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ON

SPATIAL DISTRIBUTION OF DRINKING WATER QUALITY IN NKAWIE IN THE ATWIMA-NWABIAGYA DISTRICT

BY

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DECLARATION

I hereby declare that except for references made of other people's publications and copyrighted posts, which have been duly acknowledged, this work submitted as a thesis to the Department of Material Engineering, College of Engineering for the degree of Master of Science in Environment Resource Management is the result of my own research and has not been presented anywhere for the award of a degree.

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ABSTRACT

The Nkawie area of the Atwima-Nwabiagya district of the Ashanti Region represents an urban–rural type of mixed settlement with a high prevalence of water borne epidemiological conditions. Access to good quality drinking water is known to be a major factor for such prevalence. Therefore this research sought to highlight the spatial characterization of water quality within Nkawie; using Geographical Information Systems. The spatial analysis of water quality was conducted using laboratory determined magnitudes of parameter values known to affect water quality, followed by Exploratory Spatial Data Analysis (ESDA) and spatial interpolation techniques in GIS resulting in surface generation of water quality (to show its spatial distribution). Spatial interpolation was carried out using Inverse Distance Weighting (IDW) model to generate the water quality map over the study area. Samples from 9 public water sources in the study were collected and analysis was carried out including tests for pH, *E. coli*, Total Coliform, Faecal Coliforms and Salmonella. Drinking Water Quality Index (WQI) was developed using the measured parameter values. Results from the WQI shows that it's only the Asuofia well water that is moderately good for drinking as all the sources show various levels of contamination. The study of spatial analysis and interpretations of water quality demonstrated that the applied GIS methodology is a useful tool in evaluating and describing the spatial distribution of water quality characteristics. The conclusions from this research revealed that more than half of the public drinking water sources were contaminated beyond guidelines recommended by WHO and Ghana Standard Authority. It also revealed compromised water quality, hygiene and sanitation challenges; which have resulted in the district recording high cases of water borne diseases especially diarrhoea even though it has 95% water coverage.

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CHAPTER ONE

1.0 Introduction

Access to adequate clean drinking water is essential for life and a lack of it adversely affects public health (UNICEF/WHO, 2004). Clean, safe and adequate water is vital for the survival of all living things and for the proper functioning of ecosystems, communities and economies. The importance of water as a resource for improving the social well-being of a people and for national development cannot be over emphasised. Thus the quality and quantity of water supplied to communities is crucial in determining health status, standard of living and level of development of the inhabitants (Falkenmark *et al*, 1990).

Declining water quality has become a major global concern as a result of rapid population growth; industrial activities, agricultural expansion and currently climate change, which threatens to cause major changes to hydrological cycles (UNEP, 2009). In response to this, many global initiatives have been launched to draw the world's attention to the need to protect and make water accessible without compromising on its quality. Notably among such initiatives is the International Drinking Water Supply and Sanitation Decade (IDWSSD; 1980-1990) which focused on the need for concerted efforts to accelerate activities to increase global access to safe water supply and sanitation.

The Rio Earth Summit (1992) and the World Summit on Sustainable Development in 2002, placed safe drinking water as a key component of sustainable development. In September 2000, 189 UN member states adopted the Millennium Development Goals

(MDGs) in which target 7, seeks to halve by 2015 the proportion of people without sustainable access to safe drinking-water and basic sanitation (UNJMP, 2008).

From 2002 estimates, one-sixth of humanity (1.1 billion people) lacked access to any form of improved water supply within a kilometre of their homes, and approximately 2.2 million people in developing countries, mostly children, die every year from diseases associated with lack of access to safe drinking water, inadequate sanitation and poor hygiene (WHO and UNICEF, 2004).

Waterborne diseases, such as diarrhoea, cause about 1.5 million deaths a year, especially among children in developing countries (JMP, 2008). Water-related diseases are one of the major health concerns in the world. On a global scale, the diarrhoeal disease is the sixth highest cause of mortality and third in the list of morbidity. It is estimated that 3.7 per cent of the global disease burden is derived from poor water, sanitation and hygiene (Pruss-Ustun *et al.*, 2004).

Rural water supply coverage in Ghana was estimated at 69% in 2006; which consisted of 17,280 boreholes, 4,236 hand-dug wells and 185 piped schemes (GSS, 2008). According to Azeem, (2011), the actual consumption of 8-10 litres for hand pumps and 8-15 litres for small town systems is below Community Water and Sanitation Agency (CWSA) guidelines. Interestingly, 73% of the urban populations have access to pipe borne water of which 43% obtain water outside their houses; 15% have access to water from wells, 22.5% have access to natural sources; 8.4% access tanker services; water vendor being 3.4% and sachet/bottled 4%. Only 15% of the poor have direct access to piped water (MICS 2006).

In Ghana, 85% of people living in rural communities regularly use water which is unsafe and about 28% of the urban poor have no running water in their homes (Halcrow, 2008).

Perhaps the advances in GIS technology, provides new opportunities for environmental epidemiologist to study associations among these parameters: water coverage, demographics, environmental exposures and spatial distribution of diseases (Clarke, 2001). GIS has been used in the surveillance and monitoring of vector and water-borne diseases in many parts of the world. In environmental health, disease analysis and policy planning, GIS has played significant roles in spatially distributing data for making well informed decisions.

Spatial analysis is the process of examining the locations, attributes, and relationships of features in spatial data through overlay and other analytical techniques in order to gain useful knowledge (Wade and Sommer, 2006). GIS analysis techniques include examining and exploring data from a geographic perspective, to develop and test models, and to present data in ways that lead to greater insight and understanding of spatial relationships (Anselin, 1992: Goodchild, 1993). Exploratory spatial data analysis (ESDA) is a philosophy for geographic data analysis that employs graphical techniques to maximize insight into a data set, uncover underlying data structure, extract important variables, detect outliers and anomalies, test for underlying assumptions, develop parsimonious models, detect spatial patterns in data, formulate hypotheses based on the geography of the data and Assessing spatial models as related to the data. ESDA tools are used to examine the data indifferent ways, to give a deeper understanding of the investigated phenomena. (Croarkin and Tobias, 2006)

In 1993, World Vision International (WVI) in collaboration with Desert Research Institute, USA, tried to develop an integrated approach to groundwater exploration using GIS technology in Afram Plains of Ghana. The objective was to increase the hydro-geological understanding of Afram Plains for water development efficiencies through improved well site selection and creation of maps (Timothy *et al*, 1994). But according to Amatekpor (1999), land use map of Ghana was not available until 1998 when the development of GIS-RS technology was completed under the Ghana Environmental Resource Management Programme (GERMP). However, since 1972 satellite RS technology has been applied to a great deal of natural resource management research in Ghana. Notable among them are water resources research

(Amuzu, 1989), groundwater exploration (Banoeng-Yakubu, 1999), land use inventory and mapping (Duadze *et al.* 1999).

1.1 Problem Statement

Traditionally, water is a treasured natural resource (Ofori, 1977) and the major sources of water in the Atwima-Nwabiagya district are of the customary regime. Many of these customary sources are wells, streams, rivulets and rivers listed here in order of importance, have serious water quality challenges. There is a close relationship between sanitation, water management and water with good quality attributes (WHO, 2004).

There are serious health implications for getting water through traditional water sources since they are usually contaminated with water borne diseases. But most people in developing urban communities rely solely on a communal water supply for their daily water needs (Jagals *et al.*, 1999).Water supplies in rural areas of Ghana are obtained almost exclusively from groundwater sources since it is the only economically viable option with stable and better microbial quality (WRC, 2012). Nevertheless, some wells in Ghana are prone to high levels of infection and contamination by heavy metal contaminants due to the poor management of industrial waste, floods and natural causes such as rock formation (ibid). Generally the quality of groundwater resources in Ghana is good except for some cases of localised pollution and areas with high levels of iron, fluoride and other minerals

(WRC, 2012).

It is generally assumed that since groundwater aquifers are often well protected by layers of soil and sediment, which effectively filter rainwater by removing particles, pathogenic microorganisms and many chemical constituents, it is safe as a drinking-water source. However, groundwater has been termed the 'hidden sea' because of the large amount of it, and because it is not visible, pollution pathways and processes are not readily perceived (Chapelle, 1997). Improper waste disposal accounts for a substantial amount of groundwater contamination. The major form of groundwater pollution are industrial and municipal landfills, underground storage tanks, oil spills, well injection, pesticides, fertilizers and septic tanks (Morris *et al*, 2003).

The potential of water to harbour microbial pathogens and cause subsequent illness is well documented for both developed and developing countries (Younes and Bartram, 2001). Water stored in barrels, buckets and open pans without being covered properly, will get contaminated, giving rise to diarrhoea and cholera. Containers used to store water and at the same time used for washing, increase the possibility of contamination. The presence of *Escherichia coli* in drinking water denotes the contamination of faecal matter from human or animal wastes and therefore presents a potential health risk to households that use them untreated (NGA, 2012). These pathogens potentially cause diarrhoea, cramps, nausea, headaches, and other special risk for infants. *Salmonella spp* had been implicated in several incidences of food poisoning such as salmonellosis and typhoid fever caused by *Salmonella typhi* (Onu and Isaac, 2009).

With the advent of powerful and high-speed personal computers, efficient techniques for water and disease management have evolved: of which geo-informatics technology which includes Remote Sensing and GPS (Global Positioning System) are of great significance (Sander *et al.*, 1996). The use of GIS technologies in the assessment of drinking water quality in Ghana, have not been much appreciated. Even though studies have been conducted on water quality in Ghana using GIS, their application has been limited, to bacteriological examination of drinking water quality (Amatekpor, 1999) and not the spatial extent and distribution of such contaminations.

1.2 Justification

As part of the National Community Water and Sanitation Program, 524 small-town pipe systems, 15,654 boreholes and 1,430 hand-dug wells have been constructed in Ghana (CWSA, 2004). This brings the national coverage for potable water supply in both rural communities and small towns in the country to 51.7%. Only 30% of Ghanaians have access to safe drinking water and over 50% of Ghanaians use “unprotected” sources of water (Ministry of Health, 1999). According to WHO and UNICEF statistics, only 74% of the rural population of Ghana has access to "improved" sources of water that include both boreholes and hand-dug wells (WHO /UNICEF, 2010).

Boreholes, wells and pipe systems are the main sources of water supply for domestic use in the Atwima-Nwabigya District (Atwima-Nwabigya District Assembly, 2012).

Quite often, due to the poor management of these water sources, polluted surface waters seeped into them with its attendant water-borne diseases. Even though, the district has 95% water coverage, it is still challenged with water borne diseases. Consecutively from 2005 to 2009 diarrhoea has been ranked the third prevalent disease in the district apart from 2007 where it was ranked fifth. In 2005, 1,957 cases were reported and that of 2009 was 8,626 (Ghana Health Service, 2010). Diarrhoea is ranked third amongst the 60 main diseases reported in the OPD at Ghana Health Service hospitals excluding Komfo Anokye and Korle-Bu Teaching Hospitals (Ghana Health Service 2004).

It is estimated that the district has 4.9% of its wells unprotected and 43.8% uncovered pit- latrine (CWIQ, 2003). Aside the traditional drinking water sources of wells, portions of Nkawie are connected to piped water from the Owabi Head Works. Public water stand posts are located in strategic places for use by community members but the piped system is erratic and therefore community members do not rely on it solely as the source of drinking water. A mechanised borehole facility that used to serve the entire community has broken down and the population has now resorted to drawing water from the open well. A few households also have private hand dug wells located in their compounds as a source of drinking water. In addition, sanitation facilities in Nkawie, are mainly public toilets.

An estimated 70% of the population of Nkawie do not have latrines in their houses but use mainly the public toilets. However, this level of use is highly variable across the nine unit areas of Nkawie, ranging from over 90% in Zongo and Nkorang to 50% or less in Wenachi East/West, Kubeasi Central and Toase New Town. The majority of households use public latrines early in the morning while others use chamber pots, which are generally emptied into the public toilets (Obika *et al* 2002). Open defecation is not widely practised although some children use the open dumps or defecate in shallow pits behind public latrines. Refuse is collected by individual households and dumped in specified locations, although final disposal of refuse is still a challenge. Mountains of refuse can be seen in parts of the town, often adjacent to public toilets (Obika *et al* 2002).

Faecal-oral pathogens are mostly transmitted from the excreta to the mouth via water, flies, hands, or food (Howard, 2002) and such microbiological pathogens that are transmitted by the faecal-oral route, especially those originating from human faeces, are of particular concern for water quality surveillance programs for public health. Bacteria that cause faecal-oral infections include *Campylobacter jejuni* (dysentery), *Escherichia coli* (diarrheal infection or dysentery), *Shigella* spp (dysentery), *Salmonella* spp (acute diarrheal infection), *Salmonella typhi* (typhoid fever), *Yesinia enterocolitica* and *Y. pseudo tuberculosis* (acute diarrheal infection), and *Vibrio cholerea* (cholera). In addition to bacterial pathogens, viruses transmitted in faecally-contaminated water are well recognized as agents of diarrheal disease and mortality, of particular concern for children is Rotavirus (Howard, 2002).

As a matter of policy, the Environmental Protection Authority (EPA) requires regular testing of water systems that have at least 15 service connections or regularly serve at least 25 individuals. This policy unfortunately has not been adhered to in Nkawie. The Community Water and Sanitation Agency (CWSA) data collection for microbiological water quality is limited by the availability of laboratory facilities, cost and time. These major limitations lead to few tests and long intervals for microbiological testing. This has implications for the health of people in the community as far as reducing the risk of waterborne diseases is concerned. Previous studies have shown that the microbiological quality of water can vary significantly over short periods of time and therefore water should be monitored frequently to ensure low disease risk to communities using that supply (Howard, 2002).

Other studies have shown that improved drinking-water quality can lead to a reduction in occurrence of adult diarrhoea by 15% and up to a 40% reduction for infant diarrhoea when provided in conjunction with appropriate sewage disposal practices (Rottier and Ince, 2003).

Researches on drinking water quality and related diseases in Ghana so far have focused solely on the biological factors and characteristics of the individuals affected. Although such studies are very useful, they omit the spatial and regional variations of the critical risk factors. Such studies also fail to define territories at high risk. Notwithstanding previous initiatives, there have not been any major efforts in literature to undertake a GIS based risk assessment of contaminated drinking water sources in the study area.

This study is an attempt to fill that void in literature by exploring the applications of GIS in the examination of microbial quality of public drinking water and the estimation of populations at risk. In the district, information concerning water-borne diseases and outbreaks are rare and not easily available. It is apparent that studies along this line are scanty and so relevant data are very rare. Hence, this research is an attempt to contribute to knowledge with respect to the application of geo-informatics in the understanding of environmental health and epidemiology challenges in the district, while at the same time showcasing the efficacy of GIS in the investigations of water borne infections. The study will demonstrate the usefulness of GIS in tracing the source of infections of public water.

The GIS developed database system would ensure proper management of public drinking water sources and also prevent the deterioration of water quality through proper monitoring and evaluation. The produced drinking water related database would serve as a source of critical information to institutions, researchers, drilling companies and decision and policy makers. Institutions like Community Water and Sanitation Agency (CWSA), Ghana Health Service, Environmental Protection Agency and Universities could benefit from the outcomes of this study. The study will also provide a well-organized and integrated drinking waters sources database system for the district.

1.3 Objectives

The objectives of the research are

1. To establish the spatial distribution of public water drinking sources in the district.

2. To determine the bacteriological quality of public drinking water sources and to model their spatial distribution.

1.4 Hypothesis

1. There is a lower level of bacteriological contamination in boreholes than in hand-dug wells.

2. There is a lower level of bacteriological contamination in boreholes not associated with risk factors.

3. More than half of the study population is at risk of water borne diseases.

4. Public standpipe will not have challenges with water quality.

1.5 Thesis layout.

The work reported here is in five chapters. Chapter one gives an introduction to the research whiles Chapter two is a literature chapter in which the author discusses similar researches done on water quality studies, the methodologies employed, the limitations and main findings. This guided the present choice of methodology. The main methods employed are laid out in chapter three. The findings and discussion of the results and their analysis is presented in chapter four. The final chapter five then presents the main conclusions and recommendations based on the author's findings.

CHAPTER TWO

2.0 Literature Review

This chapter reviews the mechanisms in drinking water contamination, transmission processes and GIS applications.

2.1 Perspectives on Water Accessibility and Sanitation

The demand for high quality and adequate water supply has increased over the years and has led to water scarcity in many parts of the world. This situation is aggravated by the problem of pollution of the few water sources available. Safe water is one of the felt needs of public health in developing countries as quality of water is directly linked with human welfare (Sobsey, 2003). One of the factors in assessing the overall quality of life is the availability of quality drinking water and water intended for human consumption should be safe for health and aesthetically pleasing (Nevondo and Cloete, 1999).

