THE QUALITY OF DOMESTIC WATER SOURCES AT KINTAMPO

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DECLARATION

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

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ABSTRACT

The study was to assess the quality of domestic water sources at Kintampo. Kintampo town was divided into 5 strata (stratified sampling technique), and out of 200 hand-dug wells, 30 were selected for the study at random. The 3 mechanized boreholes operating in the town and the treated water were also selected. These together made up 34 sampling points. The sampling was done on 15th October 2008, 20th December 2008, and 14th February 2009. These periods were chosen to reflect the rainy, dry, and the beginning of the rainy seasons.

Seventeen parameters were analysed. These were colour, turbidity, temperature, conductivity, pH, dissolved oxygen, total dissolved solids, total suspended solids, total hardness, iron, fluoride, chloride, calcium, sulphate, nitrate, BOD, faecal coliform, and *E. coli*. Apart from temperature, turbidity, conductivity, pH, dissolved oxygen, and total dissolved solids, which were analysed on site, all the other parameters were analysed at the Ghana Water Company's laboratory at Sunyani.

The physical parameters (colour, turbidity, and temperature) were acceptable. Considering the chemical parameters, the water from the boreholes and the treated water had a higher conductivity, total dissolved solids, total hardness, iron, chloride, and calcium than the water from the hand-dug wells. The implication is that the treated water will be tastier and harder than the water from the hand-dug wells since all these parameters impart taste when they are above a certain threshold. The taste of the treated water may be attributed to the level of chloride and calcium concentrations in the water from the boreholes.

With regards to the biological parameters, the water from the boreholes and treated water had no BOD nor were they contaminated with faecal coliform or *E. coli* bacteria, while the water from most of the hand-dug wells had all. This could be attributed to the general insanitary conditions around most of them. The dilapidated structures like broken parapet walls, lack of aprons and channels to carry waste water from the surroundings of the hand-dug wells made it possible for their water to be contaminated. A few of the hand-dug wells, which were closer to ventilated improved pit latrines, may have been contaminated with *E. coli* bacterial from them. However, water from the boreholes and the treated water are healthier than the water from most of the hand-dug wells. Chemicals like camphor and dettol are not meant for oral consumption. Hence, the use of these chemicals by some hand-dug well owners to treat their water may lead to adverse health effects (especially cancer for the consumption of camphor) on the consumers of such water.

Some of the recommendations were that the use of camphor and dettol to treat water in hand-dug wells should be discouraged by health official. The Municipal Assembly should pass a bye-law to ensure that all hand-dug wells are completely covered and fitted with simple hand pumps to reduce contamination of the water. The Kintampo Water Supply should take steps to reduce the chloride and calcium concentrations in their water since these ions contribute to the taste and hardness in the water.

CHAPTER ONE

1 INTRODUCTION

Water is essential for life. People, animals, and plants all need water to live and to grow. For many parts of the world, people lack adequate water to stay healthy. Many people have to travel long distances for water, and often the water that is available is not safe to drink. The Millennium Development Goals represent the world's agreed targets for addressing poverty in its many dimensions. Lack of access to safe drinking water and basic sanitation is one dimension affecting billions of people around the world (Conant, 2005b). Access to adequate, safe water is recognized as a human right in many international laws and agreements, for example, the United Nations Charter and several others (APEC, 2000).

Water is a basic necessity for all life and good health. Access to adequate safe water, or water security, is a very important issue (Conant, 2005b). Under most conditions, groundwater supplies are higher in mineral content than surface waters in the same area. This is due to their longer exposure to rock formations. As water seeps through the ground and adds to its mineral content, much of its suspended matter, colour, and bacteria content are filtered out. Thus, a deep well is likely to provide water that is clear, colourless and low in bacteria count. However, there are exceptions. It might be expected that the deeper the wells the more highly mineralized are their waters. In some shallow wells, however, the mineral absorption is greater than for deep wells in the same general area. (APEC, 2000).

Contaminants in water range from naturally-occurring minerals to man-made chemicals and by-products. While many contaminants are found at levels not enough to cause immediate discomfort or sicknesses, it is proven that low-level exposure to many common contaminants will, over time, cause severe illnesses including liver damage, cancer, and other serious ailments (APEC, 2000).

Groundwater is accessible to a large number of users; it can provide cheap, convenient individual supplies; and it is generally less capital intensive to develop. The most serious groundwater challenge facing the world is not in developing the resource, but in its sustainable management (Shah *et al.*, 2000).

