite map of Kintampo: The various sampling points have been inserted.

3.2. Selection of Sampling Points

A list and location of households that uses both Hand dug well water and have latrine in their homes were obtained from the Kintampo Health Research Centre (KHRC). There were 200 hand-dug wells in the town, out of which 85 had both the well and latrine (KRHC, 2010). Even though the data could not specify whether those houses have both the latrine and the Private Hand Dug Well (PHDW) in the house, the research team used the list to identify houses with both facilities. Based on old electoral area demarcation (election, 2000) the study area was divided into five zones namely; Kyermankoma; Nwoase; Sunkwa, Mo line and Dwenewoho. A total of 10 representatives of PHDW were selected from all the five zones of the study area. Two PHDWs were selected from each zone. Figure 2 shows satellite map of Kintampo, the location of the where various sampling points have been fixed. The features of the different zones have been elaborated briefly as:

1) Zone 1 (Mo line): The zone is located on the western side of the study area. The latrine-well distance was small owing to the size of individual plots and samples were taken from two wells. The mean latrine distance was 6.3 m.

2) Zone 2 (Sunkwa): This zone lies at the centre of the study area. The mean well-latrine distance was 7.2 m and samples were taken from 4 wells.

3) Zone 3 (Kyeremankoma): This zone is located to the northern part of the study area. The mean well-latrine distance was 10.8 m and samples were taken from two wells.

4) Zone 4 (Dwenewoho): This lies to the east of the study area and has mean well-latrine distance of 12.5 m. The samples were taken from two wells.

5) Zone 5 (Nwoase): This lies to the south of the study area and has mean well-latrine distance of 6.5 m. The samples were taken from two wells.

Furthermore, two other sampling sites selected were; one from a mechanised borehole (C1) and the other from public stand pipe (S1). These two were used as baseline for assessing any risk to the quality of well water from the PHDWs sited close to the latrines. Thus in all 12 sample sites were selected with their coded has been presented in Table 2.

Table 2: sampling sites and codes

Zones	Codes
1	PHDW 1
1	PHDW 2
2	PHDW 3
2	PHDW 4
3	PHDW 5
3	PHDW 6
4	PHDW 7
4	PHDW 8
5	PHDW 9
5	PHDW 10
Public stand pipe	SP 01
Bore hole	C110

3.3. Sanitary survey

A cross-sectional sanitary assessment was carried out. This is an assessment of the potential sources of hazards which included the state of the infrastructure and protection works of the well that may affect the quality of water supply from the hand dug wells. A systematic approach was taken by using a standardised sanitary inspection format recommended by the WHO. The procedure involved completing a 10-point standardised data form with a series of questions with a yes and no options for designated risks. A score of one point was awarded for each “yes” answer (risk observed) and zero point for each “no” answer (no risk observed). By summing all “yes” scores, a final risk score was obtained, which provided the overall assessment of the risk profile of each PHDW. Sample of the sanitary inspection format has been presented in Appendix F.

The total sanitary risk score was converted to a percentage. The aggregate risk score was graded as very high (81 to 100%), high (51 to 80%), medium (31 to 50%) and (0 to 30%) as low. This aggregate scoring is in line with WHO (2010) systematic approach of obtaining quantitative value from the standardised sanitary inspection.

3.4. Water sampling and analysis

3.4.1. Collection of water samples

A total of 48 water samples were collected, spanning from February, 2012 to March 2012 and from April, 2012 to May, 2012 representing the dry season and wet season respectively. The sampling interval was monthly, giving a total of 4 samples per PHDWs, public stand pipe and borehole. A field data form was completed to record the code of sampling points, location, date, and weather conditions.

Samples for the chemical analysis were collected in 1.5 litre bottles. All the bottles were sealed. The bottles were filled with the samples after rinsing it with part of the sample water. It was then covered, packed and transported to the laboratory for analysis. Samples for the microbial analysis were collected in sterilized bottles with stoppers prepared by heating for two hours at the temperature of 120°C. Slightly over 250 ml of each sample was collected in order to perform all the required bacteriological tests. The samples were collected in the morning between the hours of 06:30 and 08:00 GMT, when the water had not been adversely disturbed and labelled. Since changes of water quality occur during transit and when stored, the samples were put in a cooled box while collection continued. The required time between sampling and analysis, which is four hours for nitrates and two hours for faecal coli forms were adhered to.

3.4.2. On-site measurement of water temperature, pH and electrical conductivity

The water temperature and pH were measured using a WTWO microprocessor pH/temperature meter. The meter was calibrated with pH 4 and 7 using standard buffer solutions according to manufacturer's instructions. The electrode was rinsed with distilled water between samples. Electrical conductivity was measured using a WTWÒ microprocessor conductivity meter calibrated at 25°C.

3.4.3. Laboratory analyses

The laboratory analyses were carried out in the Ghana Water Company Regional Laboratory office in Sunyani. The bacteriological parameters analysed were total coliforms, faecal coliforms and *E coli*, while the physico-chemical parameters measured were: colour, alkalinity, chloride, total hardness, total iron, Fluoride, ammonia, conductivity, total solids (TS), total suspended solids (TSS), total dissolved solids (TDS), turbidity, nitrate (NO^{3-}), sulphate ($SO4^{2-}$), phosphate ($PO4^{3-}$) and dissolved oxygen (DO) of the well waters.

3.4.3.1. Measurement of turbidity, nitrate and chloride levels

Turbidity was measured using the HACH DR/2010 Spectrophotometer. Twenty five (25) millilitres of a well-mixed sample were measured into a clean sample cell. Another sample cell was filled with distilled water. The intensity of light scattered and absorbed by the sample was compared to that measured for standard formazin suspensions and was read at a wavelength of 860 nm.

Nitrate levels were measured using the cadmium reduction method. Twenty-five millilitres (25 ml) of sample were transferred into a sample cell, and another sample cell was filled with an equal amount of distilled water. The contents of one Nitraver 5 Reagent Powder Pillow were added to each sample cell. The sample cells were stopper and vigorously shaken for one minute. They were then left to stand for five minutes to allow development of the colour. The concentration in mg/L was measured against the blank (distilled water) at a wavelength of 500 nm using the HACH DR/2010 spectrophotometer.

Chloride levels were measured using the mercuric thiocyanate method. The sample cell was filled with 25 ml of sample and another with equal amount of distilled water. Two millilitres of mercuric thiocyanate solution were added to each cell and swirled. One millilitre of ferric ion solution was pipetted into each sample cell and again swirled. After 2 minutes, chloride concentration of the sample in mg/l was measured against the blank and read at wavelength 455 nm using HACH DR/2010 spectrophotometer.

3.4.3.2 Total coliform, faecal coliform and *E. coli*

Single strength Mackonkey broth was prepared by adding 40 g of the powder of Mackonkey to 1 litre of distilled water. This was distributed into 5 MacCarthy bottles with durham tubes inside. They were sterilized by autoclaving at 121°C for 15 min. The caps of the 5 bottles were removed one at a time. With a sterile pipette, 10 ml of sample was put into each of the bottles. The screw caps on each bottle were replaced immediately after sample addition. The durham tubes were inverted a few times to thoroughly mix the sample with the nutrient medium. After the last inversion, it was ensured that the durham tubes were upright and full of liquid with no air bubbles. The bottles were kept upright (caps up with the durham tubes inverted) for the rest of the procedure. The bottles were incubated at a temperature of 44 ± 0.25°C. After 1 hour, the durham tubes were examined for trapped air, then incubated further. At the end of 24 ± 2 h, each tube was tapped gently and examined for gas. If the colour of the broth changed from pink to yellow and the durham tubes contained gas bubbles, then coliform bacteria were presumed to be present. If no gas was present, the tubes were returned to the incubator and examined again after 48 ± 2 hours. Formation of gas in any amount constituted a positive test, while its absence constituted a negative test. If gas appeared before 24 hour had elapsed, a confirmed test bottle was inoculated without waiting for the entire 48 hour. Two (2%) of Brilliant Green Lactose Bile Broth was pipetted into each of the MacCarthy bottles for the confirmed test. From each positive presumptive bottle, 5 separate bottles for the confirmed test were inoculated, using a flame-sterilized nichrome wire loop. One loop full from a positive presumptive bottle was transferred to a confirmed test bottle, making sure not to touch the rim of each bottle. Each bottle for the confirmed test was inspected to be certain air was not trapped in the durham tubes. The confirmed tubes were placed upright in the incubator at a temperature of 44 ± 3°C. After 1 h, the tubes were examined for trapped air in the durham tubes, and incubated further. At the end of 24 ± 2 h, the bottles were checked for gas formation. The confirmed test bottles which contained gas in the durham tubes were positive for coliform. Tubes which did not contain gas were returned to the incubator and examined after 48 ± 3 hours. Absence of gas at the end of that period constituted a negative test. Gas present in any amount constituted a positive test.