The main sources of accessible water include rain, lakes, wells, streams, springs, ponds and oceans. Even though water sources are numerous, their portability reduces to a greater extent the amount of acceptable useful water on earth (Twort *et al.*, 2000). According to Prescott *et al.*, (2007), the three water environments are atmospheric water, surface water, and underground water. During rainy seasons, rain water can serve as a good source of water for domestic purpose if properly stored (Mitra and Roy, 2011).

Globally 1.1 billion people mostly in developing countries do not have access to safe water and 2.4 billion have no access to sanitation facilities (WHO/UNICEF, 2000). Estimates in 2002 indicates that, one-sixth of humanity lack access to any form of improved water supply within a kilometre of their homes, and approximately 40 per cent of humanity (2.6 billion people) lack access to any form of improved excreta disposal (WHO and UNICEF, 2004).

The adoption of resolution RES/47/193 in 1993 by the United Nations which declared 22nd of March each year as World Water Day was aimed at creating public awareness on the benefits of clean water, and the problems of water supplies (WHO/UNICEF-JMP, 2004). In September, 2000, 189 countries adopted the Millennium Development Goals (MDGs), one of which is to reduce the proportion of people without access to safe water and basic hygiene by 2015. The provision of water supply in developing countries may not be sufficient due to high population growth, conflicts, political instability, and low priority given to water and sanitation programs.

Statistics have shown that, 2.4 billion people lack adequate sanitation worldwide and six thousand children die every week from water related diseases, majority of these in Asia (20%) and sub-Saharan Africa (42%). In sub-Saharan Africa, 300 million people have no access to safe water supplies and approximately 80% live in rural areas. Therefore, increasing the coverage of rural water supply in Africa is fundamental to achieving many of the internationally agreed Millennium Development Goals (MDGs) as without safe water near to dwellings, the health and livelihoods of families can be severely affected. Children's education may also suffer as the daily tasks of survival take precedence over all other concerns (WHO/UNICEF, 2000; WHO/UNICEF-JMP, 2004).

Increasingly, greater variability in climate may be exacerbating the problems of water supply in adequate quantities and of acceptable quality in the developing world (Anayah, 2006). Water scarcity is a concern to most Sub-Saharan African countries

(Osei-Asare, 2004) and data show that 67% of the rural population has no access to safe water supply while 81% do not have access to sanitation services (Rosen and Vincent, 1999). The United Nations Environmental Programme (UNEP) estimates that 250 million people in Africa will be at risk of water stress, less than 1700 m^3 of water available per person per year by 2020 and up to 500 million by 2050 (Falkenmark *et al.,* 1989). Sub- Saharan Africa is making the slowest progress in meeting the MDGs target as one-third of its population still need safe drinking water (UNJMP, 2008).

2.2 Water Provision and Sanitation in Ghana

Water resources in Ghana play a central role in the promotion of acceptable living standards, enhancing economic growth, provision of food security, improvement in livelihoods, and eventually poverty alleviation (Anayah, 2006). Water is a crosscutting element of the Growth and Poverty Reduction Strategy (GPRS II) document of Ghana and is linked to all eight of the Millennium Development Goals. Improving water services and uses are essential for increasing hygiene and sanitation service levels that affect productive lives of people. It has been documented that available water supply improves school enrolment and enhances women's dignity through reduced morbidity, mortality and pre and post-natal risks. Health, nutrition and food production are dependent on availability of water in adequate quantities and good quality (MWRWH, 2007).

The main consumptive uses of water in Ghana include irrigation and livestock watering. On the basis of surface water resources alone, the consumptive water demand for 2020 has been projected to be 5 billion m^3, which is equivalent to only 12% of the total surface water resources. Currently, urban water supply coverage is estimated at 55% and that of the rural and small town is 51.6% (MWRWH, 2007). The frequent outbreaks of diarrhoea or gastroenteritis in rural communities in Ghana have all been attributed to the consumption of water of poor microbial quality.

Though Quality drinking water is essential for life, yet in many countries around the world, including Ghana, water has become a scarce commodity and only a small proportion of the populace has access to treated water. Only 30% of Ghanaians have access to safe drinking water and over 50% of Ghanaians use "unprotected" sources of water (Ministry of Health, 1999). This figure is 10 % higher than the average for the African continent, where 40% lack access to improved drinking water supply (Murcott *et al.*, 2008). Rural communities in Ghana, which form about 70% of the total population, rely heavily on groundwater as the main source of their drinking water (Gyau and Siakwan 2000). In Ghana, 22% of the urban population and over 30% of the rural population lack access to safe drinking water (Allison, 2007).

Alternative sources of water such as rainwater and ground water have become major sources of drinking water for people living in new settlements in Ghana. The need to assess the quality of water from some of these alternative sources has become imperative because they directly affect the health of individuals (MWRWH, 2007). Ghana Health Service, (2004), reports that about 70% of diseases in Ghana are linked to insufficient water supply and sanitation coverage. The percentage of population per access to water sources is shown below (Table 1).

Table 1. Population with Access to Water

Water Source	Population (%)
1. Pipe-borne /tanker	46.5
2. Well/ borehole /protected spring	29.4
3. Sachet/bottled water	9.3
4. Tankers/Vendors	1.1
5. Rainwater	0.7
6. Surface water	10.6
7. Others	2.4

Source: Ghana Statistics Service (2010)

In the case of sanitation, about 78% of Ghanaians lack access to improved latrines and this poses a challenge to meeting the Millennium Development Goals for sanitation. The revised Environmental Sanitation Policy of 2010 was expected to deal effectively with the issues that have led to the persistent underlying causes of poor environmental sanitation and its vital link to health (Bensah *et al*, 2010). In spite of fair progress made in water coverage in Ghana, still less than 15% of the population has access to improved sanitation (WSMP, 2008). Indeed, it has been reported that about 20% of Ghana's population defecate in drains, fields, streams, the bush and beaches (ibid). According to the MDG report on Ghana for 2008, only 21.2% of Ghanaians will have access to improved sanitation by 2015. This is below the target figure of 52%, suggesting that there are still challenges with the existing sanitation policies and programs.

Water-borne diseases in Ghana include diarrhoea, hepatitis A, typhoid, cholera and guinea worm. WHO reports that diarrhoeal cases kill an estimated 1.8 million people each year, the majority of whom are under 5. Of the approximately, 20% of all death occurring in children under five, majority occur between ages six months and three years. Diarrhoea has been identified as the second most common disease treated at clinics and one of the major contributors to infant mortality (UNICEF, 2004). The infant mortality rate currently stands at about 55 deaths per 1,000 live births (CIA, 2006).

Table 2. Regional Distribution of children under 5 with diarrhoea

Region	UWR	UER	NR	BA	AR	VR	ER	WR	CR	GA
Per Cent	20.8	26.9	15.3	13.9	14.3	13.3	15.7	14.4	15.9	12.8

Source: Van Calcar, (2006).

2.3 Drinking Water Quality and Improvement in Sanitation

Man uses water for various purposes which include drinking, transportation, industrial and domestic use, irrigation in agriculture, recreation, fisheries, and waste disposal among others (Shittu *et al.*, 2008; Ajayi and Akonai, 2005). Water of good drinking quality is important to human physiology and man's continued existence depends so much on its availability.

Safe water is one that is free from disease-producing organisms such as pathogenic bacteria and viruses whiles water quality refers to the characteristics of water that will influence its suitability for a specific use. Emphasis is normally placed on the chemical and physical properties of water (Lamikanra, 1999; FAO, 1997).

The quality of water for drinking deteriorates due to inadequacy in treatment, the direct discharge of untreated sewage into rivers and stream, and the inefficient management of piped water distribution systems (UNEP, 2009). The quality of water varies depending on location, origin and climate. Most people in developing urban communities rely on communal water supply for their daily water needs (Jagals *et al.*, 1999). The problems associated with communal supplies, include substantial distances between homes and water sources, and waiting times for filling domestic storage containers (MRC, 1999).

These problems give rise to various water storage and handling practices in households, which lead to deterioration of the microbiological water quality between collection points and storage (Jagals *et al.*, 1999) and these could affect the health of consumers (MRC, 1999). Furthermore, water that is of good quality at its source may be re-contaminated during withdrawal, transport and household storage. This may then require subsequent treatment and safe storage of water in the home (Sobsey, 2002).

Ensuring that water sources are safe is important to reducing health burdens. However, a balance in investment must be maintained to ensure that other interventions, which are important in reducing disease, are implemented. For instance, diverting resources away from excreta disposal and improved hygiene practices in order to achieve very good quality water may be counter-productive (Esrey, 1996).

Endemic and epidemic diseases derived from poor water supply affects many others who may not have directly use the contaminated water. Waterborne diseases are sometimes contagious and may lead to loss of lives, avoidable and economic costs to individuals and communities. The improvement of water quality control strategies, in conjunction with improvements in excreta disposal and personal hygiene can be expected to deliver substantial health gains in populations (WHO, 2006). It has been estimated that diarrhoeal morbidity can be reduced by an average of 6-20 per cent with improvements in water supply and by 32 per cent with improvements in sanitation (WHO, 2007).

In addition to making supply of adequate water available for consumers, protected supply is necessary for providing water which is safe to drink. Water that is contaminated with microbiological constituents is considered unsafe and can cause a variety of diseases, with diarrhoea as their main symptom (WRC, 1993). Research by Pete and Caver, (1999) has shown that bacteria can be transported underground as a result of leached liquid from municipal solid wastes, land fill, latrine or septic tanks, and have the propensity to contaminate underground drinking water supplies.

Water quality measurement is important to ascertain that certain chemical and physical quantities do not exceed standard levels. Water quality assessment involves evaluation of the physical, chemical, and biological nature of water in relation to natural quality, human effects, and intended uses, particularly uses which may affect human health and the health of the aquatic system itself (UNESCO/WHO/UNEP, 1996). The chemical composition of water is an important factor to consider before it is used for domestic or irrigation purposes (Suresh *et al.*, 1991). It is generally accepted, however, that the microbiological quality of drinking water is of fundamental importance and should never be compromised in favour of aesthetically acceptable water. It is estimated that 80% of all illnesses are linked to use of water of poor microbiological quality (WHO, 2002).

2.4 Mechanism for Water Contamination and Pathogen Transmission

Microbial contamination refers to the introduction of one of any number of harmful bacteria, viruses or protozoa collectively known as pathogens, into a water source. As the lack of treated potable water remains an important issue in many rural communities in the developing world (Herrera-Pantoja and Hiscock, 2000), microbial contamination is not uncommon.

Water contamination can originate from a variety of sources, including industrial or agricultural runoff, poorly treated or untreated sources, leaching into underground or surface water sources close to waste disposal sites, human and animal wastes. Contamination can also be naturally occurring, with chemicals, such as arsenic or fluoride, seeping into drinking water sources from geologic strata. In developing countries the most common form of contamination is microbiological and comes primarily from human or animal faeces mixing with drinking water sources, during transport, or at the point of use (Howard and Luyima, 2000).

Poor hygiene in the home is a potential source of drinking water contamination. In many cases however, contamination increases from the water source to the household (WHO, 1997). This is of much concern especially with communities without reliable water system which store water in containers. Many people also depend on water supplied by tankers. Studies in Ghana showed that water delivered from hydrants through tankers to households in Kumasi has almost the same quality as the piped system (Robertson *et al.;* 2002). Howard and Luyima (2000), states that on the contrary, drinking water supplied by small vendors, selling from small tanks and jelly can have highly degraded water quality.

Point source of water such as tube wells, wells and protected springs represent significant proportion of "improved" source of water supplies provided for communities (WHO and UNICEF, 2000). The quality of such water points vary and normally show increased faecal contamination during wet season (Barret *et al*, 2000). The public health consequence of consuming contaminated water can be severe to endemic and epidemic diseases (Pedley and Howard, 2000). Sub-surface leaching is frequently identified as the principal contamination of point water sources.

According to Feachem, (1979), water related diseases are classified according as waterborne, water-washed, and water-based and vector based as shown in table 3 below.

Table 3: Classifications of Water-Related Diseases

Classification	**Transmission Details**	**Examples**
Waterborne	Faecal-Oral Route	Cholera, Typhoid, Hepatitis A
Water-washed	Water-Hygiene	Diarrhoea, Trachoma, Scabies
Water-based	Water-Contact	Guinea Worm
Insect Vector	Insect-Blood	Malaria, River Blindness

Modified from Feachem, 1979

Open air defecation, among communities, may lead to contamination of the water supply system and result in outbreaks of diarrhoeal disease (Sarkaret, 2007). The practice of tethering animals close to human dwellings and the consequent proximity to animal faecal matter further enhances the risk of contamination of drinking water (Licence *et al*, 2001). The key to providing microbiologically safe drinking water lies in understanding the various mechanisms by which water gets contaminated, and formulating interventions at critical points to decrease and prevent contamination of drinking water (Trevett and Carter 2004).

Groundwater is also vulnerable to contamination from numerous anthropogenic activities. Improperly installed septic tanks, wastes disposal, leaking underground storage tanks, and accidental spills are all sources of groundwater contamination (Smutko, *et al.,* 1993). Pollution can be at point sources or it may not be at a source and so will be nonpoint source. Point sources include spillage at industrial sites and leakages of underground storage containers whiles nonpoint sources are more dispersed in nature and include fertilizers and pesticides applied to agricultural fields (Fitts, 2002).

While the distribution of a pollutant may be classified as point or nonpoint, changes in ground-water quality are closely related to patterns in land-use and waste disposal practices (Giese *et al.,* 1987). In trying to assess the impact of human activities on groundwater contamination, Moody (1996) grouped potential sources of contamination into waste disposal, storage, handling, agricultural, and salt water intrusion. Contamination due to saline intrusion was most commonly associated with the over pumping of coastal aquifers (Moody, 1996).

The F-diagram below Fig. 1 shows the different routes that microbes from the environment get to a new host. Microbes in faeces on the ground beside a well or any point source gets into the water (fluids) and is drunk by an individual. Hands that have not been washed after visiting the toilet can carry microbes onto foods, which are then eaten, infecting another, who gets diarrhoea and spreads more microbes.

During the rainy season, surface water sources are more susceptible to contamination via runoff from areas of open defecation. If these water sources are subsequently consumed, pathogens can be transmitted to a new host. The World Health Organization (WHO) estimates that improvements in water and sanitation sectors could reduce the burden of disease worldwide by 10 per cent (WHO, 2008).

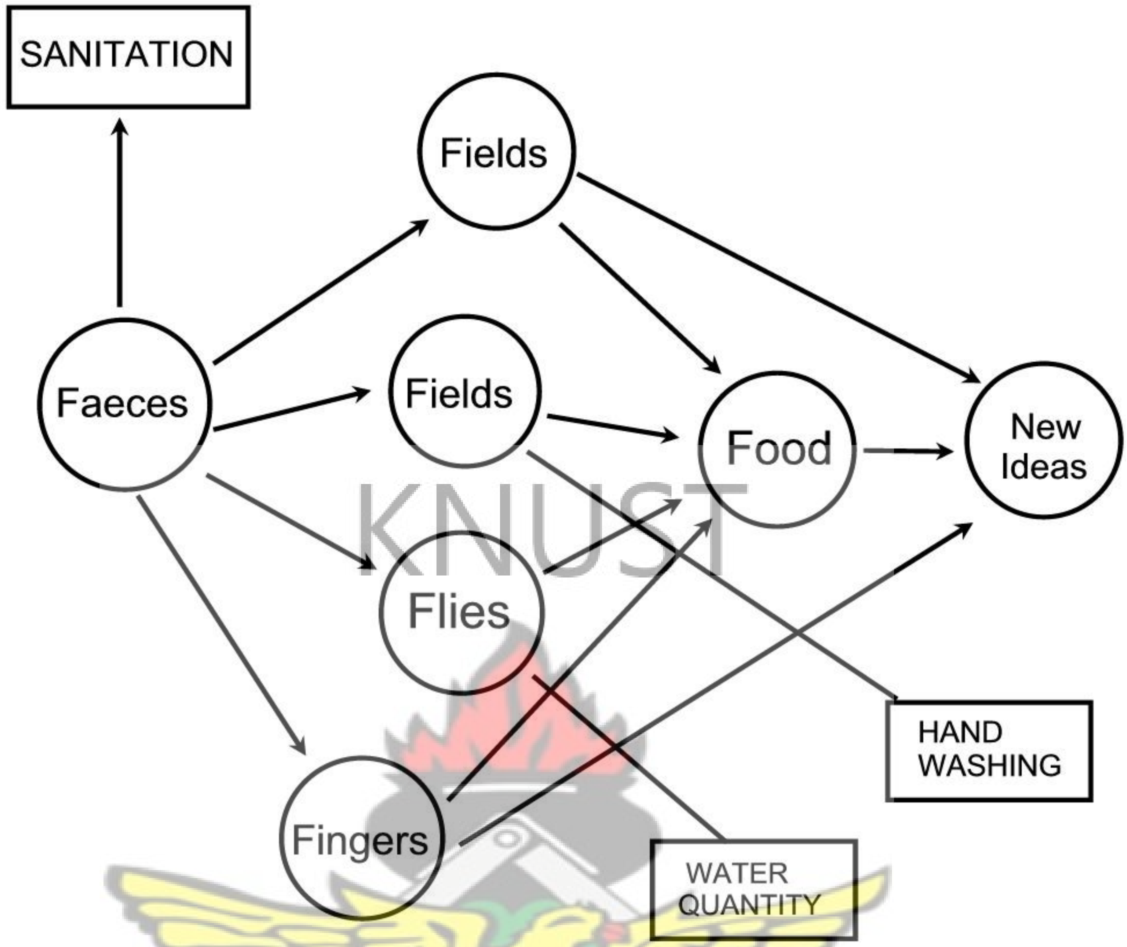

Figure: 1. F-Diagram

2.5 Water Quality Guidelines.

The primary purpose of the guidelines for drinking water is the protection of public health. As water is essential to the sustenance of life, it must be safe, adequately supplied and accessible to all. WHO guidelines state that water intended for drinking must not contain any concentration of a constituent that will or may result in any significant health risk to the consumers over a lifetime of consumption. It further states that *E. coli* or thermo-tolerant coliform bacteria must not be detectable in any 100 mL sample of water intended for drinking (WHO, 2008).