In general, the requirements for a public water supply may be considered as follows: it should be free from pathogenic organisms; should be colourless, odourless, good tasting, and non-corrosive; should be free from objectionable gases such as hydrogen sulphide (H_2S); should be free from staining minerals like iron; and should be adequate, and low in cost (APEC, 2000). Kintampo community depended mainly on hand-dug wells before the construction and distribution of mechanized boreholes by the Municipal Assembly in December 2001. The population of Kintampo was 28,276 with a growth rate of 3.6% as at May 2008 (Kintampo Municipal Assembly, 2008). There were 44 functional public standpipes and 565 domestic and institutional water points (totaling 609 water points) in the community. Treated water distributed to the community from the mechanized wells was 800 m^3. Most people in Kintampo do not use the treated water for their domestic activities, especially drinking, because they claim the water does not taste good. Unihydro (2002), in a report to the Ministry of Local Government and Rural Development stated that, "Kintampo water supply has groundwater sources with physical and chemical characteristics generally within the WHO (1993) guideline limits except for elevated iron concentrations. The standpipes however, have iron concentrations slightly higher than the WHO (1993) guideline values, but less than 1 mg/l". Among the long term recommendations was that, an iron removal plant should be installed to reduce the concentration of iron entering the distribution system. In accordance with this report, an aeration tank was constructed in 2006. According to the officials' in-charge of Kintampo Water Supply, they started with 84 public stand-pipes, but they had to stop operating about half of them due to low patronage. People were not coming for domestic water connection to their premises as expected. As at May 2008, 16 litres (size 32 bucket) of treated water was sold to domestic consumers at 4 Ghana pesewas. Hence, there is the need to test the piped-water (boreholes) to ascertain its quality. This will help in verifying the efficiency of the aeration process. Since iron concentration above 0.3 mg/l may contribute to taste (WHO, 2006), some of the parameters that also contribute to taste in water have to be tested.

The sanitation around most of the hand-dug wells is poor. More importantly, it is mostly children who go to fetch the water. They spit and play around it. Most of the wells have fitting covers with common fetching containers, which are not washed or cleaned from the first day they were hanged there. There are no run-off channels so water that splashes on and around them stay within their immediate surroundings, and probably seep back into them. Animals have free access to most of them. Siting of toilets in homes is done indiscriminately. The expected 20 m and above distance between well and latrine is often not considered during siting (Conant, 2005a). Indiscriminate defaecation is rampant in the community. All these conditions make the hand-dug wells liable to pollution. Once they are constructed and people start using, the water is never tested to ascertain its quality.

The problems associated with hand-dug wells and the public mechanized water system should be investigated to enable the people to enjoy potable water. Groundwater is easily liable to pollution mainly from human activities and the effects of polluted water on health makes it necessary for it to be tested to ascertain its quality (physical, chemical, and bacteriological) to meet both international and local standards. These hand-dug wells are privately owned, but are more or less community assets because everybody in the community has access to them.

1.1 Main Objective

The main objective of the study is to assess the quality of water from the mechanized boreholes and hand-dug wells at Kintampo.

1.2 Specific Objectives

The specific objectives of this work are to:

(i) ascertain the physical, chemical, and microbial quality of the water, and

(ii) make recommendations based on the results.

1.3 Research Questions

The following research questions needed to be answered:

(i) What are the physical properties (colour, turbidity, and temperature) of the water?

(ii) What are the chemical properties (conductivity, pH, dissolved oxygen, total dissolved solids, total suspended solids, total hardness, and iron, fluoride, chloride, calcium, and sulphate concentrations) of the water?

(iii) Do the bacteriological properties (faecal coliform, *E. coli,* and BOD) in the water conform to guidelines set by the WHO?

CHAPTER TWO

2 LITERATURE REVIEW

2.1 Water as a Resource

Freshwater is a finite resource, and is essential to agriculture and industry as it is to basic human existence. What is effectively available for consumption and other uses is small proportion of the quantity available in rivers, lakes, and groundwater. Freshwater is characterized by its highly uneven spatial distribution. Accordingly, the importance of water has been recognized, and greater emphasis is being laid on its economic use and better management (UNEP and WHO, 1996).

2.2 Groundwater Quality

Water quality is a widely used term which has different meanings to different users. Water for industry, agriculture, and domestic use may require certain standards different from each other. A user may define water quality in terms of its physical, chemical, and biological characteristics by which he evaluates the acceptability of the water. Water for domestic activities like drinking, cooking, and washing must be free from undesirable substances, not coloured, and with desirable taste. Water in this state can be said to be potable since its consumption may not lead to any health problems (Borchardt and Walton, 1971).

Groundwater remains one of the most important sources of water supply in rural communities and small towns in Ghana. Currently, over 90% of water provided for small towns for domestic use is extracted from groundwater sources. However, the occurrence of high levels of minerals including metal compounds, especially iron and manganese in most of these groundwater sources has been identified as a challenge limiting the extent to which the resource can be exploited. About 40% of drilled wells with high iron levels have been abandoned by user communities while about 60% are used marginally for purposes other than drinking, cooking, and laundry (CWSA, 2008).