Fifteen gram (15 g) of peptone water was put into 1 litre of distilled water, soaked for 10 min, swirled to mix, and distributed into 5 MacCarthy bottles. The bottles were sterilized by autoclaving at 100-120°C for 15 min. From each confirmed bottle, 5 completed test bottles were inoculated, using a flame-sterilized nichrome wire loop. One loop full from a positive confirmed bottle was transferred to a completed test bottle, making sure not to touch the side of the bottle. The bottles were incubated at 44 ± 3°C in an incubator for 48 ± 3 h. After this period, the bottles were removed, and Kovac'sIndole reagent was poured into each of the 5 bottles. The formation of a brown ring at the top of medium in each bottle indicated a positive test for *E. coli.*

3.5. Data analysis

The data were entered in Microsoft Excel programme and descriptive statistics were computed. Statistical tests were performed using SPSS programme. The Pearson product-moment correlation coefficients for candidate chemical parameters with bacteriological quality parameters; the sanitary risk score and the median counts of total coliforms, faecal coliforms and *E coli* were computed. The bacteriological counts recorded were compared with the WHO guidelines for drinking water.

3.6. Statistical Analysis

The data was analysed using GenStat and Excel. Data was analysed using completely randomized design. The mean content of the different bacteriological and physico-chemical parameters in each source of water was computed with corresponding ANOVA and least significant differences (LSD) value at 5% degree of confidence using GENSTAT. Results were mainly presented in cross–tabulations. To establish whether the mean content of a parameter was the same or not in all the sources of water, the corresponding value of Fpr in the ANOVA table was compared with an $\alpha = 0.05$ (the probability of saying the mean content of a parameter was the same in all the sources of water when in actual fact it was not). Also, to be able to establish which sources of water had their mean bacteriological and physico-chemical components being significantly different from one another; pair wise mean differences were compared with the corresponding LSD value. Conclusion was drawn on the following basis. When $Fpr < 0.05$, it was concluded that the mean content of a bacteriological or physicochemical component was not the same in all the different sources of water.

When the absolute difference of two means was greater than the corresponding LSD value, it was concluded that the mean content of the bacteriological or physico-chemical parameter in the corresponding two sources of water was significantly different from each other.

CHAPTER FOUR

RESULTS

This chapter looks at presentation of the results and discussion. It included observations made on site, the physical, chemical and microbiological parameters. The results of wet and dry seasons were compared. Data have been presented in the form of tables and figures. The characteristics of sampled well in the study area have been presented in Table 3. It can be seen from Table 2 that half (50%) of the sanitation systems were pour flush latrine which uses minimum amount of water. Other sanitation systems were VIP latrine (40%) and traditional pit (10%). These on-site sanitation systems leach contaminants into groundwater. Table 3 also shows that the distance between 6 of the hand dug wells and latrines were from 5 up to 10 metres. The other four were at a distance of 10 up to 15 metres between the latrine and well.

Table 3: Characteristics of sampled Hand dug wells

Code	Distance to pit latrine (m)	Latrine Type
PHDW 1	10.15	VIP
PHDW 2	6.14	VIP
PHDW 3	9.00	VIP
PHDW 4	14.70	Pour flush
PHDW 5	7.40	Pour flush
PHDW 6	12.76	Pour flush
PHDW 7	8.40	Traditional pit
PHDW 8	9.70	VIP
PHDW 9	5. 0	Pour flush
PHDW 10	13.90	Pour flush

4.2. Sanitary survey results

Table 4 presents the qualitative risk profile of the five zones. This covers all the 10 Private Hand Dug Wells (PHDWs) studied.

Table 4: Qualitative sanitary risk profile of the five zones in the Kintampo town

Location	Code of sampling point	Risk observed	Percent risk score	Qualitative risk profile
Mo line	PHDW 1	1,3,4,6,10	50	Medium
	PHDW 2	1,2,3,5,6,7,,9,10	80	Very High
Kyeremankoma	PHDW 3	1,2,3,4,5,,7,,9,10	70	High
	PHDW 4	1,2,5,6,7,9,10	70	High
Sunkwa	PHDW 5	1,2,3,5,6,7,9,10	80	Very High
	PHDW 6	1,5,10	30	Low
Nwoase	PHDW 7	1,5,9	30	Low
	PHDW 8	1,2,3,4,5,6,9,10	80	Very High
Dwenewoho	PHDW 9	1,6,9,10	40	Medium
	PHDW 10	1,6,9,10	40	Medium
Bore hole	C110	N/A	N/A	N/A
Public stand pipe	SP01	N/A	N/A	N/A

Key to risks observed: 1 = Latrine within 20m of well ; 2 = Latrine uphill of well; 3 = Other sources of pollution within 10m; 4 = Drainage faulty allowing ponding within 2m; 5 = Drainage channel cracked, broken or need cleaning; 6 = Head works missing or faulty; 7 = Cement less than 1m in radius around the top of well; 8 = Split water collects in the apron area; 9 = Cracks in the concrete apron; 10 = Hand pulley loose at the point of attachment

The results of the sanitary survey indicated that most of the PHDWs were at risk of contamination with bacterial or faecal organisms. The qualitative aggregate risk score varied from low through medium to very high. Thirty percent (30%) of the PHDWs had a very high risk score (80% and above), while 30% had a medium risk score (31–50%). None of the PHDWs had a risk score of zero. The common risks identified were: distance between latrine and well less than 20m; cracks in concrete apron;

fetching rope exposed to the ground; and fetching container placed anyhow. Pictures of some of the sampled wells have been presented in Appendix A

4.3. Bacteriological parameters

The quantitative bacteriological analysis of the 12 water samples for the dry season (Feb/March) and that of the wet (April/May) has been presented in Table 5 and Table 6 respectively.

Table 5: The quantitative bacteriological analysis of the 12 water samples for the dry season (Feb/March)

Parameter Feb/March	WHO	PHDW1	PHDW2	PHDW3	PHDW4	PHDW5	PHDW6	PHDW7	PHDW8	PHDW9	PHDW10	SP1	C1
Total coliform (MPN/100 (n=2)	0	9.2	5.9	5.9	16	16	0	16	16	16	16	0	0
Faecal coliform (MPN/100	0	0	0	0	0	0	0	0	0	0	0	0	0
E. coli (MPN/100	0	0	0	0	0	0	0	0	0	0	0	0	0

The quantitative aspect of bacteriological analysis for the dry season (Feb/March) presented in Table 5 indicated that nine (9) out of the 10 samples were positive to Total coliform count in the laboratory. The only Private Hand dug well (PHDW) with negative Total coliform count was PHDW6. The two control samples from the public stand pipe (SP1) and bore-hole (C1) showed negative total coliform result. The total coliform count of the PHDWs varied from 0 MPN/100 to 18MPN/100. However, all of the 10 samples from the PHDWs together with the public stand pipe and borehole gave negative results for both faecal coliform and *E. coli* with respect to the dry seasons (February/March).