Escherichia Coli, commonly known as *E. coli*, is a single species subcategory of faecal coliforms. There are many strains of *E. coli*, but only a small fraction cause diseases. The most common is the strain O157:H7, blameable for severe cases of breaches in public health (Washington State Department of Health, 2011). However, the presence of any strain of *E. coli* is likely indicative of faecal contamination of the water source. Recent studies from the Georgia Institute of Technology have drawn into question the appropriateness of *E. coli* as an indicator organism in a wide range of environmental conditions.

Researchers have identified nine unique strains of *E. coli* that have adapted to survive independently in the environment (Luo, 2011). A number of these strains exist in soil ecosystems which, when flooded with heavy rains, could easily mix with surface or ground water sources. This contamination, by naturally occurring *E.coli,* could lead to the mismanagement of safe water sources. In regions where water is scarce, an increase in false positive microbial tests could have a high negative effect on the health of the community.

2.6 GIS Application in Epidemiology

In view of the above, public health professionals continuously seek more refined methods to characterize populations exposed to environmental contamination. Such studies are conducted for identifying populations at risk from environmental hazards; exposure assessments of sensitive populations, identifying areas for the focus of public health education or community outreach; and identifying target and control populations for health studies.

Geographic information systems (GIS), coupled with census information and spatial environmental analysis techniques, offer tools to evaluate such problems. Natural resources particularly, water and related landscape elements that control the distribution of particular resource, if represented in the form of proper maps, are amenable to better insight. This aids in development and management strategies for policy decisions to be made.

In many urban and rural areas of Ghana, clean potable water and sanitation are either lacking or inadequate. Communities depend on untreated water from wells, rivers, and other surface-water for drinking, laundry and recreational purposes. The link between poor microbial water quality and infectious diarrhoea is well-established and geographic information system has been shown to be vital in mapping the spread of infectious diseases, including diarrhoea, and aiding in control strategies (Obika *et al.*, 2002). However, despite numerous outbreaks of diarrhoea in several parts of Ghana, the application of GIS technology to assist in the identification of occurrence of diarrhoea, aiming at assisting its control has not been reported.

Recognition of the linkage between humans, waste disposal, water supply and public health did not occur until the 19th century during the London cholera epidemic. In 1849, John Snows developed a map identifying residences which have contracted the cholera as a primary tool to point the source of the epidemics. This was a clear case of Geographic Information System (GIS) application in epidemiology.

Geographic Information System (GIS) is a computer based information system used to digitally represent and analyze the geographic features present on the earth's surface and the events taking place on it. It is designed to work with data referenced by spatial or geographical coordinates and integrates common database operations (such as query and statistical analysis) with unique visualization and geographic analysis. These abilities distinguish GIS from other information systems and make it valuable to a wide range of research, public and private enterprises for explaining events, predicting outcomes, and planning strategies (Goodchild, 1993).

Advances in Geographical Information Systems (GIS) technology provide new opportunities for environmental epidemiologist to study associations between demographic and environmental exposures (Clarke, 2001). GIS has been used in the surveillance and monitoring of vector-borne and water-borne diseases, environmental health and also disease policy and planning. Several cholera studies have employed GIS technologies. Total microbial quality assessment and GIS were used for evaluating the quality of water and spatial distribution of diarrhoea cases in Tshikuwi, a rural community in South Africa, during an outbreak of diarrhoea. The spatial distribution of diarrhoea cases showed a hot-spot of cases close to people who use the Khandanama River (Bessong *et al*., 2009)

GIS has also been used in map classification of groundwater quality, based on correlating total dissolved solids (TDS) values with some aquifer characteristics (Butler *et al.*, 2002). Other studies have used GIS as a database system in order to prepare maps of water quality according to concentration values of different chemical constituents (Skubon, 2005; Yammani, 2007). Singh and Lawrence (2007), prepared a groundwater quality map in GIS successfully for Chennai city, India.

Available evidence from literature reveals the extreme usefulness of GIS application in specific areas of public health such as chemical contamination of water and water borne diseases. For instance, GIS application was used to determine exposure of man to contaminated drinking water by Non-Volatile Organic Compounds (VOC) in groundwater reservoir (Ara and Maslia, 1996). Ekpo (2006) applied GIS in the investigation of guinea worm among school children in Ogun state whiles Rapid

Geographical Assessment of Bancroftian Filariasis (RAGFIL) using GIS was conducted in three countries (Ghana, India and Myamar). The spatial analyses accompanying this investigation, assisted in discovering the existence of spatial auto correlation among districts within each country (UNDP/ WHO/ World Bank, 1998). Gyapong *et al.,* (1996), suggested that the rapid epidemiological studies in Ghana were a good proxy measure of the levels of endemicity of filariasis.

CHAPTER THREE

3.0 Materials and Methods

Chapter 3 discusses the quantitative and qualitative approaches employed for data collection and analysis leading to the realisation of specific objectives. The Chapter gives brief description of the study area, followed by the materials used for the study and a detailed account of how the fieldwork and laboratory analysis of water quality was conducted and data analysed.

3.1 Study Area

3.1.1 Location and Size.

The study area is the Atwima-Nwabiagya District with its capital at Nkawie in the Ashanti Region of Ghana (Fig.2). This district was established in 2004 by Legislative Instrument (L.I) 1738 as one of the 21 political districts currently in the Ashanti Region. The district is situated in the western part of the Region and shares common boundaries with Ahafo-Ano South and Atwima Mponua Districts to the West, Offinso Municipal to the North, Amansie-West and Atwima Kwanwoma districts to the South, Kumasi Metropolis and Afigya Kwabre Districts to the East. The district covers an estimated area of 294.84 square kilometres and has a population of 149,025 (Ghana Statistical Service, 2010). The Atwima Nwabiagya district lies approximately between latitudes $6^{0}75'$N and 6.67^{0}N and between longitudes $1^{0}45$W and 1.81^{0}W (Atwima-Nwabiagya District Assembly, 2013).

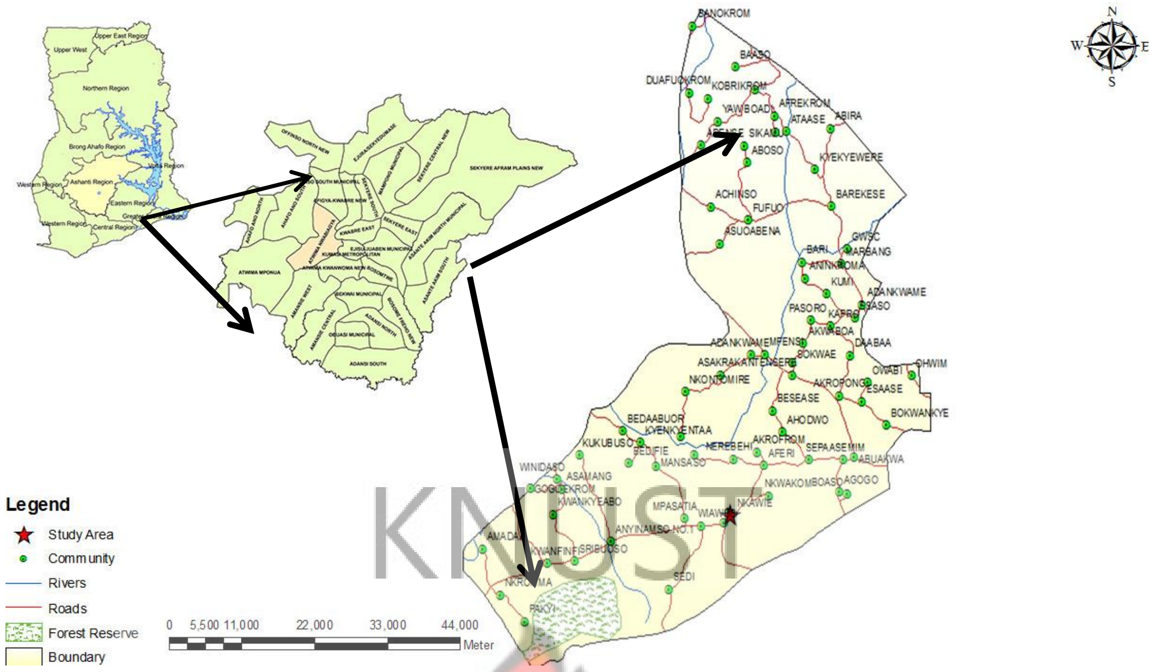

Figure 2: Map of the Study Area

Nkawie was chosen as the research area because of the high incidences of water related diseases (diarrhoea) even though the community has 95% water coverage. Nkawie also has a fair balance of urban and rural populations which makes it suitable for this study. The community is about 13km from Kumasi, the regional capital and occupies 10% of the Atwima Nwabiagya District's landmass. The research project covered all the three sections of Nkawie namely Kuma, Toase and Panin.

3.1.2 Demography and Household Characteristics

The population of Nkawie is estimated to be 9054 with 1597 households (GSS, 2010). Majority of the population (98%) are of the Ashanti tribe; about 85% are Christians, 10% Moslems and 5% traditionalists (GSS, 2000).

The settlement pattern in Nkawie is still very traditional with original owners or inheritors still living in their houses. A house inventory of Nkawie from the District Assembly gave the total number of houses to be 567. The data did not indicate the number of households per compound, but average number of people per compound is about 22. The average, household sizes are 4.8 in Ghana (GSS, 2000).

3.1.3 Topography and Drainage

The district has an undulating topography. The topography has an average elevation of 77 meters above sea level and the high lands have gentle to steep slopes. The surface area of the district is mainly drained by the Offin, Owabi and Tano rivers. Two major Dams, Owabi and Barekese have been constructed across the Owabi and the Offin rivers respectively. These dams supply pipe borne water to the residents of Kumasi and its environs. In years of above average rainfall, the Offin and its tributaries becomes flooded causing damage to crops within the confines of the floods. (Atwima-Nwabiagya District Assembly, 2012)

3.1.4 Climate and Vegetation

The district lies within the wet semi-equatorial zone marked by double maximum rainfall ranging between 170cm and 185cm per annum. The major rainfall season is from March to July and minor season is between August and mid-November. Temperature is fairly uniform ranging between 27^0C and 31^0C. A relative humidity of about 93 per cent is characteristic of the district. The vegetation found in the district is predominantly the semi-deciduous type. The vegetation type has largely been disturbed by man's activities, thus, depriving it of its valuable tree species and other forest products. There are, however, large acres of forest reserves which include the Gyemena, Tano Offin, and Owabi Water Works Forest Reserves. These reserves are rich in various timber species such as *Triplochiton screloxylon* (wawa), *Enthandrophragma cylindricum* (sapele), *Celtis spp* (esa), *Ceiba pentandra* (onyina) among others (Atwima-Nwabiagya District Assembly, 2013).

3.1.5 Geology and Soils

The predominant soils in the district are the Kumasi-Asuansi/Nsuta-Ofin Compound Associations and the Bekwai-Nzema/Oda Complex Associations. The soils have a fairly high moisture holding capacity and are marginal for mechanical cultivation. The Kumasi-Asuansi Compound Associations are found at places like Nerebehi, Abuakwa, Nkawie and Toase. Residential activities and sand winning have currently degraded most of these good agriculture lands. The valley bottoms are good for the cultivation of rice, sugarcane and vegetables (Atwima-Nwabiagya District Assembly, 2013).

3.2 Materials

Materials used for the study included hand held Garmin Personal Navigator GPS device, Aquatest device, pH metre (model 600,Fischer Scientific Co, USA), Thermometre (Centigrade 500, 0.5 divisions), digital camera, ice chest, 100ml sample containers, personal computer installed with Microsoft Excel and ArcGIS for data entry.

3.3 Methodology

The methodology is illustrated in the flow diagram below (Figure. 3) and also as discussed under this section:

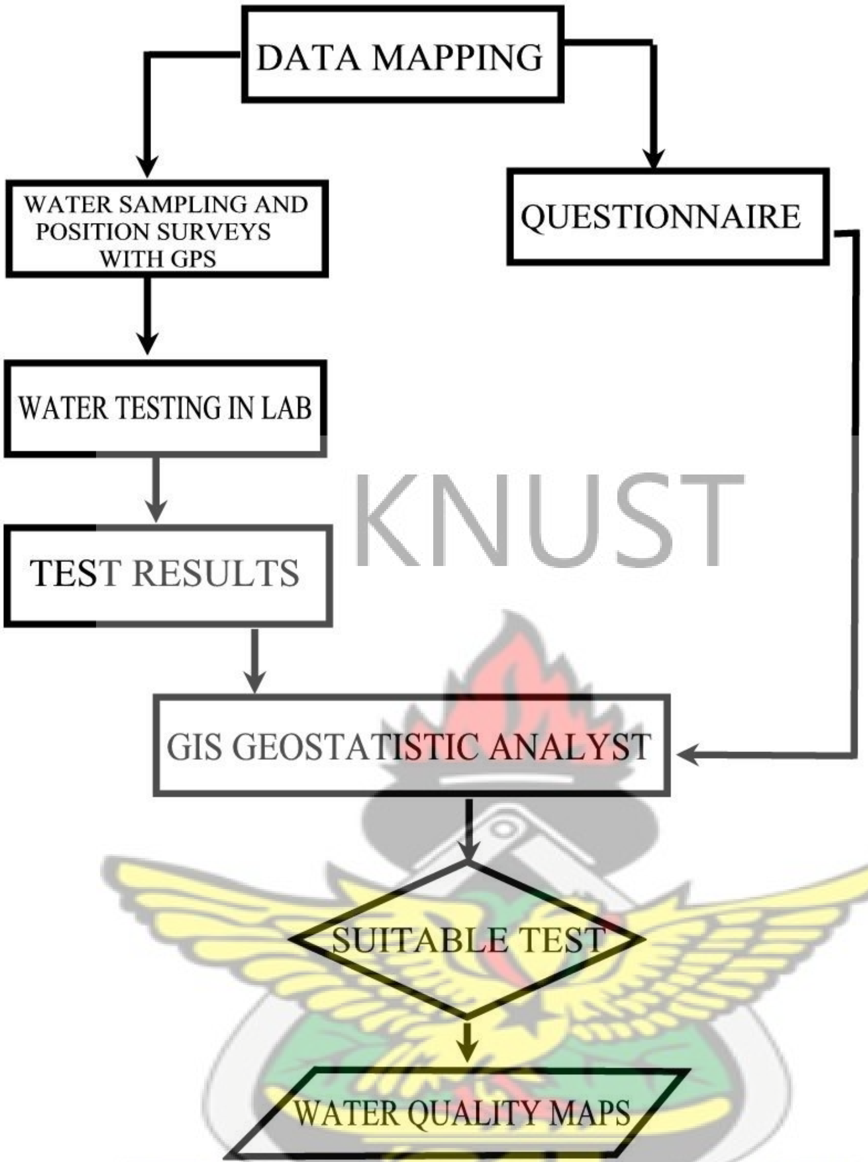

Figure: 3. Methodology Flowchart

3.3.1 Questionnaire Administration.

A survey was carried out to identify all boreholes and wells in the study area from which inhabitants draw water. Questionnaires were administered to find out which of these various sources individual households draw water from and also user's perception to contaminated drinking water from these sources.