There are three routes by which the water in a well may become contaminated; through the wellhead, lining, or water entering the intake (Watt and Wood, 1979). Generally, the closer the groundwater is to the surface, the more influential is the effect of heavy rain in carrying bacteria and other organisms through the soil into it. Poorly made concrete apron and water run-off can crack, and will allow leakage of waste water from the surface back into the well to contaminate it. Buckets and ropes which are used to raise the water, and often lie around the unhygienic rim of the well also pollute the water. Generally, shallow wells are less than 15 m deep (Morgan, 1990).

If the full benefit is to be derived from any improved water source, it is essential that the water is collected in a clean bucket and stored in a vessel with a covered lid. Thus the road to health as far as water is concerned must take place in two stages. First, the water is available, close by and in reasonable quantities; second, the water that is available must be accompanied by hygienic practices by the individual. One of these is body and hand washing (Morgan, 1990).

Currently, the most practical approach to the problem of improving and maintaining the quality of water delivered in rural water supply schemes is not to impose a set standard, but to insist on adequate measures of sanitary protection which significantly improve the quality of water (Morgan, 1990).

The quality of water expected from a hand-dug well or borehole will vary according to the type of water raising system employed. Water raised from a hand-dug well with a hand pump can be expected to contain fewer bacteria than one fitted with a bucket and windlass. However the bucket and windlass is less likely to malfunction, and is cheaper to maintain than a hand pump (Morgan, 1990).

2.3 Factors Influencing Groundwater Quality

2.3.1 Geology of Groundwater

The quality of groundwater may be affected by the source rock, soil composition, or overlaying superficial deposits. Chemical reactions between ions in the water and minerals in associated rocks also play a role in this regard. The rate of movement of groundwater, and human activity within the catchment basin affect the water quality (Holden, 1970; Todd, 1980).

Certain chemicals can be linked to igneous, metamorphic, and sedimentary rocks. Groundwater passing through igneous rocks may dissolve very small quantities of mineral matter because of the relative insolubility of the rock. Percolating rainwater containing dissolved carbon dioxide from the atmosphere dissolves the silicate minerals of the igneous rocks to produce leachate like bicarbonates. These tend to yield soft water with high pH and relatively high silica content in case of alkali rich rocks. Alkali soil and ferromagnesian rocks produce hard water with low pH and relatively low silica content (Holden, 1970 and Todd, 1980).

The rocks underlying the Kintampo North Municipal form part of the "Voltain formation" which covers about two – fifths (2/5) of the surface area of Ghana and about 80% of the District's land surface. Rocks belonging to this formation are mainly sedimentary and exhibit horizontal alignments. Sand stone, shale, mudstone and limestone are the principal examples of these rocks (Ministry of Local Government and Rural Development and Maks Publications, 2006). Sedimentary rocks, because of their relatively high solubility, coupled with their great abundance in the earth's crust produce the major soluble constituents of groundwater. Sodium and calcium are commonly added cations; bicarbonates and sulphates are corresponding anions. (Todd, 1980).

The dominant controls on fluoride occurrence in groundwater in Ghana are climate and the different rock forms at various places. The regions in Ghana most vulnerable to high fluoride concentrations are the arid zones of the north and areas where bedrock geology is dominated by granite and some Birimian rocks. Groundwater in granite rocks of the south-west plateau are considered to be at risk because of higher rainfall. Marked variations in fluoride concentration with depth were observed in groundwater from the problem areas of Bolgatanga (e.g. the Bongo granite). Shallow groundwater from dug wells had significantly lower concentrations of fluoride than borehole waters as a result of dilution by recharge (Smedley, *et al.*, 1995; Pelig-Ba, 1998).

2.3.2 Human Activities

Contamination of groundwater by pathogenic organisms most frequently cause problems in situations where private wells and poorly constructed septic tanks are in proximity (Craun, *et al.*, 1991). The bottom of latrines and septic tanks should be more than 1.5 m above the highest groundwater table. This is to prevent groundwater contamination with human excrement (Kilama and Winblad, 1985).

2.4 Measuring Water Quality

To measure the quality of any water, the characteristics of such water must be clearly defined. For drinking water, it may include the following parameters: temperature, colour, turbidity, and dissolved oxygen level, concentration of organic and inorganic compounds (Borchardt and Walton, 1971; Ray, 1995).

Table 1 shows drinking water quality guidelines as determined by WHO in 2006 and Ghana standards Board in 2006. These guidelines were set mainly for health reasons.