Table 6: The mean quantitative aspect of bacteriological analysis of all the 12 samples during the wet season

Parameter April /May	WHO	PHDW1	PHDW2	PHDW3	PHDW4	PHDW5	PHDW6	PHDW7	PHDW8	PHDW9	PHDW10	SP1	C1
Total coliform (MPN/100 ml)	0	14	9.2	18	5.1	18	0	16	16	9.2	16	0	0
Faecal coliform	0	0	0	0	0	0	0	0	0	0	0	0	0
E. Coli (MPN/100 ml)	0	0	0	0	0	0	0	0	0	0	0	0	0

Again, the mean quantitative results of bacteriological analysis for the wet season as presented in Table 5 indicated that all the samples from the PHDWs except PHDW6 were positive to Total coliform count. The total coliform count varied from 0 MPN/100 to 18MPN/100. And like the results of the dry season, all of the 10 samples from the PHDWs together with the public stand pipe and borehole gave negative results for both faecal coliform and *E. coli* in the wet season (April/May). It can be deduced from these results that the levels of the Total coliform (for most (90%) of the PHDWs exceeded the WHO contaminant level of 0 MPN/100 ml. However, the levels of both faecal contamination and *E. coli* values did not exceed the WHO (2006) guidelines of 0 MPN per 100 ml of sample which means that the PHDWs water was not faecal contaminated.

4.3.1 Seasonal Variation in Total Coliform count of the Private Hand Dug Wells

It can be seen from Figure 2 that apart from PHDW6, all the PHDWs had total coliform counts ranging from 5.9 MPN/100ml to 18 MPN/100ml in both the dry and wet seasons. In four out of 10 PHDWs the Total coliform counts for the dry season were higher than those of the wet season. On the other hand in two out of 10 PHDWs, the Total coliform counts for the wet season were higher than those of the dry season. And in three out of 10 PHDWs the Total coliform counts for the dry season were the same as those of the wet season.

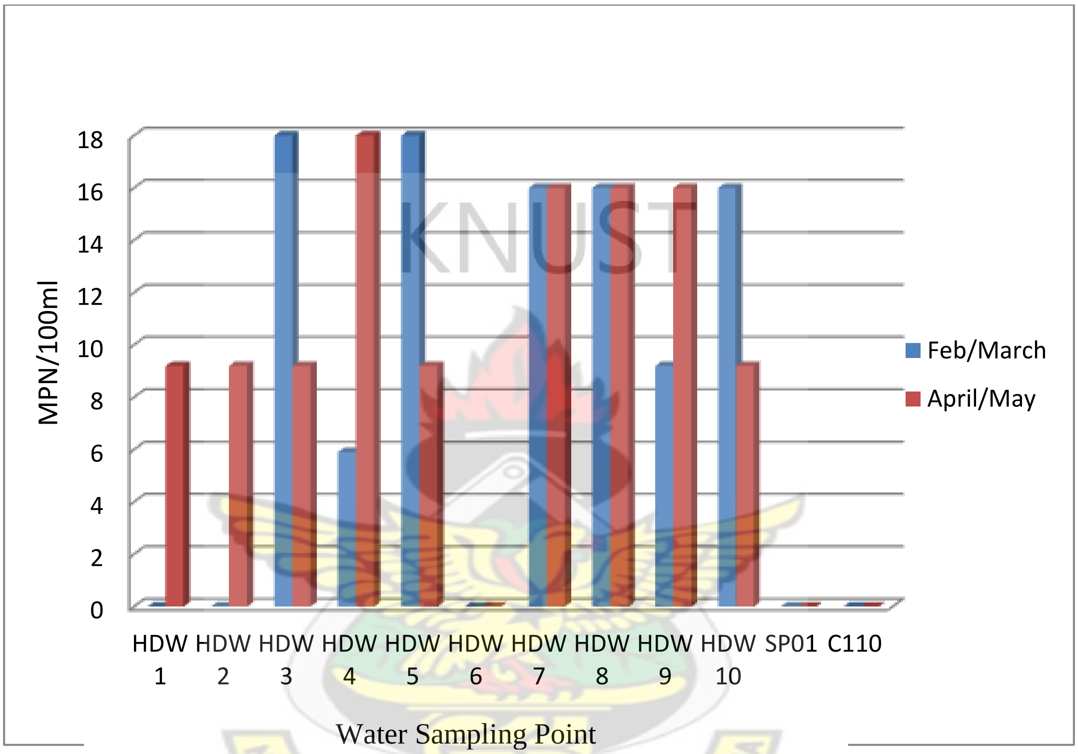

Figure 2: Seasonal variation in Total Coliform counts of the Private Hand Dug Wells at Kintampo Town

4.4. Physico-chemical parameters

4.4.1 Comparing the physico-chemical parameters of water samples to WHO standards

Table7: Comparison of physico-chemical parameter of hand-dug well water quality with WHO drinking water guidelines

Parameter	Mean ± SD	WHO Permissible Level
Temperature (^{o} C)	27.43 ± 0.26	-
Colour	4.90 ± 1.13	0-15
Turbidity (NTU)	2.60 ± 0.93	5
Conductivity (µS /cm)	327.90 ± 167.20	-
Total Dissolved Solid (mg/l)	164.10 ± 83.77	1000
Alkalinity (mg/l CaCO3)	28.83 ± 5.03	-
Dissolved Oxygen (mg/l)	4.36 ± 0.50	-
Chloride (mg/l)	90.65 ± 47.48	250
Total Hardness (mg/l)	103.60 ± 35.15	500
Calcium Hardness (mg/l $CaCO_3$)	97.70 ± 34.05	-
Nitrite (mg/l)	0.77 ± 0.16	3
Nitrate (mg/l)	11.42 ± 4.86	50
Phosphate (mg/l)	0.02 ± 0.03	0.3
Sulphate (mg/l)	6.75 ± 15.46	400
Iron Total (mg/l)	0.15 ± 0.03	0.3
Fluoride (mg/l)	0.21 ± 0.20	1.5
Ammonia (mg/l)	0.25 ± 0.21	1.5
pH	6.55 ± 0.12	6.5-8.5

Table 7 shows that none of the physico-chemical parameters were above the WHO (2006) permissible values. The mean Colour level was 4.90 ± 1.13 which is far below the WHO permissible values of 0-15. Again, the mean Turbidity (NTU) level was 2.60 ± 0.93 whiles the WHO permissible value is 5. And for Total Dissolved Solid (mg/l) the mean level was 164.10 ± 83.77 whereas the WHO permissible value is 1000. Similar lower mean levels were obtained for Chloride (mg/l) –value: 90.65 ± 47.48, WHO permissible value: 250; for Nitrite (mg/l) with value of 0.77 ± 0.16, the

WHO permissible value is 3 and the Nitrate (mg/l) level of 11.42 ± 4.86 has WHO permissible value: 50; for Fluoride (mg/l) with level of 0.21 ± 0.20 has WHO permissible value of 1.5. Furthermore the mean level for Iron Total (mg/l) was 0.15 ± 0.03 and it's WHO permissible values are 0.3.

It can be seen from Table 8 that the physico-chemical parameters showing significant seasonal variations were: Temperature (^{o} C) with mean value in the dry season as 28.00 ± 0.45 and for the wet season as 26.90 ± 0.20 and a p-value of 0.0001; Colour had mean value in the dry season as 3.33 ± 0.89 and for the wet season as 6.25 ± 1.27 and the p-value was 0.0001.

Similarly the mean values for Alkalinity (mg/l CaCO3) in the dry and wet seasons were 44.88 ± 48.18 and 48.71± 48.66 with a p-value of 0.0001. Nitrite (mg/l) has mean value in the dry season as 0.83 ± 0.17 and for the wet season as 0.74±0.14 and a p-value of 0.001. Nitrate (mg/l) also has mean value in the dry season as 14.34 ± 6.69 and for the wet season as 9.82 ± 3.90 and a p-value of 0.0197. Again, the mean value for Dissolved Oxygen (mg/l)in the dry season was 4.11 ± 0.57 and for the wet season was 4.42 ± 0.46 with a p-value of 0.0001. Others were: Total Hardness- mean value (mg/l) in the dry season was 109.70 ± 36.14 and for the wet season was 103.40 ± 32.16 with a p-value of 0.003. The mean value for Fluoride (mg/l) in the dry season was 0.35 ± 0.32 and for the wet season was 0.25 ± 0.24 with a p-value of 0.0053. Finally the pH mean value in the dry season was 6.34 ± 0.24 and for the wet season was 6.71 ± 0.20 and the p-value was 0.0001.

On the other hand the p-values of the following physico-chemical parameter showed that they were not of significance when the dry and wet seasons were compared. Ammonia (p- value = 0.0487); Iron Total (p- value = 0.1275); Sulphate (p- value =

0.2404); Phosphate (p- value 1); Calcium Hardness (p- value = 0.048); Total Dissolved Solid (p- value = 0.427); Conductivity (p- value = 0.3768); and Turbidity (p- value = 0.3677).