Cluster sampling, which is a technique by which the entire population is divided into segments or groups (clusters). Nkawie was divided into 10 clusters; A, B, C, D E, F, G, H, I and J. From each cluster, approximately 6 households were randomly selected for questionnaire administration.The formula below was used to determine the sample size of for the study.

$$n=N/ [(1+N (a^2)]$$

N=Total Number of Households

a=Margin of error estimated at 5%

n=Sample Size (Sanders *et al* 2007)

The respondents were mothers, grandmothers or female family members because it is generally accepted that adult respondents are more suitable to interview when data regarding household activities are needed. It is considered best to interview the mother or caretakers of children for health data (Ahmed *et al.*, 1994).

Questions asked were based on drinking and domestic water sources, challenges encountered with the available drinking water sources and methods for mitigating unsafe water sources. The community health centre was also visited to investigate recorded cases of water related diseases. Other information captured with the survey questionnaire in all the 64 sampled households included treatment of water before use, sanitation and hygiene and type of toilet facilities used. Interviews and collection of household demographic data were conducted after a signed informed consent had been obtained from the head of each household. Data on physical characteristics of the house, refuse disposal point and household energy source (electricity or otherwise) were obtained.

3.3.2 Sample Bottle Preparations

To obtain accurate results, standard sampling procedures were adopted to eliminate or minimise potential contamination of the samples. Sample containers were soaked in nitric acid (NHO_3) overnight and were washed with distilled water, rinsed with deionised water and dried in a drying cabinet. Sample containers were clearly labelled to enhance record keeping.

3.3.3 Water Sampling

Nine public water drinking sources namely were sampled from March to May. Public water drinking sources such as piped system (tap), boreholes and wells had samples collected. For boreholes and tap, the samples were collected after running the water for about 1 minute (to mimic normal practices) during the raining season. There was no flaming of the pump outlet, because the aim of the study is to know the quality of water being collected by the users. Samples from well sources were also collected using the same types of containers households would usually use to draw water.

Samples were immediately analyzed using the Aqua test devices as preliminary test. This was done because water stored for more than two weeks tends to deteriorate in quality (Jusara *et al.*, 2003). A water chain was developed to track water from source to water storage containers and collection vessels. This provided a platform to propose technical or educational interventions. .

Nine (9) samples were taken and transported to the microbiology laboratory at the Kwame Nkrumah University of Science and Technology in ice packs for analysis. Relevant information such as location of drinking source, year of construction, ownership and depth were recorded. At each sampling water source, a visual sanitation survey of the point source was conducted and recorded.

3.3.4 Sample Position Mapping.

A hand-held Global Positioning System (GPS) receiver (Gamin GP 12 Personal Navigator) with an accuracy of ±5 degrees with user caliberation was used to obtain coordinates of public taps, wells and boreholes from which samples were collected. Other relevant facilities such as health centres, refuse dumps and public toilets had their coordinates captured. The geo-ecological characterization of the study area was obtained by incorporating the existing spatial and in-situ data into ArcView 9.3 (Dangendorf *et al.*, 2002).

A hand held GPS was used to take coordinates of public boreholes, standpipes, wells.

The use of a geographical information system was to allow an overlapping of spatial location of water sources and bacteriological quality to generate maps for the study area. Drinking water quality data based on bacteriological analysis were attributed to each sampling locations after laboratory analysis. The surfaces were generated and classified based on the desirable and permissible limits of individual parameters according to Ghana drinking water guidelines.

The maps (shape files) regarding the location of taps, boreholes and wells were analysed based on the screening criteria. The screening criterion included the selection of taps, boreholes and wells which exceeded microbiological concentration and a buffer distance of 500, 1000 and 1500m radius around each contaminated water source. The exposed population to each contaminated water source was calculated by multiplying the created buffer zone with the population density of the buffered area.

The database of Nkawie was created using existing district data sets provided by the District Assembly together with field data. Information on location of water drinking sources, year of construction, ownership and depth were captured. At each borehole, standpipe and well, a visual sanitation survey of the point source was conducted and recorded.

3.3.5 Water Sample Tests

3.3.5.1. Physical Parameters

The main physical parameters that are analyzed for water are the pH (hydrogen ion concentration of water medium), the temperature and the odour and colour. Suspended matter (in particular clay and organic particles) has a large absorption of the surface and constitutes an ideal support for ions, various molecules and micro-organisms. In this view, the analysis of colour provides useful information on the mobility of hydrophobic pollutants in the water.

The pH of the samples was determined using the Fisher accument pH meter (Model 600 Fisher Scientific Co, U.S.A). 10ml of each of the samples was poured into a sterile beaker and the anode of the pH meter dipped into it for readings to be taken when it was stable.

A simple thermometer in centigrade scale (500, 0.5 divisions) was used to measure the water temperature of each sample. The thermometer was inserted into the water sources to determine their mean temperature from several readings.

The odour and the colour of the water samples were observed after collecting the samples by physical observation.

3.3.5.2 Microbiological Identification and Enumeration

The preliminary bacteriological identification and enumeration was done using the Aquatest Device. The Aquatest device is an integrated *E. coli* detection medium/device test system designed for use in field settings. The Aquatest device is a self-contained plastic water sampling and testing unit that contains both a selective growth medium for the bacterial species, *Escherichia Coli* (*E.coli*), the most widely accepted indicator of faecal contamination (Aquatest Technical Information Pack, 2011).

The Aquatest incubator was filled with warm water to approximately 500 millilitres and was allowed to stand for 30 minutes. The phase change material melted, absorbing energy from the hot water. The water in the incubator was later poured out and filled with water samples from the field. The device collected 100 ml of sample water from the field and divided into 11 separate chambers of the device. The Chambers were sealed to prevent microbiological cross-contamination between chambers and left for more than 24 hours in an incubator at 37°C with periodic agitation.

The number of chambers that support E. coli growth after a 24 hour incubation period provides a 'Most Probable Number", an estimate of the number of *E. coli* in the water sample. The MPN method involved dividing the original sample into a number of separate chambers, amplifying any present bacteria through the introduction of a growth media. After incubation, the presence or absence of the bacteria was assessed (as indicated by fluorescence) in each of the subdivisions. Statistical calculations, based on the volume of water in each chamber, were used to develop the MPN results table below.

Table 4: Aquatest MPN Results

Number of Chambers Positive	Most Probable Number	95% Confidence No Fewer than	95% Confidence No Fewer than
0	0	0	3.3
1	2.4	0.051	33
2	11	0.91	59
3	22	3.3	81
4	36	9.1	97
5	51	16	120
6	69	25	140
7	92	33	180
8	120	48	240
9	160	59	320
10	230	81	520
11	>230	130	N/A

Source: **Aquatest Technical Information Pack, 2011**

3.3.5.3. Laboratory Examination

Faecal Coliform

The Most Probable Number (MPN) method was used to determine faecal coliforms in the samples. Serial dilutions of 10^{-1} to 10^{-4} were prepared by picking 1 millimetre of the sample into 9 millimetre of sterile distilled water. One millilitre aliquots from each of the dilutions were inoculated into 5ml of MacConkey Broth and incubated at 44^0C for 18-24 hours. Tubes showing colour change from purple to yellow and gas collected in the Durham tubes after 24 hours were identified as positive for faecal coliforms. Counts per 100 millilitres were calculated from MPN Table.

E. coli (thermotolerant coliforms)

From each of the positive tubes identified a drop was transferred into a 5 millilitres test tube of trypton water and incubated at 44^0C for 24 hours. A drop of Kovacs' reagent was then added to the test tube of trypton water. All tubes showing a red ring colour development after agitation denoted the presence of indole and recorded as presumptive for thermotolerant coliforms (*E. coli*). Counts per 100ml were calculated from MPN tables.

Salmonella

Prepared 10 millilitres of manufactured formula of Buffered Peptone Water (BPW) was put in a universal bottle and serial dilution samples added to it. It is incubated at 37^0C for 24 hours. Then 0.1 millilitres of the sample from the BPW is placed in 10ml of Selenite broth in universal bottle and incubated at 44^0C for 48hours. Swaps from the bottle were made onto Salmonella Shigella Agar (SSA) and incubated for 48 hours at 37^0C.

Black colonies with an outer cream margin on the SSA indicate the presence of *Salmonella*. Suspected colonies are then confirmed with Triple Sugar Iron Agar (TSI Agar). Slants of this agar (TSI agar) is prepared in test tubes and swap of these suspected colonies is made with an inoculating loop and stabbed into the slants and incubated at 37^0C for 24 hours, positive colonies are indicated by a the formation of a black colour (H_2S production) in the slant, gas production, evident by cracks in the media, and yellow colouration as a result of acid production leading to pH change.

3.3.6.1 Distribution of the data

The data is tested for normality before performing any spatial modelling. Transformations necessary to drive the data to normal distribution in case of non-normality could include Box–Cox also known as power transformations, or logarithmic transformation.

3.3.6.2 Spatial interpolation

The estimation of the surface values at un-sampled points based on known surface values of surrounding points is known as spatial interpolation (Wade and Sommer, 2006). There are different interpolation techniques that can create surfaces from measured points, in GIS such as the Inverse Distance Weighted (IDW)) or Geostatistical interpolation techniques such as kriging which utilizes the statistical properties of the measured points and also quantify the spatial autocorrelation among measured points (Johnston *et al*, 2003).

This research used the IDW interpolation method to determine the suitability of drinking water sources. To determine the suitability of water for drinking purpose, the WQI was computed using the following four steps: (Asadi *et al,* 2007, Yidana and Yidana, 2010).

i. Each of the six measured parameters was assigned a weight (wi) on a scale of 1 to 5 based on their perceived effects on primary health. The maximum weight of 5 had been assigned to parameters like total coliforms, faecal coliforms, *E. coli*, and Salmonella. The pH was assigned a relative weight of 3 whilst temperature was assigned, on the scale, a minimum weight of 1 as it plays an insignificant role in the water quality assessment.

ii. The relative weight (Wii) of each parameter was computed from $W_{ii} = \frac{W_i}{\sum W_i}$

iii. In the third step, the quality rating scale (qi) for each parameter was calculated using: $q_i = \left(\frac{C_i - S_l}{S - S_l}\right) x100$

Where, qi is the quality rating, Ci is the concentration of measured parameter in each water sample and S is the WHO standard for each parameter and Sl represents their respective ideal values (Table 10).

- **iv.** Then water quality index WQI is computed from $WQI = Antilog[\sum W_{ii}\ log\ q_i]$(table 11A & 11B). (Tiwari and Mishra (1985), Asadi *et al*, (2007)).

Drinking water quality data based on bacteriological analysis was attributed to each sampling locations. The surfaces were generated and classified based on the desirable and permissible limits of individual parameters according to Ghana Drinking Water Guidelines. A drinking water quality classification map from thematic maps was later developed based on spatial and non-spatial data. Based on the location data obtained using GPS, ArcGIS, was used to prepare surface quality maps with the source positions superimposed on the surfaces in relation to community residents. Spatial and the non-spatial database formed were integrated for the generation of spatial distribution maps of the water quality parameters (Robinson and Metternicht, 2006; Goovaerts, 1999).

The screening criterion included the selection of drinking water sources microbiological concentration and creating a buffer distance of 500, 1000 and 1500 metres radius around each contaminated water drinking source. The exposed population to each contaminated water sources was calculated by multiplying the created buffer zone with the population density of the buffered area.

3.3.6.3 Model Validation

Validation should be carried out before producing the final surface, as it helps in making an informed decision as to which model provides the best predictions. The most popular methods for verifying predictions are cross validation and validation provided in ArcGIS Gcostatistical Analyst. In this research only the cross validation was used for model validation.

Cross-validation uses all of the data to estimate the model. Then it removes each data location, one at a time, and predicts the associated data value. For all points, cross validation compares the measured and predicted values. The fitted line in the prediction plot through the scatter of points with the generated regression equation indicates whether the model and/or its associated parameter values are reasonable.

CHAPTER FOUR

4.0 Results Analysis and Discussions

4.1.1 Socio-economic Characteristics of Respondents

The ages of respondents range between 18 to 55 years. The wide spread of respondents provided the appropriate platform to capture and understand community perception about water consumption, quality, waste disposal, hygiene and sanitation practices. Women with children less than five years were specifically targeted as such children are susceptible to water borne diseases. Women also suffer the burden of fetching water for domestic activities as it is generally accepted that female adults perform most household activities (Ahmed *et al.*, 1999).

The average number of household members is 5, lower than the national average of 5.1 people (GSS, 2010). However, majority of the people live in compound houses where they occupy single rooms. This condition is a prerequisite for overcrowding: a push factor for the deteriorating of household drinking water quality.

The educational status of respondents' showed that 4.7% have completed Senior Secondary School, 48.4 % had completed Junior High school, 31.3 % had Primary school education and 7.8% have had no formal education. They therefore responded variedly to perceptions of the quality of their drinking water sources.

The ability of households to dispose a part of their income to access portable water is paramount for the reduction of water related diseases in Nkawie. Averagely households spend Gh¢1.70 daily to access water. Table 5 shows the occupational distribution of respondents.

Table 5: Occupation of Respondents

Occupation	Frequency	Per cent
House wife	3	4.6
Self employed	24	36.9
Sales woman/service worker	2	3.1
Trader	20	33.1
Farmer	4	6.2
Unemployed	11	15.4
Total	**64**	**100**

Source: Author's Field Work

4.1.2 Distribution of Water Source Use by Respondents

Table 6, below shows that, 43.7% of all respondents had their drinking water from the piped system in their homes while 18.8% get theirs from public standpipes, 17.2 % use boreholes as their source of water supply. 14% of the respondents use protected wells and 6.3% rely on unprotected wells.

Table 6: Sources of Drinking Water

Water Source	Frequency	Per cent
Piped water	28	43.7
Public standpipe	12	18.8
Borehole	11	17.2
Protected well	9	14.0
Unprotected well	4	6.3
Total	**64**	**100**

Source: Author's Field Work

It is significant to underscore the fact that only 6.3% of all respondents access unprotected water source but the district is credited with having one of the highest cases of diarrhoea. Trevett *et al.* (2005) pointed out that water contamination at source may represent a greater hazard than contamination in the home. The quality of water points vary in quality and would normally show increased faecal contamination during wet season (Barret *et al*, 2000).

The distribution of sources suggest that respondents spend an average of 12 minutes to fetch water daily which is within the national threshold for time used to access water and within the 30minutes threshold of World Health Organization guidance (WHO, 2004).

4.1.3 Preference for Water Sources

Distance of water source accounted for 26% of the reasons why respondents use a particular water source, whiles reliability of the source accounted for 8% (Fig. 5). Distance to water sources in Nkawie is within the recommended guideline limits of the World Health Organization which stipulates that people must not cover a distance of 1km to access water (WHO, 2004).

Perceived water quality is probably one major driving reason for community preference to a particular water source as revealed in Fig. 5. Non availability of safe drinking water is associated with the four categories of water related diseases as stated by Bradley, (1977) which are; water borne, water-washed diseases, water-based diseases and insect vector-related diseases. Waterborne diseases are caused by drinking polluted water containing urine or faeces and include typhoid, bacillary and amoebic dysentery, cholera and other diarrhoeal diseases.

Furthermore, water-washed diseases such as trachoma, flea, scabies, lice and tick-borne illnesses are as a result of bad personal hygiene and contaminated water. Water-based diseases also result from parasites that live in water-based organisms (Jamison *et al*, 2006).