Table 1: Drinking Water Quality Guidelines

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

(Source: WHO, 2006; GSB, 2006)

Colour in drinking water may affect aesthetics, and can be rejected by consumers. It is determined using a spectrophotometer (Hach, 2000).

Turbidity in water is caused by the presence of particulate matter such as clay, silt, colloidal particles, and microorganisms. Turbidity is the measure of the water's ability to scatter and absorb light. High turbidity levels can reduce the efficiency of disinfection by creating a disinfection demand. The particles may also provide absorption sites for toxic substances in the water. It may protect pathogens from disinfection by absorbing or encasing them, and may interfere with total coliform analysis. It is measured in Nephelometric Turbidity Units (NTU), using a turbidity meter (USEPA, 1995).

Temperature. Depending on whether it is high or low, may affect other parameters including conductivity and dissolved minerals. Cool water is generally more palatable than warm water. It affects the reaction rates and solubility levels of chemicals present in water. It is determined using a Temperature meter (Schindler, 1990; Hach, 2000; WHO, 2006).

Conductivity is a measure of the water's ability to conduct electric current. It is directly related to the total dissolved salt content of the water. This is so because the salts dissociate into positive and negative ions and can conduct electric current proportional to their concentration. It is reported in micro Siemens per centimetre (μS/cm) using a conductivity meter (Hach, 2000).

pH is the measure of acidity or alkalinity of the water. The pH of most raw water sources lies within the range of 6.5 – 8.5 (WHO, 1984). Usually it has no direct impact on consumers; it is one of the most important operational water quality parameters (WHO, 2006). Depending on the pH and sometimes the temperature of water, metals may dissolve into ions. It is determined using a pH meter (Langelier, 1946).

Dissolved oxygen (DO) is the amount of molecular oxygen dissolved in water. The amount of dissolved oxygen in water depends on temperature, degree of turbulence, light penetration, and turbidity. It also depends on chemical and biochemical reactions such as photosynthesis, respiration, and decomposition. It can be measured on the field using a DO meter (Andrews, 1972; Hach, 2000).

Total Dissolved Solids (TDS) is made up of inorganic salts (principally calcium, magnesium, potassium, sodium, bicarbonates, chlorides, and sulphates) and small amounts of organic matter that are dissolved in water. It originates from natural sources, sewage, urban run-off, and industrial waste water. Its concentration in water varies considerably in different geological regions owing to differences in the solubility of minerals. It is measured in milligram per litre (mg/l). (Hach, 2000; WHO, 2006).

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

Iron occurs in groundwater in high concentrations in many places throughout Ghana. It is generally associated with acidic groundwater or anaerobic (oxygen-free) groundwater. Concentrations as high as 57 mg/l have been found in some water sources (Pelig-Ba, 1989). Staining of laundry and household fixtures can occur in waters with high iron concentration. Its concentration in water is determined using a spectrophotometer (AWWA, 1999).

Fluoride occurs naturally in most soils and in many water supplies. A UV-Visible spectrophotometer is used to determine fluoride ion concentration in water (AWWA, 1999).

Chloride is present in all potable water supplies and in sewage usually as a metallic salt. It originates from natural sources, sewage and industrial effluents, urban runoff, and saline intrusion. Its concentration in water is determined using precipitation titration (Hach, 2000; WHO, 2006).

Total Hardness in water is caused by dissolved calcium and, to a lesser extent, magnesium salts. It is usually expressed as the equivalent quantity of calcium carbonate ($CaCO_3$). Depending on pH and alkalinity, hardness above 200 mg/l can result in scale deposition, particularly on heating. It is determined by titration with EDTA (Ethylenediaminetetra-acetic acid) (WHO, 2006; Kruis, 2007). Water with less than 75 mg/l $CaCO_3$ is considered to be soft and above 150 mg/l as hard. Calcium ion concentration may be determined by titration with EDTA (AWWA, 1999; Hach, 2000; Kruis, 2007).

Sulphate is found in natural waters in a wide range of concentrations. A Spectrophotometer is used to determined sulphate concentration in drinking water (USEPA, 1990; Hach, 2000).

Faecal coliform and ***Escherichia coli*** are indicators for the presence of recent faecal contamination in water. *E. coli* is a more specific indicator of faecal contamination than is the faecal coliform group. They are determined based on the production of acid and gas from lactose using Multiple Tube Fermentation Technique. It is measured as Most Probable Number (MPN) (AWWA, 1999; WHO, 2006).

Biochemical Oxygen Demand (BOD) measures the content of biologically degradable substances in water. The substances are broken down by microorganisms in the presence of oxygen. Oxygen demand is measured in terms of the quantity of oxygen consumed by the microorganisms over a period of five days (BOD_5) in decomposing the organic pollutants in the water at a temperature of 20°C (Hill and Pertrucci, 1999; Kruis, 2007).