Table 8: Seasonal variations of physic-chemical parameters of the water samples

Parameter	Season Dry Feb/Mar	Wet Apr/May	P – Value
Temperature (^{o} C)	28.00 ± 0.45	26.90 ± 0.20	0.0001
Colour	3.33 ± 0.89	6.25 ± 1.27	0.0001
Turbidity (NTU)	2.29 ± 1.58	2.72 ± 0.55	0.3677
Conductivity (µS /cm)	309.20 ± 162.90	307.30 ± 161.70	0.3768
Total Dissolved Solid (mg/l)	154.60 ± 81.86	153.70 ± 80.85	0.427
Alkalinity (mg/l CaCO3)	44.88 ± 48.18	48.71 ± 48.66	0.0001
Dissolved Oxygen (mg/l)	4.11 ± 0.57	4.42 ± 0.46	0.0001
Chloride (mg/l)	86.50 ± 46.29	83.92 ± 45.68	0.005
Total Hardness (mg/l)	109.70 ± 36.14	103.40 ± 32.16	0.003
Calcium Hardness (mg/l $CaCO_3$)	103.50 ± 35.24	98.08 ± 31.48	0.048
Nitrite (mg/l)	0.83 ± 0.17	0.74 ± 0.14	0.001
Nitrate (mg/l)	14.34 ± 6.69	9.82 ± 3.90	0.0197
Phosphate (mg/l)	0.01 ± 0.03	0.01 ± 0.03	1
Sulphate (mg/l)	6.79 ± 17.01	4.75 ± 11.35	0.2404
Iron Total (mg/l)	0.17 ± 0.06	0.13 ± 0.04	0.1275
Fluoride (mg/l)	0.35 ± 0.32	0.25 ± 0.24	0.0053
Ammonia (mg/l)	0.32 ± 0.26	0.25 ± 0.18	0.0487
pH	6.34 ± 0.24	6.71 ± 0.20	0.0001

Data is presented in Mean with Standard Deviation, P – value < 0.05 is considered to be statistically significant.

4.4.2 Comparison of physical characteristics of Private Hand Dug Well to the public water supply C110 and SP01

It can be seen in Figure 3 that the only physical characteristic of the water samples that showed marked different between the control(borehole and the public stand) and the private hand dug well (PHDW) was conductivity. However other physical parameters such as temperature colour and turbidity of PHDWs did not show any marked difference.

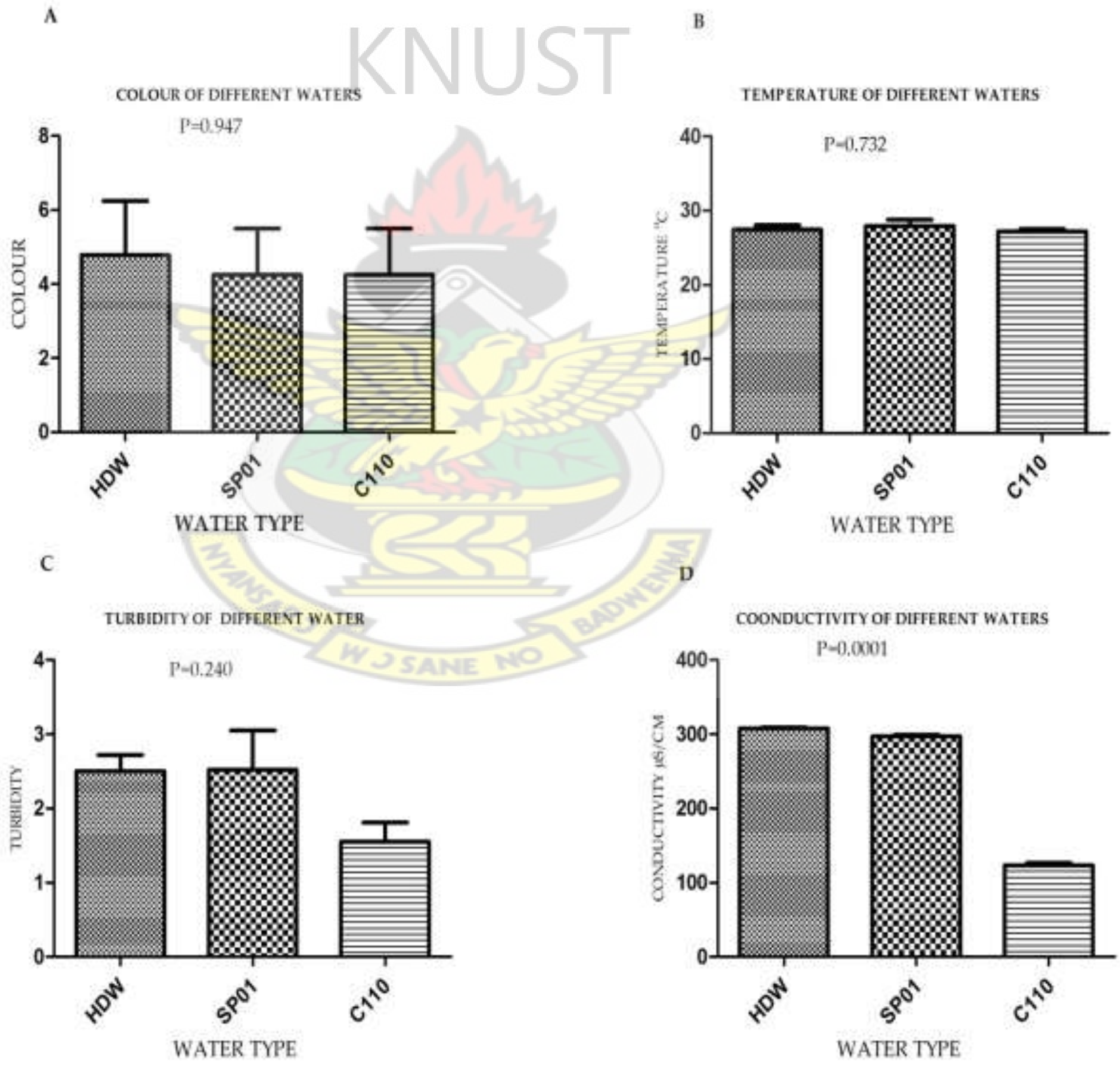

Figure 3: Comparison of physical parameters of PHDW, SP01 AND C110

4.4.3 Comparison of the chemical characteristics of PHDW to the public water supply (SP01and C110)

Figure 4 shows that the level of total dissolved solids was almost the same for the PHDWs and SP01 but that of C110 was lower. Similar pattern can be seen in the chloride content. In parameters such as alkalinity, total hardness and calcium hardness, the levels of SP01 were higher than those of PHDWs and C110. And such pattern is more pronounced in alkalinity levels. With regards to dissolved oxygen, the levels of the PHDWs, SP01 and C110 were of gradually descending order. An opposite ascending order was depicted in the levels of nitrate content of the three waters. The nitrite levels in all (PHDW, SP01 and C110) were almost the same.

Figure 4 also shows that some of the chemical parameters of the private hand dug wells (PHDWs) were different from the public water supply (stand pipe-SP01 and the bore hole -C110), whiles other parameters of the PHDWs were not. The chemical parameters that did not show much difference in the pattern included: dissolved oxygen, nitrite and nitrate. Other chemical parameters namely: Total dissolved solids, Alkalinity, Chloride content, Total hardness, and Calcium hardness showed much difference in the pattern.

Figure 5 show that there were various variations with respect to other chemical parameters of the different water types (PHDWs, SP01 and C110) that were assessed. The level of fluoride content was almost the same for the C110 and SP01 but that of PHDWs was lower. On the other hand the level of total iron content was almost the same for the C110 and PHDW but that of SP01 was higher. The level of phosphate for both the SP01 and C110 were zero. And for sulphate content the level of SP01 was zero, and that of the PHDW was higher than that of C110. With regards to ammonia content, the levels of the PHDWs, SP01 and C110 were of gradually ascending order. The pH levels in all (PHDW, SP01 and C110) were almost the same except that of PHDWs were a little lower.