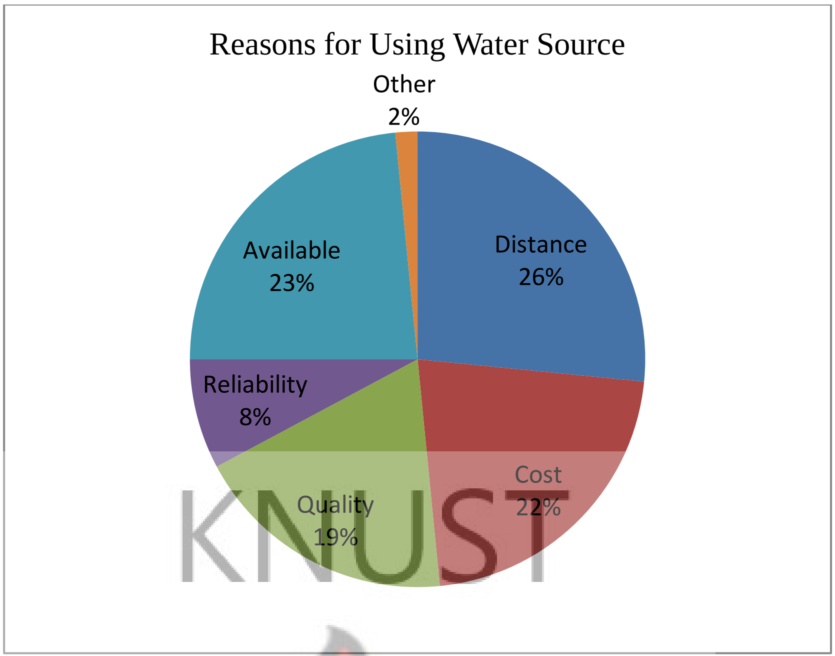

Fig 4: Reasons for Water Usage

4.1.4 Respondents Perception of Water Quality

66.7% of respondents did not know that their primary drinking water sources have been tested and declared safe for drinking. 27.8% thought their primary water source has been tested and so the water is safe whilst. 22% indicated that they treat their water before drinking.

It is generally accepted, that the microbiological quality of drinking water is of fundamental importance and should never be compromised in favour of aesthetically acceptable water as indicated by Dietrich (2006), It is estimated that 80% of all illnesses are linked to use of water with poor microbiological quality (WHO, 2002). Water that is contaminated with microbiological constituents is considered unsafe and can cause a variety of diseases, with diarrhoea as their main symptom (WRC, 1993).

According to respondents water collected from public sources and stored showed presence of contaminations as indicated in Table 7 below.

Table 7: Presence of Visible Particles in Water

Presence of Particle	Frequency	Per cent
No Visible Particles	32	50.8
Less often	21	33.3
Often	7	11.1
Very Often	4	4.8
Total	**64**	**100**

Source: Author's Field Work

The presence of visible particles in about 49.2% of drinking water is a potential threat to the health of respondents. Such contaminants could be microbiological, coming primarily from human or animal faeces mixing with drinking water sources, during transport, or at the point of use (Howard and Luyima, 2000)

4.1.5 Water Source Management and Cleanliness of Source Surroundings

Water sources in the community are managed by the government, community and individuals. The pipe system is managed by the Ghana Water and Sewage Company whiles the boreholes and wells are managed mostly by the community and individuals respectively. There was also no functional Water and Sanitation Committees (WATSANS) in the study area.

The surroundings of the wells are regularly cleaned as against the other water sources. This is because the other water sources are seen as communal properties. The Abotia well, which was a mechanized system, was in a very deplorable condition. This water point, services a greater part of the population around Nkawie and Kuma. The surroundings were bushy with choked outlets at the time of this survey with debris and plastic wastes commonly around the borehole. The outlet was greenish with stagnating water around it. Users of the facility were also seen washing around the water source. According to WHO (2006), poor drainage around water points, causes water related diseases. It is also associated with bad smell caused by growing algae, grasses and waste from livestock. In addition, there is the possibility of waste water re-entering the source (Demeke, 2009).

4.1.6 Water Collection and Storing Containers

Water storage containers are believed to be the major factors leading to the deterioration of stored water (Jagals *et al*., 1999; Trevett *et al*., 2005).

Studies have shown that water stored in open-top buckets is of lower microbiological water quality than water stored in screw-top closed containers (Jagals *et al.*, 1997). Uncovered containers are exposed to environmental conditions, such as dust and dirt, which may contribute to the deterioration in water quality (Jagals *et al*., 1997; Trevett *et al.*, 2005). In addition, storage containers placed on the floor may be more likely to be contaminated by animals or children than containers placed on an elevated surface (Jensen *et al.*, 2004). Daily, 42.6% of respondents clean their water storage facilities, 29.5% of respondents clean their cisterns more than once a week, 24.6% clean these containers weekly and 3.3% do the cleaning more than once a month. About 72.4% of storage containers had lid whiles 27.6% did not have.

Inspection of drinking water containers indicated that 50.9% were clean and 49.1% were not. Research have suggested that the vessels used to fetch water from the storage container may also contribute to the microbiological deterioration of water quality (Jagals *et al.*, 1997). In many of the households, containers for fetching water were placed unguardedly on the floor.

The major water collecting materials used to fetch water from sources are jerry cans and pans. A jerry can, also known as jerrican, was originally a robust fuel container designed in Germany in the 1930s for military use to hold 20 to 25 litres of fuel. Today similar designs are produced in plastic as water containers. The use of jerry cans reduces the burden of carrying heavy containers for water as these are made from light material and it also minimizes the possibilities of post contamination as water can be tilted to flow from the jerri can instead of the dipping of cups into other container types.

Studies conducted around the globe have shown that the level of water contamination is high at the point of consumption than at the point of collection (Licence *et al*, 2007). The method used to draw water either from the source or storage containers is crucial to post contamination of water sources. Unfortunately, adequate cleaning of the can is limited since the cleaning material cannot reach the base of it. Examination of jerricans at public water sources revealed greenish and sometimes dark patches of growth at the base. The collection pans are similarly easily exposed to microbes since they are not covered during the collection of water.

4.1.7 Refuse Disposal

Good water supply conditions without sanitation and hygiene behaviour is practically a fruitless venture (Water Aid, 2009). Respondents making up of 74.2%, dispose of their refuse to garbage bins supplied at transfer sites. 24.2% only send their household wastes to open fields and 1.6% compost their waste.

There are five public refuse disposal sites in the study area which virtually have become like land filling sites because they have no containers except one near the market which had an over-flowing refuse container. Some of these dumps are close to water sources. A typical example is the Abotia Well which is close to a huge drain turned into a refuse disposal site. Due to the District Assembly's lack of equipment to manage the volume of refuse generated, it is common to see huge volumes of refuse piled up at the various refuse dumps.

In the case of Faecal Matter Disposal, about 30.5% of respondents disposed of faeces in plastic bags and placed them in waste bin or heap. 59% dispose children's faeces in latrine and bucket toilets, 5.1% bury them in the soil whiles 1.7% do nothing with the faeces of their children. In the case of animal stools, 52.4% of respondents put their animal stool into garbage bins, 42.9% dispose theirs in drains ditches and gutters whiles 4.8% put into latrines.

The availability of toilet facilities in households ensures a more efficient and hygienic method for human waste disposal. Faecal matter has been reported as the main cause of some water borne diseases. As stated by Sarkar *et al* (2007), open air defecations, among communities, lead to contamination of the water supply system and result in outbreaks of diarrhoeal disease. It was found that, there were only 15.3% households with functional latrines with 84.7% households without functional latrine.

Among the households sampled, 39% were clean whilst 27% were found dirty (Fig. 7). In addition, 23.7% of households had animals on their compounds whiles 76% had no animals. The practice of tethering animals close to human dwellings and the consequent proximity to animal faecal matter enhances the risk of contamination of drinking water (Licence *et al,* 2007). According to Curtis *et al* (2000), improving domestic hygienic practices is potentially one of the most effective means of reducing the burden of the diarrhoeal diseases in children. (Vanderslice and Briscoe, 1995)

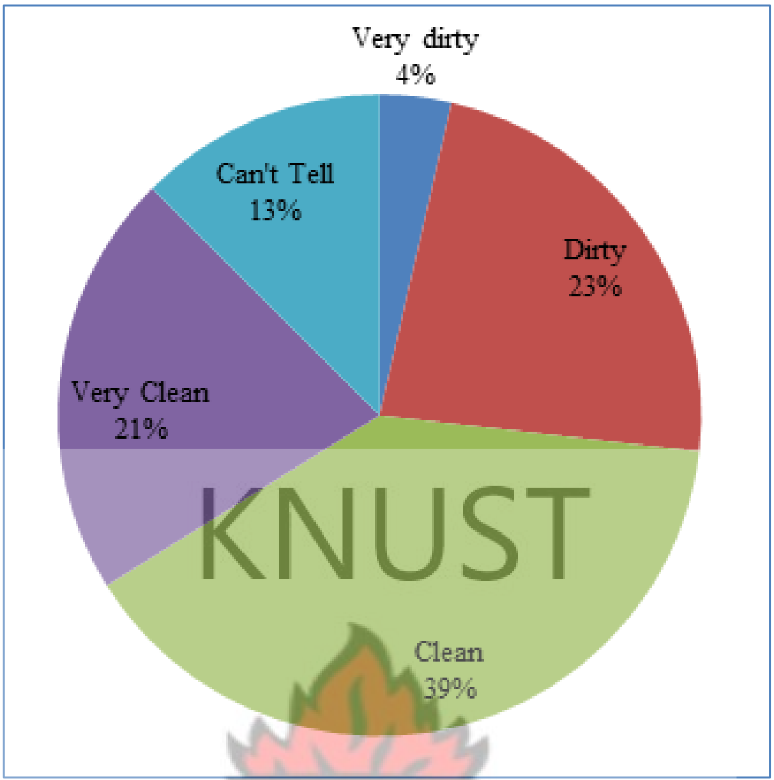

Figure: 5. Household Cleanliness

4.2 Bacteriological Analysis

An estimated 75% of both improved and unimproved drinking water samples analyzed showed concentrations of total coli forms, faecal coli forms, *Escherichia coli* and *salmonella* well beyond approved recommended levels of the Ghana Standard Authority and WHO guidelines (Table 9 and Table10).

The Zongo Well had the highest levels of total coliforms (4.2 $x10^4$ cfu) and the least was that of Nkawie Payin Borehole 1 (NkaPayBH1) was (1.3 $x10^4$cfu).

Apart from the NkawiePayBH1 which had no faecal coliforms, all the other drinking water sources had concentration exceeding recommended levels in the guidelines. The highest of 1.6 $x10^2$ cfu was recorded for Zongo Well.

The Zongo well also had the highest level of *E. coli* recording 0.15 $x10^2$cfu whiles the wells at Botswana, Asuofia, NkawiePayBH and Abotia BMB were within recommended levels (Table 8). According to Ali (1996), however, a negative test for *E. coli* in water samples does not necessarily imply that *E. coli* is entirely absent in the sample because *E. coli* is likely to be detected only when there is bacteria activity in the sample.

The borehole NkawiePayBH1 recorded 0.21 $x10^2$ cfu for the concentration of *salmonella* which is the highest whiles Abotia BMD, NkawiePayBH, Asuofia Well and "*Botswana"* recorded no concentration of *Salmonella.*

Table 8: **Bacteriological Quality**

Sample ID	**Total Coliforms/100ml** ($x10^4$)	**Faecal coliforms/100ml** ($x10^2$)	***E. coli/100ml*** ($x10^2$)	***Salmonella/100ml*** ($x10^2$)
School CPD	2.3	1.2	0.05	0.15
Well Zongo 1	4.2	1.6	0.15	0.11
BotswanaWell	1.6	0.9	0	0
NkawPayBH1	1.3	0	0.12	0.21
Nkaw SP	2.5	0.56	0.08	0.18
Asuofia Well	3.1	1.1	0	0
NkawPayWell	2.5	1.4	0.12	0
NkawPayBH	1.8	0.65	0	0.13
Abotia BMB	2.3	1.2	0	0

Table 9: **Physical Parametres**

Sample ID	School CPD	Zongo Well	Bots Well	Nkaw PayB1	Asuofia Well	Nkaw SP	Nkaw PayWell	Nkaw PayBH	Abotia BMB
Temp. (^{o}C)	28	28.7	28.8	29.2	28.7	28.5	29.3	28.6	29.7
pH	4.98	5.64	5.1	5.71	6.57	5.3	4.85	5.38	4.92

For water to be considered as of no risk to human health, total coliforms, bacteria and *E. coli* should be zero (Table 11).

Table 10:

Water quality standards, ideal value and weightage factors considered for Water Quality Index calculations.

Parameter	WHO Standard	Ideal Parameter Value	Weight	Relative Weights
Total coliforms	0.05	0	5	0.208
Faecal coliforms	0.05	0	5	0.208
E. coli	0.05	0	5	0.208
Salmonella	0.05	0	5	0.208
Temperature	33	25	1	0.043
pH	8.5	7	3	0.125

From Tables 10, 11 and 12, it can be seen that, most of the drinking water sources in Nkawie tested were well below the Ghana Standards Authority's and WHO recommended guidelines. The total and faecal coliforms, *E. coli* and *salmonella* were conducted to assess bacteriological water quality of public drinking water sources. Total and faecal coliforms are usually associated with faecal contamination and thus their numbers reflect the degree of health risk. Traditionally, total coli forms have been used to indicate the presence of faecal contamination. However, this parameter has been found to exist and grow in soil and water environments and is therefore considered a poor parameter for measuring the presence of pathogens (Stevens *et al.*, 2003). According to Green (1998), *Escherichia coli* remain an important worldwide cause of diarrhoea disease and mortality of infants and young children.

The poor bacteriological quality of water sources might be due to contamination caused by human activities and livestock tethering (Trevett *et al.*, 2005).

It is therefore not surprising that, even though the Atwima-Nwabiagya District has 95% water coverage, it has constantly placed third with regards to reported diarrhoeal cases.

4.2.1 Drinking Water Quality Index

A Water Quality Index (WQI) provides a single number (like a grade) that expresses overall water quality at a certain location and time based on several quality parameters. The index thus turns various water quality data into a single measurable, understandable and useable value that can be compared. The WQI provides a very useful and efficient method for assessing and comparing the quality of water from various sources (Veerabhadram, 2005), and could also be a useful tool for communicating information on overall quality of water. Below is the calculated WQI for the water sampled in Nkawie for the research work.

Table 11A: Water Quality Index Description

Sample ID	**Total coliforms**	**qi**	**Feacal coliforms**	**qi**	***E. coli***	***qi***	***Salmonella***	***qi***
Abotia BMB	23000	1.178	120	0.703	0.05	0	0.05	0
Asuofia Well	31000	1.205	110	0.695	0.05	0	0.05	0
Botswana Well	16000	1.145	90	0.677	0.05	0	0.05	0
NkawiePayBH	18000	1.156	65	0.648	0.05	0	13	0.502
Nkawie PayBH1	13000	1.126	0.05	0	12	0.495	21	0.546
NkawieSP	25000	1.185	56	0.634	8	0.458	18	0.532
Nkawwie Pay Well	25000	1.185	140	0.717	12	0.495	0.05	0
School CPD	23000	1.178	120	0.703	5	0.416	15	0.515
Well Zongo	42000	1.232	160	0.729	15	0.515	11	0.487

Table 11 B: Water Quality Index Description

Sample ID	Temp. (oC)	*qi*	pH	*qi*	WQI
Abotia BMB	29.7	0.119	4.92	1.073	1183.04
Asuofia Well	28.7	0.119	6.57	0.388	255.27
Botswana Well	28.8	0.119	5.1	1.033	941.89
NkawiePayBH	28.6	0.119	5.38	0.964	2449.06
Nkawie PayBH1	29.2	0.119	5.71	0.865	1415.79
NkawieSP	28.5	0.119	5.3	0.985	8184.65
Nkawwie Pay Well	29.3	0.119	4.85	1.087	4008.67
School CPD	28	0.118	4.98	1.06	9772.37
Well Zongo 1	28.7	0.119	5.64	0.888	9332.54

Computed WQI values have been classified into five categories as excellent, good, poor, very poor and unfit for drinking (Table 12).

Analysis of the water samples for the various parameters as per WHO standards and the determination of water quality index (WQI) that reflects the extent of water contamination. These results are presented spatially using Geographical Information System Software (GIS).

Table 12: WQI Range and Meaning

WQI Range	Type of Water
0-50	Excellent Drinking Water.
50-100	Good Drinking Water
100-200	Poor Drinking water
200-300	Very Poor Water
300 and above	Unfit for Drinking.

Per the categorization of drinking-water systems based on compliance with performance and safety targets for population between 5000 to100000 (WHO, 2004), Nkawie's drinking water sources are poor (Table 14), based on the fact that more than 70% of water tested proved positive to total coliforms, faecal coliform, *E. coli and Salmonella.*

Table 13: Safety Targets and Population Characterization

Water Quality	Proportion (%) of samples negative for *E. Coli*		
	Population Size		
Excellent	<5,000	5,000-100,000	>100,100
Good	90	95	99
Fair	80	90	95
Poor	70	85	90
Very Poor	60	80	85

(WH0, 2004)

4.2.2 Distribution of Water Sources in Nkawie

The spatial distributed water drinking sources in Nkawie is shown below.