2.5 Health and Aesthetics

Water is a basic need for all life and good health. Water is used to prevent and treat diseases. Washing hands with soap and water after using the toilet and before eating or handling food helps prevent diarrhoea diseases. It may be difficult to know if water is safe or not. Some of the things that cause health problems are easily noticed by looking at, or tasting the water. Others can be found by testing the water. Understanding what makes water unsafe and taking steps to protect water from contamination can prevent many problems from unsafe water. Therefore, health and aesthetics are the principal motivations for water treatment (Conant, 2005b).

Fluoride in drinking water reduces dental caries. However, over 20 mg/l can result in nausea, diarrhoea, abdominal pains, headache, and dizziness. Some long term effects are dental and skeletal fluorosis (AWWA, 1999). Also, it can have adverse effect on tooth enamel and may give rise to mild dental fluorosis at concentrations between 0.9-1.2 mg/l, depending on intake (WHO, 2006).

A relationship has been postulated between the incidence of cardiovascular disease and the amount of hardness in water, or, conversely, a positive correlation with the degree of softness. Many investigators attribute a cardiovascular protective effect to the presence of calcium and magnesium (AWWA, 1999). The degree of hardness in water may affect its acceptability to the consumer in terms of taste and scale deposition (WHO, 2006).

High concentrations of iron are not directly problematic for human health. It may cause indirect problems because of abandonment of affected water sources due to unpleasant odour and taste, in favour of surface waters which may be contaminated by harmful bacteria (Pelig-Ba, 1989). In individuals genetically susceptible to haemochromatosis, too much iron can be accumulated in the body, resulting in liver, pancreatic, and heart dysfunction and failure after long term exposure (Motulsky, 1988). Nitrate converted to nitrite in the body causes methemoglobinemia, especially in infants under one year of age (USEPA, 1989).

High concentrations of sulphate in drinking water may cause transitory diarrhoea (USEPA, 1990). At high sulphate levels (above 600 mg/l), bottle-fed infants develop diarrhoea. Adults living in areas having high sulphate concentrations in their drinking water easily adjust, with no ill effects. Sulphate may impact taste at levels above 300-400 mg/l (AWWA, 1999).

In addition to health issues, consumer satisfaction and confidence are also important. Aesthetic components of drinking water quality include taste, odour, turbidity, colour, mineralization, hardness, and staining. Taste problems in water derive in part from salts (Total Dissolved Solids) and the presence of specific metals, such as iron, copper, manganese, and zinc. Specific salts may be more significant in terms of taste, notably magnesium chloride and magnesium bicarbonate. Concentrations of chloride above 250 mg/l may give water a salty taste. The presence of turbidity increases the apparent, but not true colour of water (AWWA, 1999).

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

2.6 Groundwater Management

Constructing individual water supply wells is always cost-effective where groundwater is abundant and of suitable quality. Where natural groundwater quality is exceptionally poor or where supplies are insufficient, the most costly option of piping treated water from a centralized source is a solution to provide suitable water (AWWA, 1999).

Managing rural water quality is a significant challenge due to its site-specific nature and the typically inadequate financial and human resource available to address problems. Microbial health risks remain one of the major challenges. The most commonly detected problem of rural private wells is the occurrence of total coliform bacteria and other disease causing microbes. These may result from faecal matter coming from poorly constructed and poorly sited latrines and septic tanks, refuse dumps, and animal farms. Another problem is pesticide and nitrate infiltration from farmlands (AWWA, 1999). Public water supplies can also be contaminated, but they are more likely to be isolated from contamination sources and are better sited and constructed (USEPA, 1990; USGS, 1997).

The natural environment has impact on groundwater quality. This is reflected in the physical, chemical, and biological actions interacting with the water itself. As part of the hydrological cycle, the water falls as precipitation and is influenced by soil and organisms at or near the surface. The influence of the aquifer formation depends on how long the water has been held in it, and how rapidly stored water is recharged by fresh water from the surface. Water moves in close contact with the minerals that make up the particles or fracture channels of the aquifer (AWWA, 1999).

Management of groundwater quality also concerns human impacts. Within the overall scope of management, regulation is largely focused on human impacts. Adverse human impacts include providing routes for potential pathogens or chemicals to reach groundwater, and aquifer depletion. Other human activities can prevent or mitigate such adverse effects, and these are the agents of appropriate stewardship of the groundwater (Morgan, 1990).