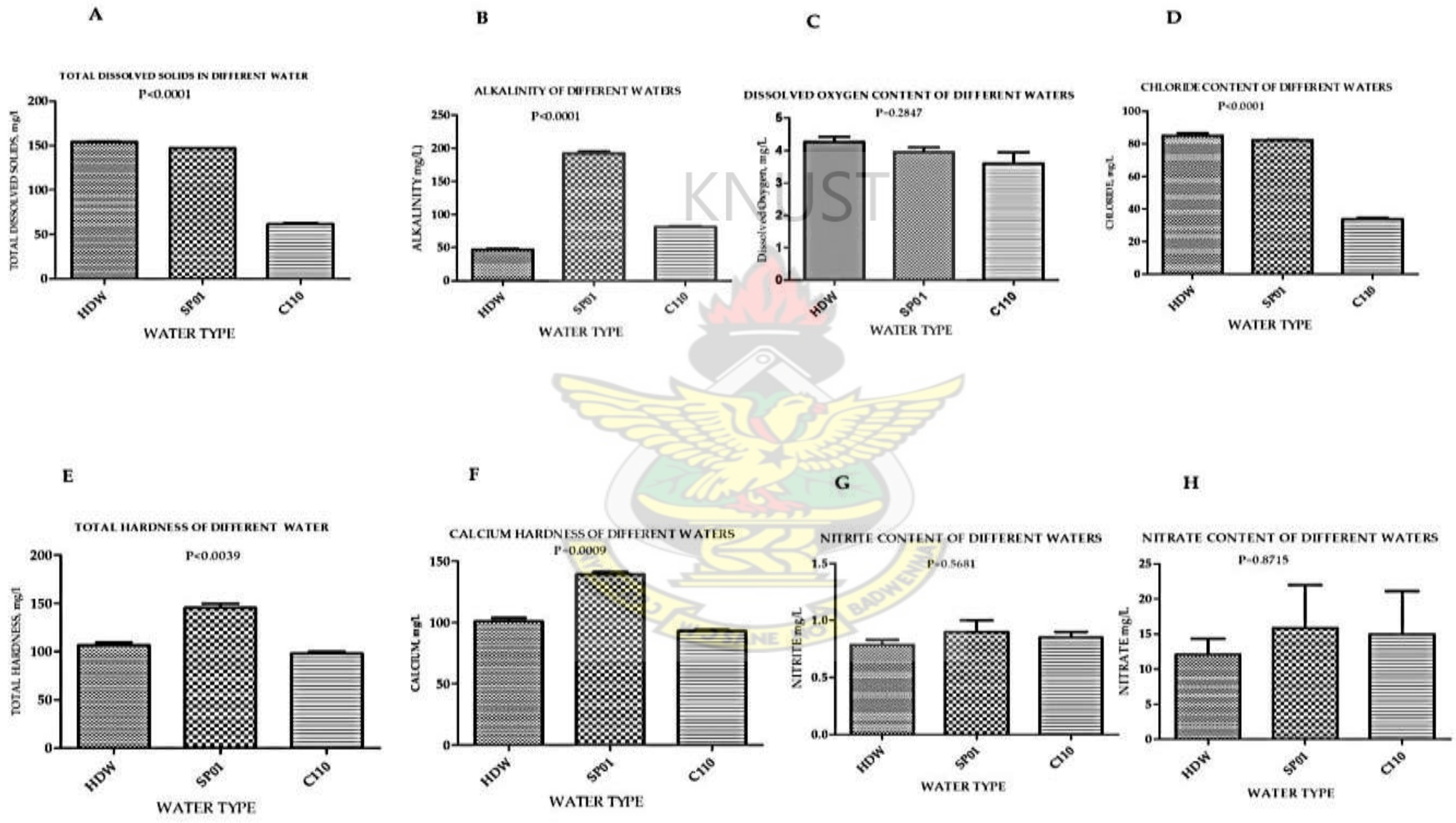

Figure 4: Comparison of chemical parameters of PHDW, SP01 AND C110

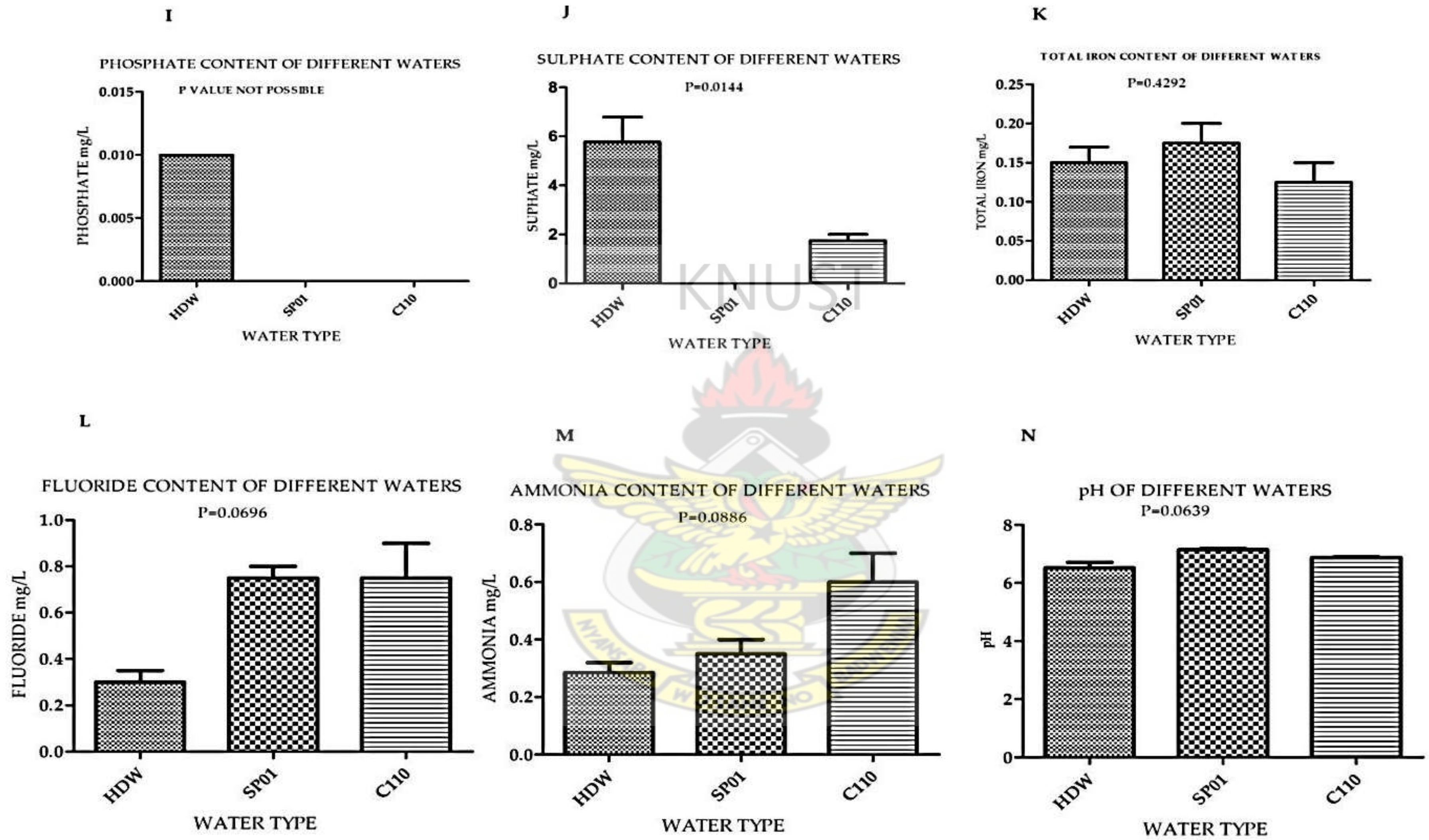

Figure 5: Comparison of other chemical parameters of PHDW, SP01 AND C110

4.4 Seasonal Variation of physicochemical parameters of Hand Dug Wells measured at two separate distances (5 up to 10 meters and 10 up to 15 meters from latrine

Table 9: Comparison of Seasonal Variation of physico-chemical parameters of Hand Dug Wells located within 5 up to 10 metres and 10 up to15 metres from Latrine Sites