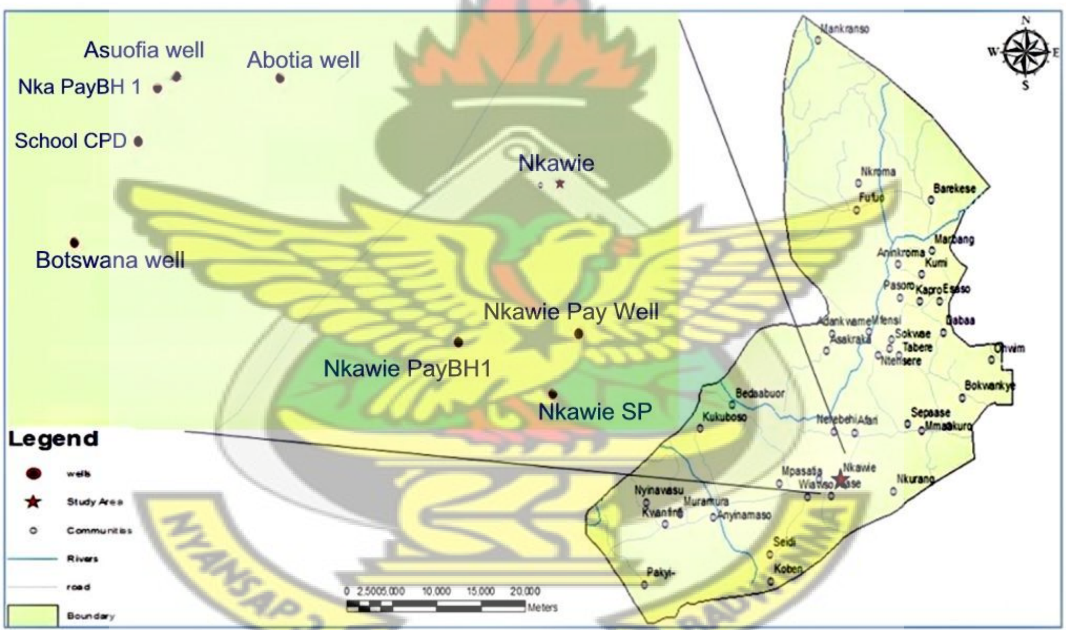

Figure: 6. Distribution of Water Sources in Nkawie.

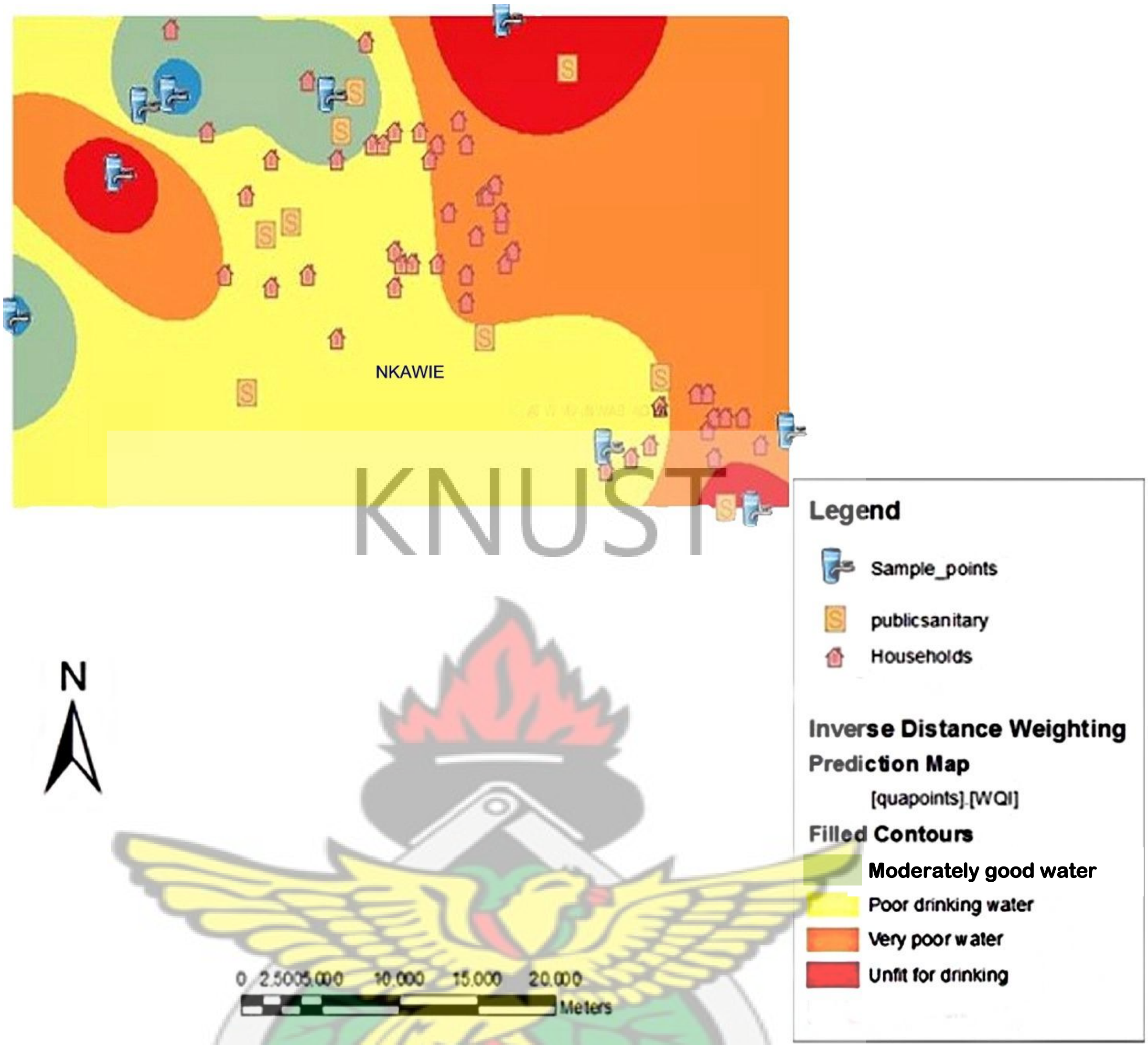

Figure: 7. Spatial Distribution of Water Quality in Nkawie.

Figure 9 shows a surface map of the distribution of water quality over Nkawie. As seen, all water drinking sources did not meet recommended level as per the computed quality values. The Nkawie payBH1, Abotia BMB and the Botswana are within the good drinking water region. The Nkawie BH is within the poor drinking water region whereas the Nkawie Pay Well is within the region classified as very poor water for drinking. The Nkawie SP, the school CPD and the Zongo well are all in the unfit for drinking region.

The only functional public standpipe in the study area failed all the considered bacteriological parameters. This result however could be the result of contamination through broken pipes along the transmission line. This assertion however needed investigation but it is worth noting that there is a KVIP toilet facility just close to this standing pipe.

Contamination of wells might probably have come from runoffs as a result of rainfall since the water sampling was conducted in the raining season. Runoffs have the propensity of blowing and carrying particulate matter over partially and unconfined well surfaces. The shallowness of wells as was seen in the School CPD also facilitates the contamination of the water source through animal waste. The proximity of wells to toilet facilities, refuse dump, improper waste disposal and open wells were noted as possible sources of well contamination.

Contamination of boreholes could also be attributed to the proximity to latrine, refuse dump and unhygienic environment around the boreholes. The proximity of the water source to the contaminants fall short of the recommended 30 metre distance by World Health Organisation. It could also be that the riser pipes have cracks or might not have been fixed properly thus allowing seepage of microbial contaminants into the boreholes. Inadequate protection measures during construction could allow pollutants to bypass the natural soil protection given by the aquifer. According to Ham (1996), the risk of faecal groundwater pollution from pit latrines is minimal when the thickness of relatively fine unconsolidated strata between the base of the latrine and the highest elevation of the groundwater table is greater than 2m.

The quality test conducted concluded that the two public boreholes (NkawPayBH and NkawPayBH1) had the lowest bacteria count which may be due to the depth, thickness and nature of the soil overlying the aquifer.

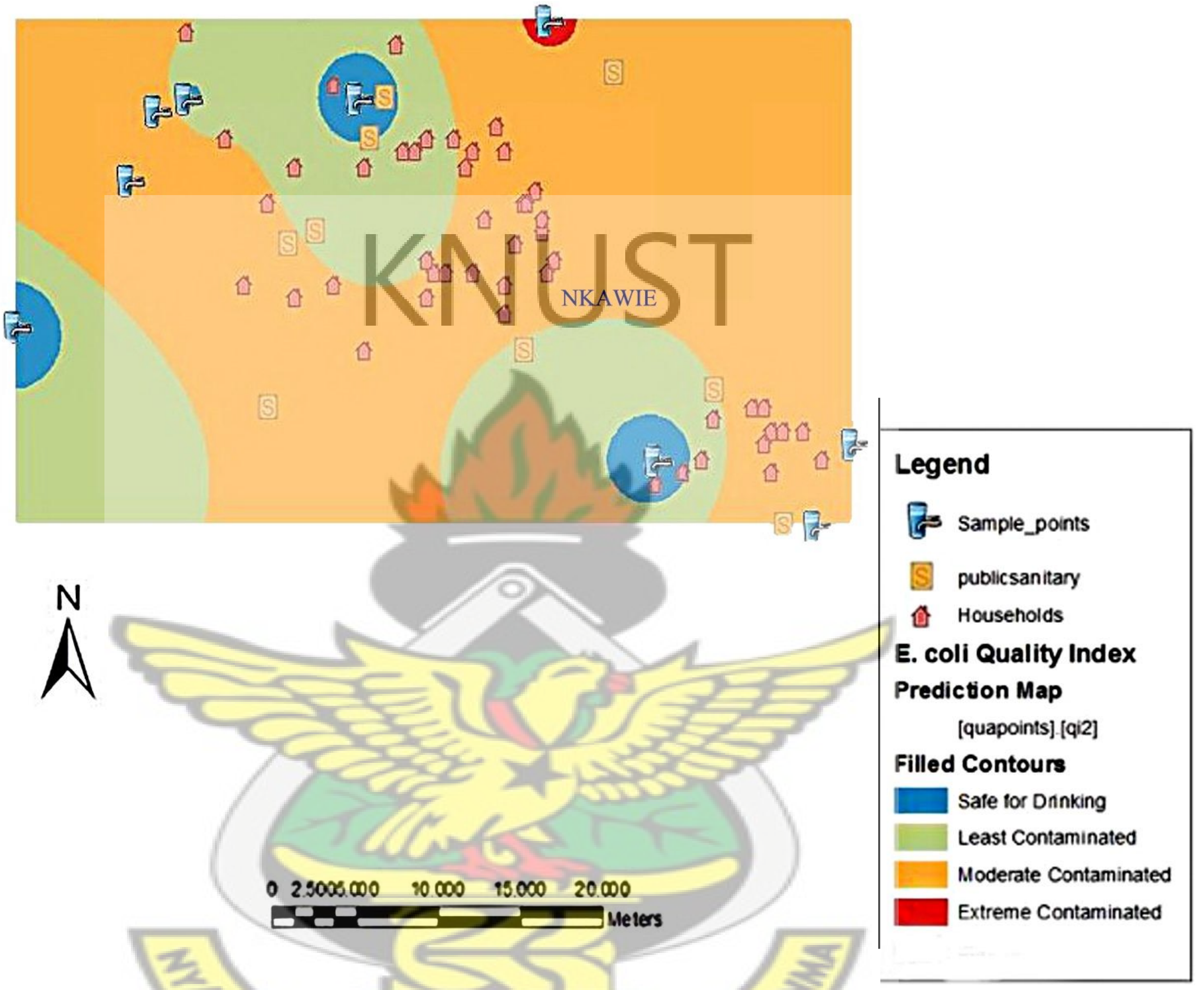

Figure 8: Water Contamination Surface by *E. coli*.

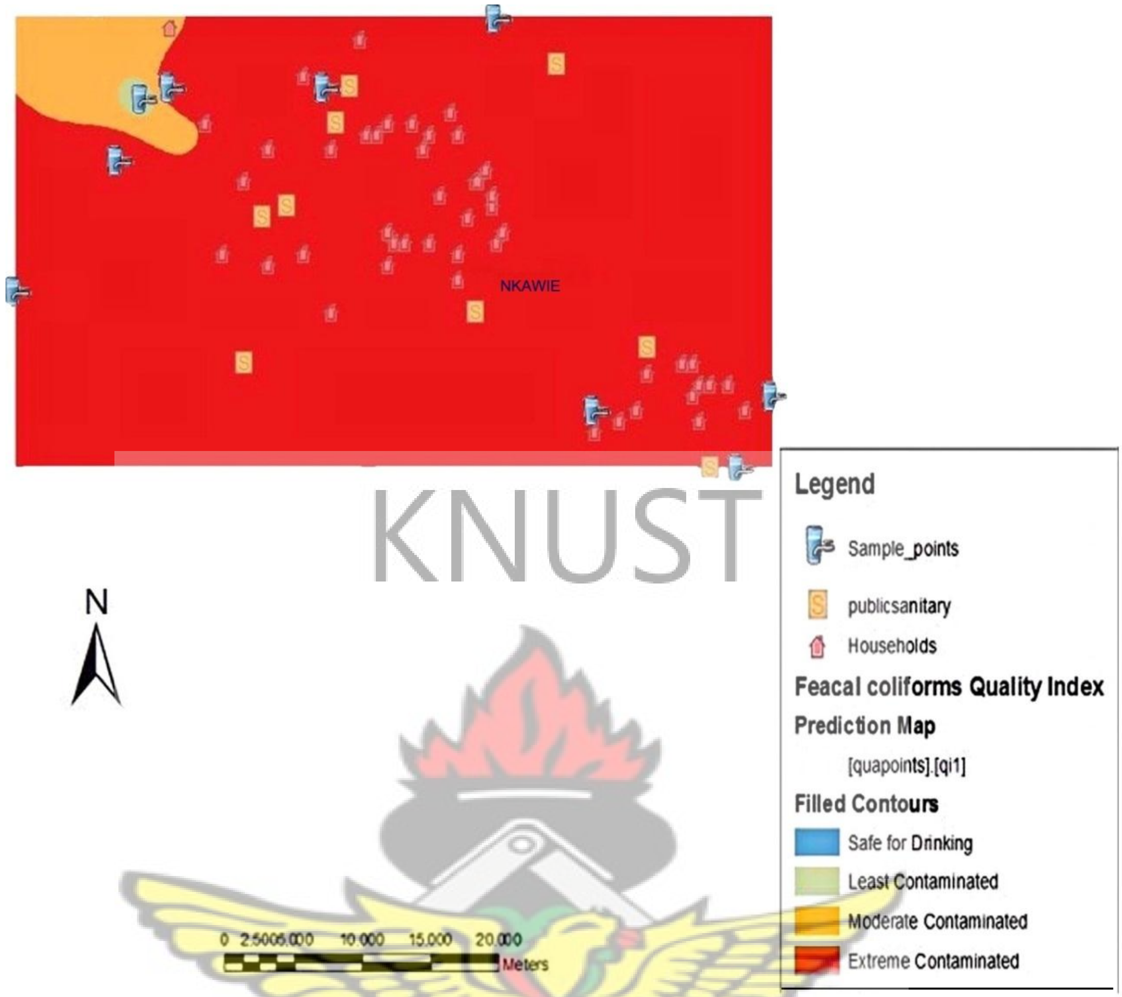

Figure 9: Water Contamination Surface due to Faecal Coliforms.