Once the many factors that affect groundwater has been understood, methods of management can be implemented or evaluated. Groundwater management is by nature localized. However, it can be planned simultaneously at the local, regional, and national levels. In addition to public policy and regulation, there is a range of technical tools available to assist in groundwater quality management. The best tool is accurate and adequate information. To effectively protect a well, its owners and managers need to know what can be expected of it in volume and quality. For example, where does the water come from; what is the area of influence of the well field; is pumping going to draw in water from the landfill site or cause upcoming of saline water; are the well spacing and arrangement the best they can be to prevent over drafting and maintenance problems? Major components of an information system needed for groundwater management decisions are hydrology, water extraction and use patterns, potential contamination sources and characteristics, and population patterns (AWWA, 1999).

Most people are willing to pay a reasonable price for safe drinking water. However, in most places, water that people need for drinking is sold at a price they cannot afford. Whether water is managed by the community, government, private companies, or a partnership of these groups, the people who need water most must have a say in how it is priced, distributed, and used. They have to understand how to protect, store, and treat water. The community must be motivated to change what does not work, and to make these changes through community organization and action (Conant, 2005b).

It is sometimes assumed that if people do not accept a protected source, the answer is education. Depending on the methods used, educators may be able to achieve some results, but they cannot make people to change their behaviour just by telling them they ought to, or even by just explaining why they ought to (White, 1981). Often it is not a question of people not knowing that the protected source is healthier, for instance, but whether they are prepared to make the effort to change. If this happens, water agency personnel are tempted to think that they have done all they can, and if the people will not listen to reason that is their fault. In this kind of situation, the only answer is for the water agency to be willing to meet people's actual requirements as far as possible. For example, providing water sources as close as the contaminated ones, and not much more salty, hard, or otherwise objectionable. Where this is not possible, the difficulty should be discussed with them with the view of arriving at an agreed solution, instead of treating their concerns as a manifestation of ignorance and backwardness (Damme and White, 1984).

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

CHAPTER THREE

3 METHODOLOGY

3.1 Background of the Study Area

Kintampo community, which is the study area, falls under Kintampo North Municipal Assembly, of which it is the capital. The people are predominantly farmers. The indigenous people are Mos and Brongs, with other smaller ethnic groups from most parts of the country living in the municipality. Kintampo had a population of 28,276 as at May 2008 with a growth rate of 3.6% (Kintampo North Municipal Assembly, 2008). At that time there were only 44 functional public standpipes and 565 domestic and institutional water points (totaling 609 points) in the community. There are 200 hand-dug wells in the town. The sale of food crops is the major economic activity of the people.

3.2 Selection of Sampling Points

Kintampo Township was divided into 5 sampling sites, and 6 hand-dug wells were selected at random from each site (30 sampling points). This was carefully done to ensure that sampling points were as far apart as possible. The 3 boreholes serving as the main source of pipe-borne water for the community, and the point of distribution provided 4 sampling points. Therefore the number of sampling points for the study area was 34.

3.3 Preparation for Sampling

Samples for the chemical analysis were collected in Voltic mineral water bottles. The bottles were rinsed with tap water then with distilled water before samples were collected. Samples for the microbial analysis were put in sterile bottles. These were done to avoid the introduction of errors into sampling results. Two plastic buckets and nylon ropes were used to collect samples from the hand-dug wells.

3.4 Sampling

Sampling points were inspected to ascertain the prevailing physical conditions like the state of the wells (e.g. dilapidated or in good shape, had fitting covers, fitted with hand-pumps or not) and their depths. Samples were collected at times when women and children had collected water from the wells. This was done as a means of practically purging the wells. In some instances, purging was done manually as an additional measure.

Equipment like conductivity meter, pH meter and others which were used on-site were calibrated before use. Sample containers were rinsed with the water to be sampled before sampling. To ensure that representative samples were collected, the buckets were carefully immersed into the water. Sample bottles were filled to the brim to prevent the accumulation and escape of gases into the air space. For the safety of sampling personnel, wellington boots, and hand gloves were put on. On-site analyses were carried out for parameters like pH, temperature, turbidity, total dissolved solids, conductivity, and dissolved oxygen. Samples were preserved in a cooler at 4°C and taken to the laboratory after 1.5 h of collection, and analysed immediately.

In all, three batches of samples were collected on 15th October 2008, 20th December 2008, and 14th February 2009. This was done to reflect the rainy, dry, and beginning of the rainy seasons.

Table 2 shows the preservation method used, and maximum holding time between sampling and analysis, if any, for each parameter. Table 3 presents the place for samples analysis (on-site or laboratory) and instrument or method of analysis.