Parameter	Season	Distance from Latrine (d)	
		5 up to 10 Metres	**10 up to 15 Metres**
Temperature (^oC)	Dry	28.03 ± 0.45	27.89 ± 0.33
	Rainy	26.88 ± 0.21 (P = 0.0002)	26.88 ± 0.23 (P=0.003)
Colour	Dry	3.83 ± 0.75	2.75 ± 0.96
	Rainy	6.92 ± 1.20 (P=0.003)	5.63 ± 1.32 (P=0.012)
Turbidity (NTU)	Dry	3.12 ± 1.94	1.38 ± 0.26
	Rainy	2.93 ± 0.53 (P=0.828)	2.54 ± 0.43 (P=0.003)
Conductivity (μS /cm)	Dry	356.80 ± 196.10	287.00 ± 129.90
	Rainy	355.20 ± 192.90 (P=0.989)	284.40 ± 129.80 (P=0.978)
Total Dissolved Solid (mg/l)	Dry	183.70 ± 98.53	135.90 ± 58.50
	Rainy	180.80 ± 97.75 (P=0.960)	138.00 ± 57.60 (P=0.960)
Alkalinity (mg/l CaCO3)	Dry	24.92 ± 4.20	30.00 ± 4.42
	Rainy	28.58 ± 4.16 (P=0.160)	33.88 ± 5.89 (P=0.333)
Dissolved Oxygen (mg/l)	Dry	4.15 ± 0.60	4.35 ± 0.49
	Rainy	4.43 ± 0.47 (P=0.396)	4.60 ± 0.50 (P= 0.501)
Chloride (mg/l)	Dry	102.80 ± 55.92	76.00 ± 32.52
	Rainy	98.92 ± 55.97 (P=0.906)	74.31 ± 31.62 (P=0.954)
Total Hardness (mg/l)	Dry	108.80 ± 37.34	103.50 ± 43.06
	Rainy	102.40 ± 31.24 (P=0.753)	97.38 ± 40.34 (P=0.842)
Calcium Hardness (mg/l)	Dry	103.00 ± 35.80	97.13 ± 43.16
	Rainy	95.42 ± 29.31 (P=0.697)	93.75 ± 40.25 (P=0.913)
Nitrite (mg/l)	Dry	0.75 ± 0.15	0.88 ± 0.21
	Rainy	0.69 ± 0.12 (P=0.471)	0.79 ± 0.19 (P=0.558)
Nitrate (mg/l)	Dry	11.17 ± 5.34	15.51 ± 7.74
	Rainy	8.68 ± 0.63 (P=0.283)	11.81 ± 6.85 (P=0.502)
Phosphate (mg/l)	Dry	0.08 ± 0.04	0.00±0.00
	Rainy	0.05 ± 0.08 (P=0.698)	0.00±0.00
Sulphate (mg/l)	Dry	11.50 ± 23.83	2.75 ± 4.86
	Rainy	7.83 ± 15.83 (P=0.760)	2.00 ± 4.00 (P=0.820)
Total Iron (mg/l)	Dry	0.19 ± 0.08	0.15 ± 0.04
	Rainy	0.14 ± 0.05 (P=0.255)	0.12 ± 0.054 (P=0.468)
Fluorine (mg/l)	Dry	0.30 ± 0.24	0.19 ± 0.28
	Rainy	0.18 ± 0.15 (P=0.329)	0.14 ± 0.19 (P=0.779)
Ammonia (mg/l)	Dry	0.20 ± 0.23	0.38 ± 0.28
	Rainy	0.17 ± 0.16 (P=0.352)	0.31 ± 0.18 (P=0.683)
pH	Dry	6.40 ± 0.11	6.52 ± 0.12
	Rainy	6.60 ± 0.09 (P=0.007)	6.70 ± 0.14 (P=0.107)

Table 9 shows that seasonal variation of temperature of Hand Dug Wells measured at the two distances from Latrine that is from 5 metres up to 10 metres and from 10 up to 15 metres were significant different in both dry and rainy seasons. The p – value = 0.0002 for dry season and at a distance of 5 up to 10 metres from latrine; and for wet season the P=0.003 at the distance of 10 up to 15 metres. Other parameters where seasonal variations of Hand Dug Wells measured at the two distances from Latrine that is from 5 meters up to 10 metres and from 10 up to 15 metres that showed significant difference included: Colour (P=0.003) and (P=0.012) for dry and rainy seasons, respectively.

The following seasonal variations of physico-chemical parameters of Hand Dug Wells measured at the two distances from Latrine that is from 5 meters up to 10 metres and from 10 up to 15 meters were not significant in both locations: Conductivity (P=0.989) and (P=0.978); Total Dissolved Solid (P=0.960); Alkalinity (P=0.160) and (P=0.333); Dissolved Oxygen (P=0.396) and (P= 0.501); Chloride (P=0.906) and (P=0.954); Total Hardness (P=0.753) and (P=0.842) ; Calcium Hardness (P=0.697) and (P=0.913); Nitrite (P=0.471) and (P=0.558) for dry and rainy seasons respectively.

CHAPTER FIVE

5.0 DISCUSSION

5.1 Sanitary survey around the Private Hand Dug Wells (PHDWs)

The results of the sanitary survey, from Table 3, indicated that most of the PHDWs were at risk of contamination with bacterial or faecal organisms. The qualitative aggregate risk score varied from low through medium to very high. Thirty percent (30%) of the PHDWs had a very high risk score (80% and above), while 30% had a medium risk score (31–50%). None of the PHDWs had a risk score of nil (0%). The common risks identified were: lateral distances between latrine and PHDWs less than 20m; cracks in the concrete apron and hand pulley loose at the point of attachment. This agrees with Appiah and Momende (2010) who studied the quality of drinking water in Kintampo in which they indicated that there were general insanitary conditions around most of the hand dug wells. They concluded that dilapidated structures like broken parapet walls, lack of aprons and channels to carry waste water from the surroundings of the hand-dug wells made it possible for their water to be contaminated.

5.2 Microbiological Quality of Water Samples

The WHO recommends that, for water to be considered no risk to human health, the total coliform bacteria, faecal coliform and *E. coli* in water sample should be zero (WHO, 2008). In this study the Total coliform bacteria count of the water samples from all the PHDWs except one was positive. The values ranged from 5.1 to 18 MPN/100 ml. The possible reason may come from the fact the results of the sanitary survey; where it was observed that most of the PHDWs were at risk of contamination with bacterial or faecal organisms. However, the values of Faecal coliform and *E. coli* were 0 MPN/100 ml for all the water samples. This results conform to the WHO and Ghana Standard Board guideline value of 0 MPN/100 ml.

However, the result of this study is at variance with the earlier findings from Appiah, and Momende (2010), in which they reported that all the hand-dug wells they studied in Kintampo were contaminated by faecal coliform. This difference mighty comes from the fact that the current studies took samples from PHDWs in houses where most of the floor of the house were made of concrete, thus there is minimum leaching of water to the well. In Appiah and Momende (2010) studies, they indicated that there were leakages of contaminated water to the well.

The results also disagreed with Nkansah *et al.*, (2010), who assessed quality of water from Hand-Dug Wells in Ghana. They found out that Total coliform and *Escherichia coli* were below the minimum detection limit (MDL) of 20 MPN per 100 ml in all the samples.

The results agreed with most of the literature (Odai and Dugbantey, 2003) with the assertion that proximity in terms of lateral distance of site of hand dug wells to pollution source; in this case, the pit latrine may not necessarily pose a risk of contamination. The findings however disagreed with ARGOSS (2001) that maintains that increased lateral separation between pollution source and groundwater supply reduces the risk of faecal pollution. Appiah and Momende (2010), stated that poorly made concrete apron and water run-off into crack will allow leakage of waste water from the surface back into the well to contaminate it may be able to be associated with this finding. Buckets and ropes which are used to draw the water, often lie around the unhygienic rim of the well may contaminate the water (Appiah and Momende, 2010).