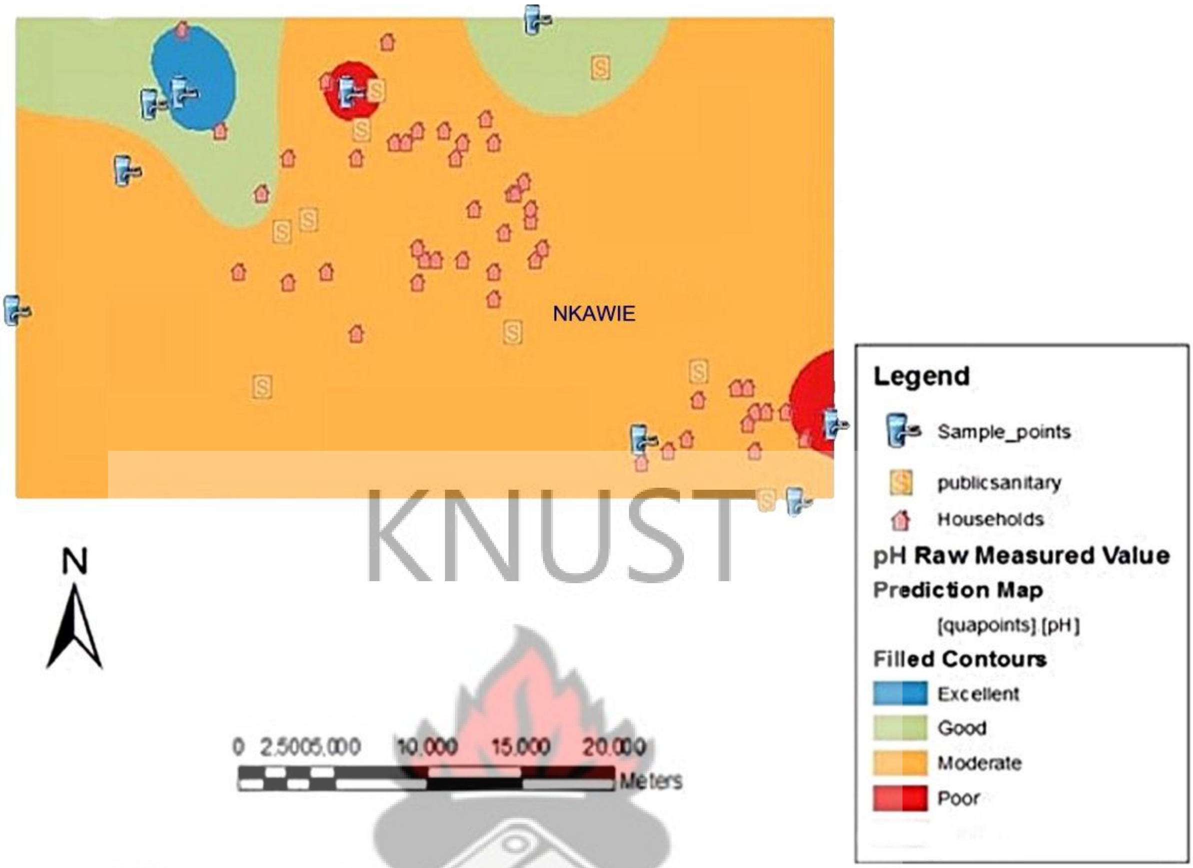

Figure 10: pH Distribution in Drinking Water.

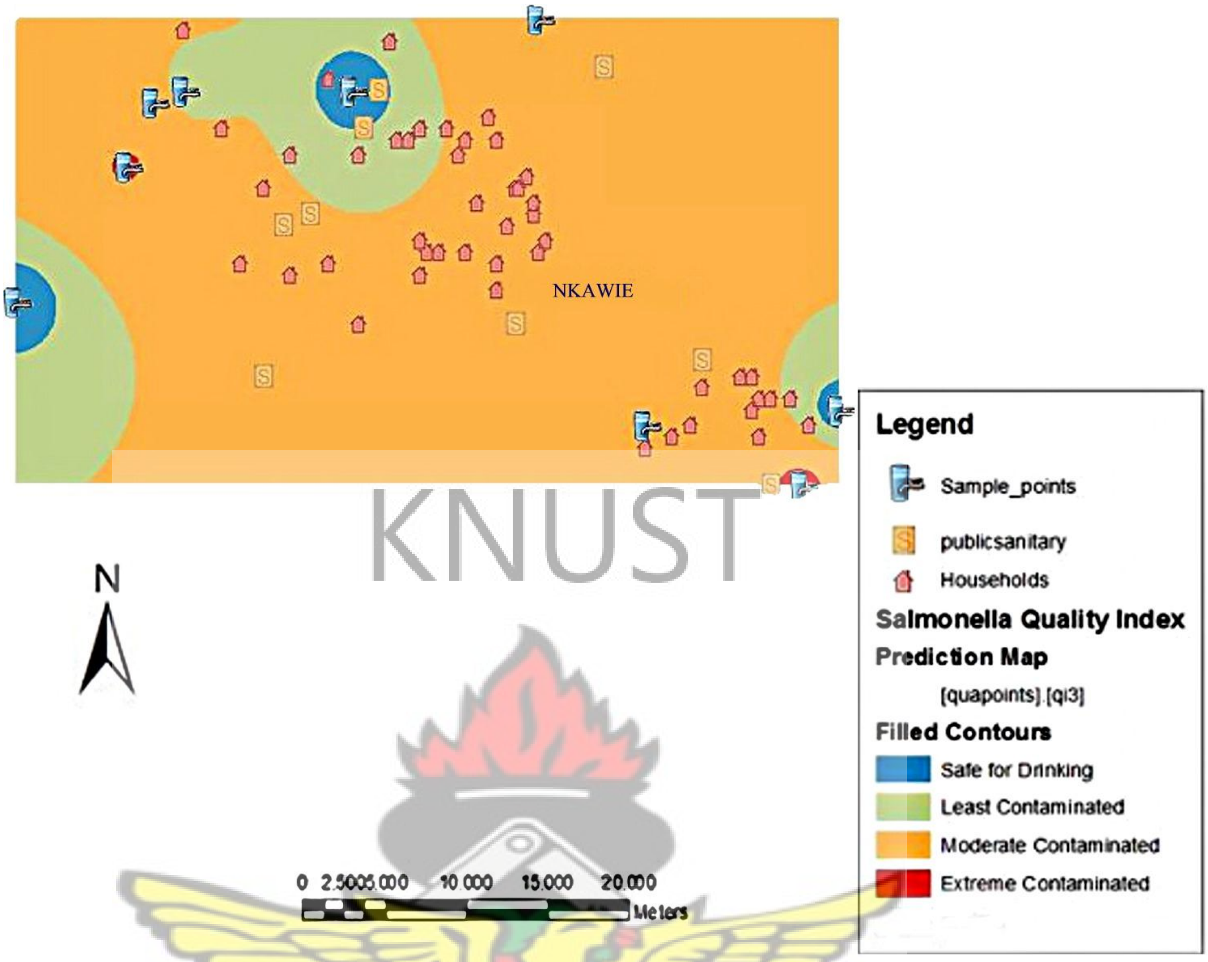

Figure 11: Spatial Distribution of *Salmonella* Contamination.

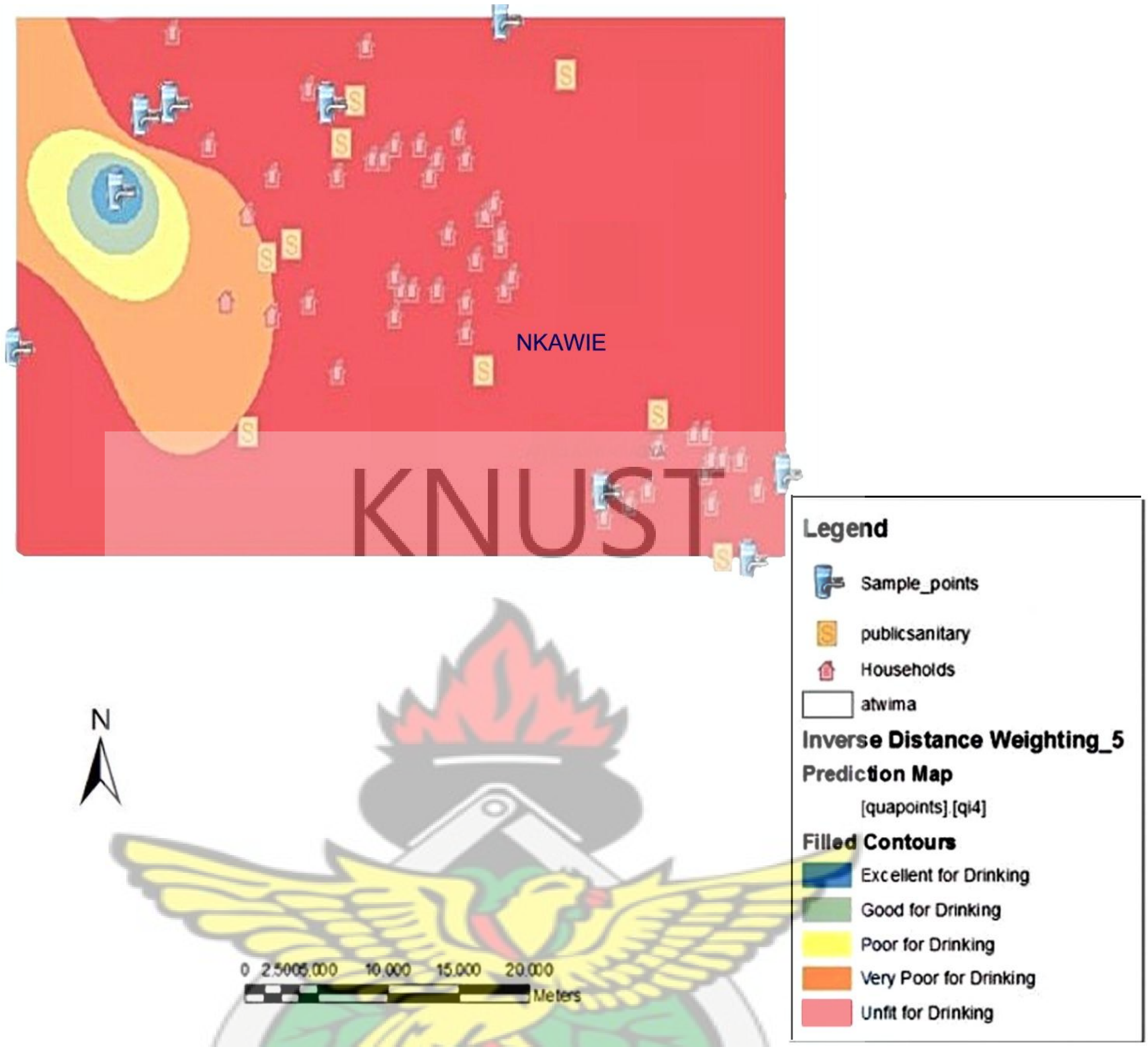

Figure 12: Inverse Distance Weightings Prediction Map

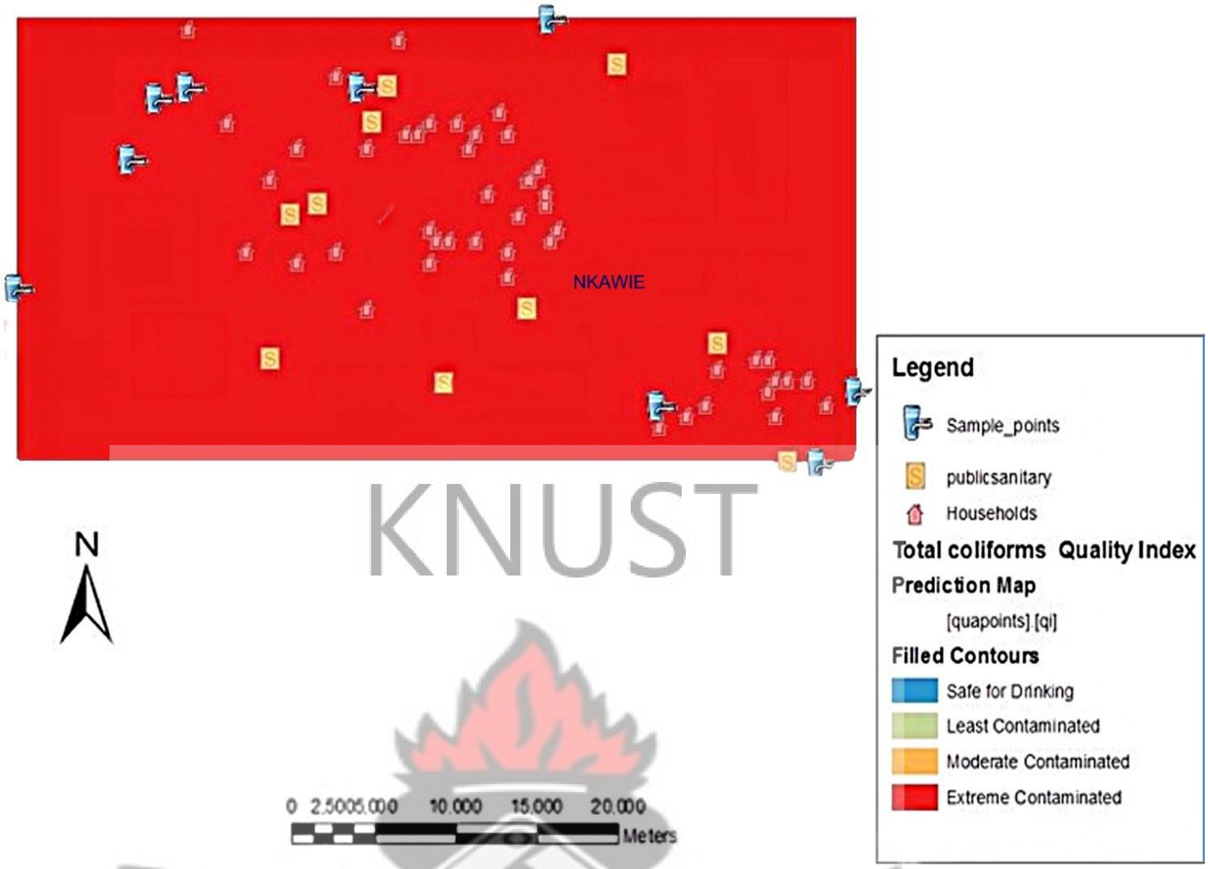

Figure 13: Total Coliforms Surface

Table 14: Estimated Distance of Water Sources to a Sanitary Facility/Site

Description	Distance (Metres)
Zongo Well to Refuse Dump E	145
Abotia Well to Refuse Dump (Gutter)	114.02
Asuofia to Refuse Dump (Gutter)	292.63
NkawPayBH1 to Refuse Dump (Gutter)	451.41
SCH CPD to Refuse Dump D	475.16
Botswana Well to KVIP A	533.46
NKawPayBH to Refuse Dump A	170.30
NkawSP to KVIP B	35.91
NkawPay Well	168.97

Authors' Field Work

CHAPTER FIVE

5.0 Conclusion and Recommendation

5.1 Conclusion

Even though, Nkawie has 95% water coverage, it is still challenged with water borne diseases. The drive to make water available to the public is in tandem with the provisions of the Millennium Development Goal which aim to provide sustainable access to improved drinking water sources for people without water.

The study of spatial analysis and interpretations of water quality demonstrates that the applied GIS methodology is a useful tool in evaluation and describing the spatial distribution of water quality characteristics. The conclusions from this research revealed that public drinking water sources in Nkawie were contaminated beyond guidelines recommended by WHO and Ghana Standard Authority.

The spatial interpolation for the water quality data carried out using the Inverse Distance Interpolation surface method to produce the water quality map shows the spatial variation of water quality over the study area. .

The research revealed serious water quality, hygiene and sanitation challenges which has resulted in the district recording high cases of water borne diseases especially diarrhoea.

5.2 Recommendations

There should be regular monitoring of public water drinking sources for bacteriological quality and other parameters to ensure that they meet the required guidelines. Institutions should be strengthened with resources to monitor bacteriological quality of public water drinking sources.

A lot of awareness creation and activities should be done on sanitation and hygiene through extension workers in homes, schools, churches, mosques, markets and other public places. The District Assembly should design sanitation programmes and propagate these through environmental education in the community to prevent pollution of water bodies and the spread of water related diseases.

Wells should be sited at least 30 metres away from septic tanks, latrines and refuse dumps. Wells and boreholes aprons should be well reinforced with steel wire to avoid cracking. Receptacles for drawing water from open wells should be kept clean and well lids must be kept dry, clean and covered always. Also, wells must be well lined with concrete rings instead of cementing.

Improved forms of latrines and proper waste disposal facilities should be constructed for the inhabitants living in the community to avoid defecating and indiscriminate waste disposal in communities.

Water resource management programmes which seek to minimize faecal pollution of wells, boreholes and surface waters within communities must take the form of an integrated approach. There must be the need for greater community participation in water management as it is crucial to poverty reduction, economic growth, food security and maintenance of natural resources.

GIS and related technologies such as the GPS are useful for providing precise locations and other stationary data in researches and it should be encouraged since it can identify source and route of potential exposure in a study area and estimate levels of target contaminants and exposure assessment activities.

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APPENDIX

Appendix 1: Sampled Household locations.