Table 2: Maximum Delay between Sampling and Analysis

Parameter	Preservation	Maximum holding time
Temperature, Turbidity, pH, Conductivity, Dissolved Oxygen, Total Dissolved Solids	Nil	Nil (On-site analysis)
Colour, Fluoride	Nil	Nil
Iron	HNO_3	Nil
Total Suspended Solids, Sulphate	Storage at 4°C	5 days
Total Hardness, Chloride	Nil	Nil
Calcium	HNO_3	5 days
Total coliform/*E. coli*	Nil	Nil
BOD	Storage at 4°C	10 days

3.5 Field Analysis

3.5.1 Temperature, Conductivity, and Total Dissolved Solids

A Hach digital field equipment (model 44600) was used to measure the temperature, conductivity, and total dissolved solids of the samples collected on site. 1000 mg/l NaCl standard solution was used to calibrate the meter. The probe of the temperature meter was first rinsed with tap water then with some of the sample. A quantity of the sample was poured in a 200 ml beaker, and the stable temperature value in °C was recorded.

Then the probe of the conductivity meter was rinsed with tap water and with some of the sample. The probe of the meter was immersed into the beaker containing the sample, and the stable conductivity value in mg/l was then recorded. The probe of the total dissolved solids meter was then rinsed with tap water, then with some of the sample. The probe of the meter was immersed into the beaker, and the stable value of TDS in mg/l was recorded.

Table 3: Method of Sample Analysis

Parameters	Place of Analysis	Instrument/Method used
Temperature TDS Conductivity pH Dissolved Oxygen Turbidity	On-site On-site On-site On-site On-site On-site	Temperature meter TDS meter Conductivity meter pH meter Dissolved Oxygen meter Turbidity meter
Colour, Iron, Nitrate, Total Suspended Solid, Fluoride, Sulphate	Laboratory	Spectrophotometer
Total Hardness, Calcium Chloride	Laboratory Laboratory	EDTA titration Precipitation titration
Faecal coliform/*E. coli* BOD	Laboratory Laboratory	Multiple Tube Fermentation BOD bottles and incubator

3.5.2 pH

Two standard buffer solutions of pH 4.0 and 7.0 were used to calibrate the Hach digital pH meter (UC-23 model). The electrode of the pH meter was rinsed with tap water and with some of the sample. A quantity of the sample was poured in a 200 ml beaker. The electrode of the meter was immersed into the beaker containing the sample, and the stable pH was subsequently recorded.

3.5.3 Turbidity

Formazine standard solution made up of hydrazine sulphate ($(NH)_2.H_2SO_4$) and hexamethylenetetramine ($C_6H_{12}N_4$) was used to calibrate the Jenway turbidity meter (6035 model). The electrode of the turbidity meter was first rinsed with tap water and with some of the sample. A quantity of the sample was put in a 200 ml beaker, and the electrode of the meter immersed into it, and the stable value of turbidity in mg/l was recorded.

3.5.4 Dissolved Oxygen

Zero O_2 standard solution (2 g of sodium sulphate dissolved in 100 cm³ of deionised water) was used to calibrate the Jenway DO meter (9300 model). A quantity of the sample was first used to rinse the electrode of the dissolved oxygen meter. The electrode was then immersed in the sample in a beaker. When the meter reading had stabilized, the value in mg/l was recorded.

3.6 Laboratory Analysis

3.6.1 Colour (True Colour)

A filter of pore size 0.5 μm and 90 mm diameter, filter holder (funnel), and filter flask were first assembled. Filter was rinsed with about 50 ml of distilled water by pouring it through the filter. The filtered distilled water was then discarded. Another 50 ml of distilled water was poured through the filter. A sample cell of 7 mm long and 2.5 × 2.5 mm square bottom was filled with 25 ml of filtered distilled water to serve as a blank. A Hach Direct Reading spectrophotometer (DR/2000 model) was used for the analysis. The same equipment was used in determining total suspended solids, iron, fluoride, sulphate, and nitrate. The stored programme number for true colour was entered (120 READ/ENTER was pressed, and the display showed DIAL nm TO 455). The wavelength dial was rotated until the display showed 455 nm. READ/ENTER was pressed and the display showed UNITS Pt Co colour.

About 50 ml of the water sample was poured through the filter. A second sample cell for the prepared sample was filled with 25 ml of the filtered water sample. The blank was placed into the cell holder and the light shield closed. After pressing ZERO, the display showed WAIT, then 0. UNITS Pt Co COLOUR. The prepared sample was also placed into the cell holder and closed. When READ/ENTER was pressed, the display showed WAIT, the result in platinum-cobalt units was displayed. This was recorded accordingly.

3.6.2 Total Suspended Solids

500 ml of water sample was put in a blender at high speed for exactly 2 min. The blended sample was put in a 600 ml beaker. The sample was stirred with a magnetic stirrer and 25 ml poured into a sample cell. The stored programme number for non-filterable residue was entered (630 READ/ENTER). The display showed DIAL nm TO 810. The wavelength dial was rotated until the display showed 810 nm. READ/ENTER was pressed and the display showed mg/l SUSP. SOLIDS. 25 ml of distilled water was poured into a sample cell as the blank. The blank was put into the cell holder and the light shield closed. When zero was pressed, the display showed WAIT, then 0 mg/l SUSP.SOLIDS. The prepared sample was swirled to remove any bubbles and uniformly suspend any residue. The prepared sample was subsequently placed into the cell holder,

and the light shield closed. When READ/ENTER was pressed, the display showed WAIT, the result in mg/l for non-filterable residue was displayed, and recorded.