5.3 Comparison of physic-chemical parameters of hand – dug well water quality with WHO drinking water guidelines.

It can be seen from Table 6 that none of the physico-chemical parameters of all the PHDWs and the public water supply were above the WHO permissible values of (2008).The study agrees with Appiah and Momende (2010),who reported that the colour ,turbidity and conductivity of wells in Kintampo were below the WHO permissible values. Appiah and Momende (2010), had values between 3.7 and 6.3 colour units for colour, turbidity range of 0.4 to 23.5 NTU; conductivity range of between 420 µS/cm to 5180 µS/cm with a mean of 1737.1 µS/cm. Whereas this study reported a mean temperature of 27.43 ± 0.26,Appiah and Momende (2010) reported that a higher temperature of 28.5 °C for the water of hand-dug well W1 and a minimum temperature of 26.2 °C for W 25 in 30 hand dug wells they studied in Kintampo. The results of these two studies were similar perhaps due to the fact that water samples were taken from the same study area.

Furthermore, this study reported a mean pH value of 6.55 ± 0.12. Appiah and Momende (2010) reported that all the hand-dug wells they studied in Kintampo had pH values of 5.5 to 6.5.The findings of these two results were all with the WHO/GSB permissible value and the results are similar since the water samples were taken from the same community and hence have similar environmental conditions. In a separate study by Darko-Mantey *et al.,* (2005), on drinking water from different sources, they observed a pH range of 6.1 to 7.2. Darko-Mantey *et al.*, (2005).The findings of these authors were slightly different from the findings of this study due to the fact that the samples were from different communities where different environmental conditions pertain.

5.4 Comparison of physical characteristics of HDW, SP01 AND C110

Figure 3 shows that turbidity and conductivity were different from that of samples of the PHDWs and the public water supply. Whereas turbidity and conductivity were similar for the PHDWs and borehole (C110) that of the public stand pipe was lesser. This may be due to the fact that the water from the Pipe stand has gone through some level of treatment such as aeration to reduce iron levels Furthermore, it is only the conductivity that is of significant difference (p-value of 0.0001) when the PHDWs SP01 and C110 were compared.

Changes in the physico-chemical parameters such as: temperature, and for other parameters like colour, alkalinity, nitrite, nitrate, and dissolved oxygen occurred due to infiltration of runoffs into the wells. In some wells, particularly drive-point wells or other shallow wells, nitrate may only be present during the spring or after a heavy rainfall when rapid infiltration of surface water occurs. Because nitrate can move rapidly down through the soil into the groundwater, the presence of nitrate may provide an early warning of possible problems and can sometimes indicate the presence of other contaminants (Minnesota Department of Health, 2010).

5.5 Comparison of chemical characteristics of PHDW, SP01 AND C110

Figure 4 shows that there were various variations with respect to the chemical parameters of the different waters assessed, that is the private hand dug wells (PHDWs), the public stand pipe SP01 and the bore hole C110. For instance, the level of total iron content was almost the same for the C110 and PHDW but that of SP01 was higher. And there was no significant difference in the total iron content level (p= 0.4292). This agreed with the fact that consumers who patronize the public pipe stand complain about high iron content (Appiah and Momende, 2010). And for sulphate content the level of SP01 was zero, and that of the PHDW was higher than that of

C110 and the difference was significant (p=0.0144). With regards to ammonia content, the levels of the PHDWs, SP01 and C110 were of gradually ascending order. However, this difference was not significant (p=0.0886) when the water from the public water supply were compared with water from the PHDWs.

5.6 Seasonal Variation of Water Quality parameters of Hand Dug Wells located within 5 to 15 meters from Latrine Sites

Table 8 shows that seasonal variation of temperature of Hand Dug Wells measured at the two distances from Latrine that is from 5 metres up to 10 metres and from 10 up to 15 metres were significant in both dry and rainy season. This reason is obvious; in the dry season temperature is higher than the rainy season. Appiah and Momende (2010) recorded similar seasonal changes in temperature of water samples in Kintampo. Another parameter where seasonal variations of Hand Dug Wells measured at the two distances from Latrine that from 5 meters up to 10 metres and from 10 up to 15 meters showed significant difference is colour. This may be due to infiltration of run off during the rainy season. This study agrees with Odai and Dugbantey (2003).

CHAPTER SIX

CONCLUSION AND RECOMMENDATION

6.1 Conclusion

The study sought to investigate the physical, chemical, and bacteriological quality of Private hand dug wells sited close to pit latrines at Kintampo, and whether they meet international and local water quality standards set by WHO and GSB, respectively.

The study revealed that most of the PHDWs were at various level of sanitary risk of contamination. The common risks identified were cracks in the concrete apron distance between latrine and well less than 20 m and hand pulley loose at the point of attachment.

The results also showed that all the samples of the PHDWs were positive to Total coliform count. However, sample of the control (the public stand pipe and borehole) showed negative total coliform result. The samples of the PHDWs together with the public stand pipe and borehole indicated negative results for both faecal coliform and *E. coli*. Again, the study revealed that none of the physico-chemical parameters such as pH, temperature, conductivity, total solids (TS), total suspended solids (TSS), total dissolved solids (TDS), turbidity, nitrate (NO_3^-), sulphate (SO_4^{2-}), phosphate (PO_4^{3-}) and dissolved oxygen (DO), of the well waters were above the WHO permissible values. Physico-chemical parameters showing significant seasonal variations were: Temperature, Colour; alkalinity, Nitrite, Nitrate and Dissolved Oxygen. They all have p-values of 0.0001.

6.2 Recommendation

From the analysis, it is recommended that:

- The Kintampo Municipality water and sanitation programme of the Municipal Assembly should encourage house owners with private hand-dug wells to routinely treat their well with chlorine tablets.
- The Kintampo Municipal Water and Sanitation Team should educate owners of private hand-dug wells to keep the head of their wells clean and routinely disinfect the well.
- The Environmental Health unit of the Municipal Assembly should encourage people to approach them for advice on where to site household latrine.
- The Kintampo Water Supply should take steps to reduce the chloride and calcium concentrations in their water since these ions contribute to the taste and hardness in the water.
- The Kintampo Municipality water and sanitation programme of the Municipal Assembly should enforce by laws on the minimum lateral distance of 20 m between a latrine and well water.
- The implementation of regulations on safe drinking water by the Ghana Standards Board, the Ghana EPA and district environmental units and other state enforcements agencies will go a long way to reduce incidences of water pollution and the associated water borne diseases.
- Further research on other communities in the District for the assessment of the quality of drinking water is required as levels of contaminants may vary due to different soil types, water chemistry and different human activities.

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APPENDICES

APPENDIX A

SOME OF THE SAMPLED HAND-DUG WELLS

i) The distance betwwen the well and the latrine is less than 10 meters

ii) The distance betwwen the well and the latrine at the corner is less than 10 metres

iii) The distance betwwen the well and the latrine is less than 10 meters

iv) The distance betwwen the well and the latrine is less than 12 meters

v) **Part of the head works may contaminate the water**

vi) **Items on the head works may contaminate the water**

vii) Exposing fetching bucket may contaminate the water.

viii) Exposing fetching rope on the floor may contaminate the water.

APPENDIX B:

WELLS WITH IMPROVED METHODS OF DRAWING WATER

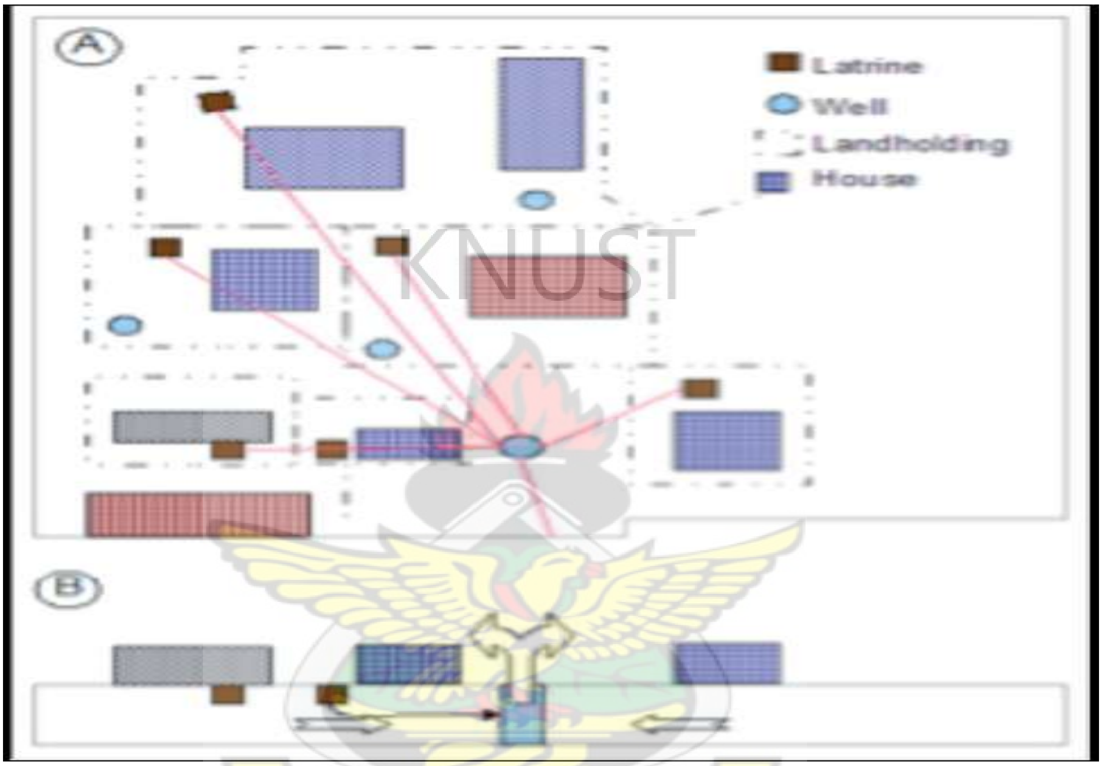
A) SIMPLE HAND PUMPS

B) MOTORIZED PUMP

APPENDIX C

A. **Plan view of a typical setting relevant in the study of health risk assessment of water supplies from OSS, red lines show distance to potential OSS threats for a community well**

B. **Cross-section view of the area through the community water well**



APPENDIX D: KINTAMPO MUNICIPAL MAP

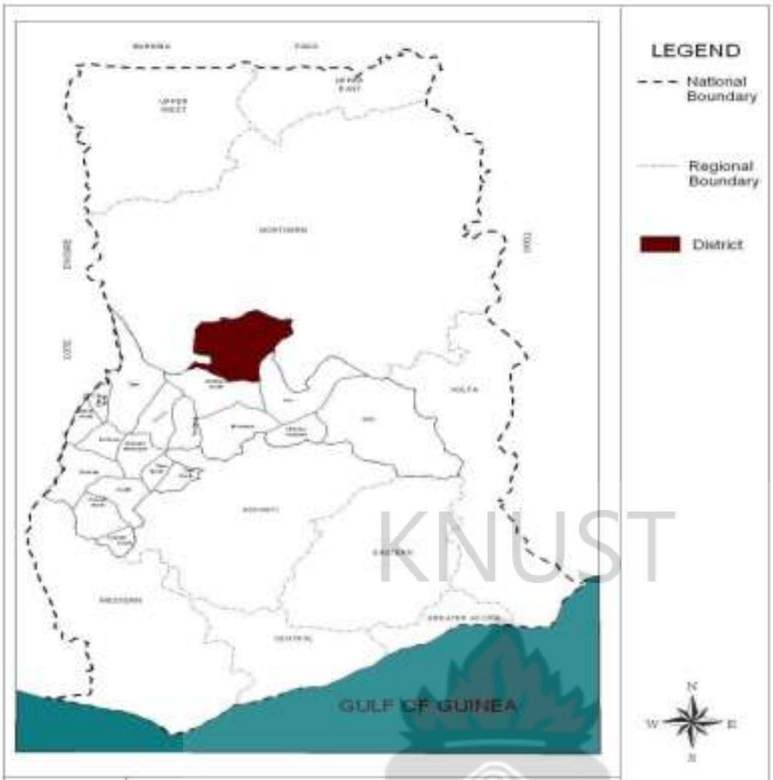
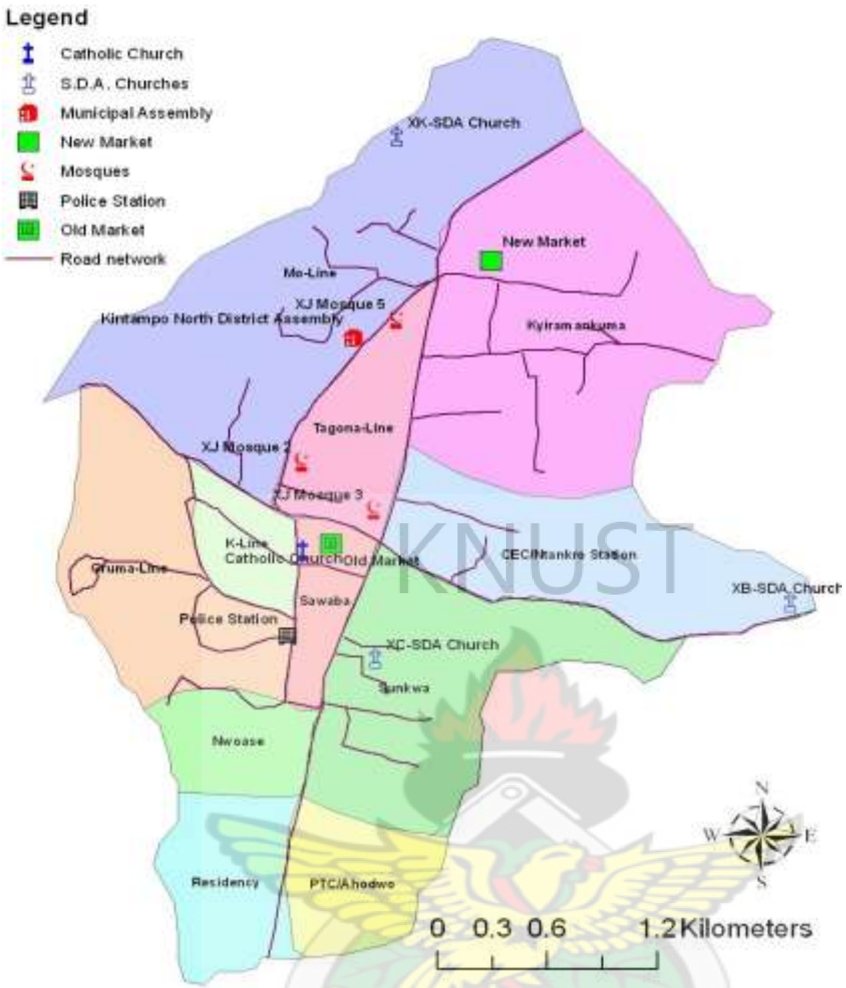


FIG.1.1 **KINTAMPO MUNICIPAL MAP IN NATIONAL AND REGIONAL CONTEXT**

SCALE 1:2000,000

Appendix E: Map of Kintampo town capturing important sites



APPENDIX F

SANITARY INSPECTION FORMAT FOR THE HUND DUG WELLS

(ADOPTED FROM WHO, 2010)

1. General Information of Sampling site:

2. Village/zone:

3. Date of Visit

4. Water sample taken? ……. Sample No. ……… FC/100ml ………..

II Specific diagnostic information for assessment Risk

1. Is there a latrine within …20.m of the well? Y/N

(Please put in distance calculated from the manual)

2. Is the nearest latrine uphill of the well? Y/N

3. Is there any other source of pollution within 10m of well? Y/N

(e.g. animal breeding, cultivation, roads, industry etc)

4. Is the drainage faulty allowing ponding within 2m of the well? Y/N

5. Is the drainage channel cracked, broken or need cleaning? Y/N

6. Is the cement less than 1m in radius around the top of the well? Y/N

7. Does spilt water collect in the apron area?
Y/N

8. Are there cracks in the concrete apron?
Y/N

9. Is the hand pump loose at the point of attachment to well head? Y/N

10. Is the well-cover insanitary? Y/N

Total Score of Risks …./10

Risk score: 9-11 = Very high; 6-8 = High; 3-5 = Medium; 0-3 = Low

III Results and recommendations:

The following important points of risk were noted: (list nos. 1-10)

Signature of Research Team leader:……………….

Comments:…………………………………………