No.	Household ID	X-Coordinates	Y-Coordinates
1	NK.B.01	W001.80276	N06.66193
2	NK.B.02	W001.80486	N06.66346
3	NK.B.02	W001.80216	N06.66382
4	NK.B.03	W001.80276	N06.66194
5	NK.B.04	W001.80436	N06.66357
6	NK.B.05	W001.80296	N06.66372
7	NK.B.06	W001.80415	N06.66381
8	NK.B.07	W001.80308	N06.66414
9	NK.C.01	W001.80296	N06.66417
10	NK.C.02	W001.80284	N06.66424
11	NK.C.04	W001.80254	N06.66425
12	NK.C.05	W001.80394	N06.66450
13	NK.C.06	W001.80312	N06.66468
14	NK.C.07	W001.80334	N06.66471
15	NK.C.07	W001.80334	N06.66471
16	NK.D.01	W001.80946	N06.66543
17	NK.D.02	W001.80724	N06.66608
18	NK.D.02	W001.80724	N06.66608
19	NK.D.03	W001.81049	N06.66626
20	NK.D.03	W001.81049	N06.66626
21	NK.D.03	W001.81049	N06.66626
22	NK.D.04	W001.80846	N06.66627
23	NK.D.04	W001.80846	N06.66627
24	NK.D.05	W001.80722	N06.66637
25	NK.D.05	W001.80722	N06.66637
26	NK.D.06	W001.81126	N06.66652
27	NK.D.07	W001.80992	N06.66653
28	NK.D.07	W001.80992	N06.66653
29	NK.E.01	W001.80654	N06.66662
30	NK.E.01	W001.80654	N06.66662
31	NK.E.02	W001.80818	N06.66664
32	NK.E.04	W001.80776	N06.66668
33	NK.E.07	W001.80838	N06.66670
34	NK.E.07	W001.80838	N06.66670
35	NK.F.05	W001.80851	N06.66687
36	NK.F.01	W001.80640	N06.66691
37	NK.F.04	W001.80698	N06.66703
38	NK.F.06	W001.80656	N06.66728
39	NK.F.07	W001.80667	N06.66738
40	NK.G.02	W001.80753	N06.66744
41	NK.G.03	W001.80695	N06.66766
42	NK.G.04	W001.81100	N06.66769
43	NK.G.05	W001.80682	N06.66774

44	NK.G.06	W001.80671	N06.66781
45	NK.G.07	W001.80944	N06.66815
46	NK.H.01	W001.80784	N06.66817
47	NK.H.02	W001.81049	N06.66836
48	NK.H.03	W001.80861	N06.66840
49	NK.H.05	W001.80718	N06.66842
50	NK.H.06	W001.80882	N06.66848
51	NK.H.07	W001.80771	N06.66852
52	NK.H.08	W001.80840	N06.66855
53	NK.I.01	W001.81165	N06.66856
54	NK.I.02	W001.80803	N06.66870
55	NK.I.03	W001.80740	N06.66876
56	NK.I.04	W001.80990	N06.66947
57	NK.I.06	W001.80898	N06.67000
58	NK.I.06	W001.80898	N06.67000
59	NK.J.02	W001.81225	N06.67017
60	NK.J.03	W001.81342	N06.67066
61	NK.J.04	W001.81341	N06.67067
62	NK.J.05	W001.81357	N06.67127
63	NK.J .06	W001.81367	N06.67147
64	NK.J.07	W001.81358	N06.67177

APPENDIX 2: Public Water Sources

Sampling Point	X-Coordinates	Y-Coordinators
School CPD	001.81320	06.66799
Zongo Well	001.80652	06.67065
Botswana Well	001.81487	06.66592
NkaPayBH1	001.81271	06.66909
NkaSP	001.80238	06.66281
Asuofia Well	001.81221	06.66932
NkaPay Well	001.80170	06.66402
NkaPayBH	001.80484	06.66386
Abotia BMB	001.80950	06.66929

Appendix 3: Public Sanitary Facilities

Sanitary Facility	X Coordinates	Y-Coordinators
KVIP (Private)	001.81022	06.66717
KVIP A	001.81061	06.66713
KVIP B	001.80287	06.66293
KVIP C	001.80693	06.66550
Refuse Dump A	001.80389	06.66490
Refuse Dump B(Gutter)	001.80912	06.66922
Refuse Dump C	001.80697	06.66540
Refuse Dump D	001.80931	06.66858
Refuse Dump E	001.80552	06.66961

KWAME NKRUMAH UNIVERSITY OF SCIENCE AND TECHNOLOGY

COLLEGE OF ENGINEERING

DEPARTMENT OF MATERIAL ENGINEERING

HOUSEHOLD QUESTIONNAIRE

HOUSEHOLD INFORMATION PANEL		**HH**
HH1. Cluster number: ___ ___ ___	HH2. Household number: ___ ___ ___	
HH3. Interviewer name and number: Name____________________ ___ ___	SERIAL NUMBER OF QUESTIONNAIRE ( ) **GPS Location of dwelling ___ ___ ___**	
HH5 Name of Locality	**Domestic water code**	**Public water code**
HH7. Day/Month/Year of interview:	___ ___ / ___ ___ / ___ ___ ___ ___	

I am from KNUST and working on a project concerned with family health. I would like to interview you on the subject matter and it will take about (***25***) minutes. All the information we obtain will remain strictly confidential.

PLEASE TICK

A. SOCIO – DEMOGRAPHIC BACKGROUND

1. Estimated age

1. Less than 15 years [ ] 2. 15-19 years [ ] 3. 20-29 years [ ] 4. 30-39 years [ ]
5. 40-49 years [ ] 6. 50-59 years [ ] 7. 60 or more years [ ]

2. Sex 1. Male [ ] 2. Female [ ]

3. Educational level?

1. No formal education [ ] 2.Completed primary school/JSS [ ]
3. Completed secondary school [ ] 4. Completed university [ ]

4. How many people make up your household? ……………….

5. Occupation

1. House wife [ ] 3. Civil servant [ ] 4. Artisan [ ] 5. Professional [ ]

6. Self employed [ ] 7. Trader [ ] 9. Farmer [ ] 10. Unemployed [ ]

6. Marital status

1. Single [ ] 2. Married [ ] 3. Living with partner [ ] 4.Widowed [ ]

5. Divorced/Separated [ ]

B. WATER SOURCE

1**.** What is the main source of DRINKING WATER for members of your household?

1. Piped water [ ]
2. Protected spring [ ]
3. Unprotected spring [ ]
4. Public tap/standpipe [ ]
5. borehole [ ] ....
6. Unprotected well [ ]
7. Rainwater collection [ ]
8. Tanker-truck [ ]
9. Cart with small tank/ drum [ ]
10. Surface water river, stream, dam,lake
6. Protected well [ ] ....
11. Sachet and bottled water

2. Why do you choose to get water from this place mentioned in B1?

[**Please rank 1-8 with 1 being the most important reason and 8 being the least important]**

REASONS	**RANK**	**REASONS**	**RANK**
Distance		Only source	
Cost.		Only tap	
Quality		Personal/family reasons	
Reliability		Other	
Available		…………………………………………….	

4**.** Please indicate your perception of the water quality of the source mentioned in B2.

1. Unacceptable [ ] 2. Favorable [ ] 3. Highly favorable [ ]
4. No comment given by the informant or no effect [ ]

5. What kind of container do you use to collect/draw water at the source?

1. Bucket [ ] 2. Jerry can [ ] 3. Barrel/ drum [ ] 4. Clay-pot [ ] 5. Bottles [ ] 6. No container [ ] 7. Basin pan [ ] 8. Other…………….

6. How many jerry cans of water do you collect from this source each day? ……………

7. Do you pay for water from this source? 1. Yes [ ] 2. No [ ]

8. If yes? How much do you pay in Gh¢? ……………………………………

9. In your view, is the charge for the water appropriate? 1. Yes [ ] 2. No [ ]

10. Are there times when you find no water at this source? 1. Yes [ ] 2. No [ ]

11. What coping mechanisms do you adopt during water shortage at this source?
……………………………………………………………………………………………
……………………………………………………………………………………………

12. Who owns the water source?
1. My household [ ] 2. Private owner [ ] 3. Land lord [ ] 3. Ghana water company [ ] 4. Community [ ] 6. No-one [ ] 7. Other (specify) ………….

13. Who supervises the water supply?
1. My household [ ] 2. Private Owner [ ] 3. Land lord [ ] 4. Community care taker [ ] 5. No-one [ ] 6. Other (specify) ……………………..

14. When was the water source constructed?
1. 0- 6 Months [ ] 2. 6 – 12 Months [ ] 3. 1 – 3 years [ ]
4. More than 3 years [ ] 5. Don't know [ ]

15. How often is the cleaning done?
1. Daily [ ] 2. More than once a week [ ] 3. Weekly [ ] 4. more than once a month [ ] 5. monthly [ ] 6. Less than once a month [ ]
7. Don't know [ ]

16. Is there a restriction on how much water a person takes from the source?

1. Yes [ ] 2. No [ ]

17. If yes, why is there a restriction?

1. Source has low flow [ ] 2. Too many people use the source [ ] 3. Limited time for care taker [ ] 4. Other (specify) ………….. 5. Don't know [ ]

18. Which of the primary sources you mentioned is nearest to your home? ………………

19. What is the walking time from your home to the primary water source? (Minutes) …………………………….

20. Social interaction with other people affects your decision not to use the water source.

1. Strongly agree [ ] 2. Agree [ ] 3. Uncertain [ ] 4. Disagree [ ] 5. Strongly disagree [ ]

21. Do you ever collect rain water? 1. Yes [ ] 2. No [ ]

22. Do you buy water from vendors? 1. Yes [ ] 2. No [ ]

23. If yes, how often do you buy water from a vendor?

1. Daily [ ] 2. More than once a week [ ] 3. Weekly [ ] 4. more than once a month [ ] 5. other……………….. 6. don't know [ ]

24. How much water do you buy for the first (1st) purpose indicated?

1. 1- 10 liters [ ] 2. 11- 20 liters [ ] 3. 21 – 30 liters [ ] 4. 31 – 40 liters [ ] 5. Above 40 liters [ ]

25. Where does your water vendor obtain water from?

1. Private owner [ ] 2. Ghana water company [ ] 3. Community [ ]

4. Project [ ] 5. Public tap/standpipe [ ] 6. Don't know [ ] 7. Other Specify ……………….

26. What is your perception of the quality of the water that is vended to you?

1. Unacceptable water quality [ ] 2. Favourable water quality [ ] 3. Highly favourable water quality [ ] 4. No comment [ ]

C. WATER COLLECTION, TREATMENT AND STORAGE

1. Who is the primary drawer of water?

1. Female adult [ ] 2. Female + children [ ] 3. Children [ ]
4. Male adult [ ] 5. Male + female [ ] 6. Male + female + children [ ]
7. Porter/vendor [ ]

2. By which means do you transport water ?

1. Walking [ ] 2. Bicycle [ ] 3. Animal [ ] 4. Water tanker [ ] 5. Vehicle (car or truck) [ ] 6. Other (Specify) …………………

3. How often is water stored in the home?

1. Daily [ ] 2. More than once a week [ ] 3. Weekly [ ] 4. more than once a month [ ]

4. Where do you keep or store water?

1. In kitchen [ ] 2. In dwelling [ ] 3. On compound[ ] 4. In store room [ ] 5. Overhead storage tank [ ] 6. Ground storage tank [ ]

18. Does the vessel have a cover? 1. Yes [ ] 2. No [ ]

20. Do you do anything to your water before you drink it? 1. Yes [ ] 2. No [ ]

21. If yes, what do you do to it?

1. Boil [ ]   2. Add bleach/chlorine [ ]   3. Strain it through a cloth [ ]

4. Use water filter (ceramic, sand, composite, etc.) [ ]

5. Solar disinfection [ ]   6. Let it stand and settle [ ]

7. Other (*specify*)________________

8. Don't know [ ]

22. What do you use to get/pour drinking water out of storage container?

[Please rank by 1 – 8, with 1 being the most frequent and 8 being least frequent]

1. Cup [ ]   2. Laddle [ ]   3. Pitcher [ ]   4. Bowl [ ]   5. Bucket [ ]

6. Poured directly from container [ ]   7. Nothing [ ]   8. Use of spigot [ ]

9. Other (specify) …………………………………

23. How often do you clean the vessel used to draw water?

1. Daily [ ]   2.Weekly [ ]   3. Monthly [ ]   4. Every 6 months [ ]

5. Once a year [ ]   9 . Rarely [ ]   10. Never [ ]   11 .Don't know [ ]

24. How often do you clean your water storage container?

1. Daily [ ]   2.Weekly [ ]   3. Monthly [ ]   4. Every 6 months [ ]

5. Once a year [ ]   9 . Rarely [ ]   10. Never [ ]   11 .Don't know [ ]

1. Yes [ ]   2. No. [ ]   3. Can't tell [ ]

D. WATER QUALITY

1. Perception of drinking water quality.

1. Unacceptable water quality [ ]   2. Favourable water quality. [ ]

3. Highly favourable water quality [ ]   4. No comment [ ]

2. How do you dispose of animal stools?

1. Put/rinsed into toilet or latrine [ ]   2. Put/rinsed into drain or ditch [ ]

3. Thrown into garbage (solid waste) [ ]   4. Burried [ ]   5. Left in the open [ ]

4. Does your drinking water have any taste? 1. Yes [ ] 2. No [ ]

5. How will you describe the odour of your water?

1. No odour [ ] 2. Mild odour [ ] 3. Strong odour [ ] 4. Uncertain [ ]

6. How will you describe the colour of your water?

1. No colour [ ] 2. Mild coloration [ ] 3. Strong coloration [ ] 4. Uncertain [ ]

7. How often do you see visible particles in the water?

1. No visible particles [ ] 2. less often [ ] 3. often [ ] 4. Very often [ ] 5. Uncertain [ ]

8. Has water from your primary source ever been tested

1. Yes [ ] 2. No[ ] 3.Can't tell [ ]

10. Who was responsible for the testing?

1. My household [ ] 2. Owner [ ] 3. Land lord [ ] 4. Community [ ] 5. District assembly/ Town council [ ] 6. Government agency [ ] 7. No-one [ ] 8. NGO/Donor [ ] 9. Don't know[ ]

11. Were the results of the water test communicated to you? 1 .Yes [ ] 2. No [ ]

E. SANITATION & HYGIENE

1. How is household waste water disposed?

1. Open ground [ ] 2. Water body [ ] 3. Latrine [ ] 4. Bucket latrine [ ] 5. Septic tank [ ] 6. Sewer-no treatment[ ] 7. Sewer-treatment [ ] 8. Soak-away pit[ ]

2. By which means do you dispose of refuse?

1. Burning [ ] 2. Garbage bin [ ] 3.Open field [ ] 4. Burrying [ ] 5. Incineration [ ] 6. Composting [ ]

3. Is a latrine available within your household ? 1. Yes [ ] 2. No [ ]

5. If yes, what type is it?

1. WC in house/dwelling [ ] 2. In compound pit [ ] 3. In compound Pan [ ] 4. In compound KVIP [ ] 5. In compound WC [ ]

6. If you do not own a latrine, what is your primary means of toilet disposal?

1. WC in house [ ] 2. In compound pit [ ] 3. In compound Pan [ ]
4. In compound KVIP [ ] 5. In compound WC [ ] 6. Public toilet [ ]
7. Open defecation (Bush) [ ]

7. Does your household reuse the latrine contents? 1. Yes [ ] 2. No [ ]

8. If yes, what is what arrangements are made for reuse?

…………………………………………………………………………………………
…………………………………………………………………………………………
………………

9. How do you dispose off children's faeces?

1. Do nothing [ ] 2. Place in latrine/bucket toilet [ ] 3. Bury in soil [ ]
4. Throw in garden [ ] 5. Place directly in waste bin/heap [ ]
6. Place in plastic bag and place in waste bin/heap [ ]
(g) Other…………………..

10. How frequently do you wash your hands with water and soap?

1. No washing with soap [ ] 2. less often [ ] 3. Often [ ] 4. Very often [ ]
5. Uncertain

F. HEALTH AND DIARRHOEA

1b. Which of the following **have you** suffered from in the past 2 weeks? Please tick

1. Not suffered any disease/symptoms [ ] 2. Cold/catarrh [ ] 3. Nausea/vomiting [ ]
4. Cough [ ] 5. Body pains [ ] 6. diarrhoea [ ] 7. Headaches [ ]

8. Fever [ ] 9. skin/eye infections [ ] 10. Other ………………………………..

3. Has any member of your household had diarrhoea in the past 2 weeks?

1. Yes [ ] 2. No [ ]

3. If any member of your household suffers diarrhoea from where will you seek care?

Please rank 1- 3 with '1' being first '2' second, '3' third.

Public Sector

1. Government Health Facility [ ] 2. Pharmacy [ ] 3. Private Health Facility [ ]

4. Herbalist [ ]

4. Please provide reasons for your answer

…………………………………………………………………………………………………
…………………………………………………………………………………………………
………………

5. Have you ever had education on the management/treatment of diarrhoea?

1. Yes [ ] 2. No [ ]

6. If yes, by what means did you get educated?

1. Radio [ ] 2. Television [ ] 3. Midwife [ ] 4. Hospital staff[ ]

5. A formally organized briefing session [ ] 6. Can't remember