3.6.3 Iron

The programme number for iron was entered (265 READ/ENTER). The display showed DIAL nm TO 510. The wavelength dial was rotated until the dial showed 510 nm. When READ/ENTER was pressed, the display showed mg/l Fe FV (Ferrover). 25 ml of water sample was poured into a cell. The content of one Ferrover Iron reagent powder pillow was added to the prepared sample cell, and swirled to mix. Shift timer was pressed and a 3 min reaction period then began. After the timer had beeped, the display showed mg/l Fe FV. A blank sample cell was filled with 25 ml of water sample, and placed into the sample cell holder and closed. When ZERO was pressed the display showed WAIT, then 0.0 mg/l Fe FV. Within thirty minutes after the timer beeped, the prepared sample was put into the cell holder, and the light shield closed. READ/ENTER was pressed and the display showed WAIT. The result in mg/l was displayed and recorded.

3.6.4 Fluoride

The stored programme number for fluoride (F^-) was entered (190 READ/ENTER), the display showed DIAL nm TO 580. The wavelength dial was rotated until the display showed 580 nm. READ/ENTER was pressed afterward and the display showed mg/l F^-. 25 ml of water sample was measured into a dry sample cell (the prepared sample). 25 ml of distilled water was measured into a second dry sample cell (the blank). 5 ml of SPADNS reagent was pipetted into each cell. They were swirled to mix, using pipette filler. Shift timer was pressed to allow for a 1 min reaction time. When the timer beeped, the display showed mg/l, the blank was placed into the cell holder, and the light shield closed. ZERO was pressed and the display showed WAIT, then 0.0 mg/l F^-. The prepared sample was placed into the cell holder and the light shield closed. When READ/ENTER was pressed, the display showed WAIT, the result in mg/l F^- was displayed and recorded as such.

3.6.5 Sulphate

The stored programme number for sulphate-powder reagent was entered (680 READ/ENTER), and the display showed DIAL nm TO 450. The wavelength dial was rotated until the display showed 450 nm. READ/ENTER was pressed for the display to show mg/l SO_4^{2-}. A sample cell was filled with 25 ml of sample. The content of one SulfaVer 4 Sulphate reagent powder pillow was added to the sample cell (the prepared sample), and swirled to dissolve. SHIFT/TIMER was pressed to allow for a 5 min reaction period. When the timer beeped, the display showed mg/l SO_4^{2-}. A second sample cell (the blank) was filled with 25 ml of sample. The blank was put into the cell holder, and the light shield closed. When ZERO was pressed, the display showed WAIT, then 0.0 mg/l SO_4^{2-}. Within five minutes, after the timer had beeped, the prepared sample was placed into the cell holder, and the light shield closed. After READ/ENTER had been pressed, the display showed WAIT, then the result in mg/l SO_4^{2-} which was displayed was recorded.

3.6.6 Total Hardness

The total hardness of the water samples were determined by titration with 0.02 M EDTA. The EDTA solution was poured into a burette. 100 ml of sample was pipetted into a 250 ml conical flask. 1 ml of buffer of pH 10 was added to the sample. 5 drops of 5% erichrome black T indicator was also added to the sample. The solution was titrated slowly and stirred continuously until the last reddish tinge turned to blue. The last few drops of EDTA were added at 3-5 seconds interval.

Total Hardness (mg/l) = 1000VM

Where, V = EDTA used, ml

M = molarity of EDTA = 0.02

1000 = factor

(APHA, 1992).

3.6.7 Chloride

The chloride concentration of the water samples were determined by titration with 0.02 M $AgNO_3$ solution. The 0.02 M $AgNO_3$ solution was poured into a burette. 100 ml of sample was poured into a 250 ml conical flask. 1 ml of 5% K_2CrO_4 indicator was poured into the sample. This was titrated with the $AgNO_3$ solution and stirred continuously until the colour changed to red-brown.

Chloride concentration in sample (mg/l) = (V-0.2)10

Where, V= $AgNO_3$ used, ml

10 and 0.2 = factors

(Hach, 2000)

3.6.8 Calcium

The calcium concentration of the water samples were determined by titration with 0.02 M EDTA. The 0.02 M EDTA was poured into the burette. 100 ml of sample was measured into a 250 ml conical flask. 1 ml of 4 M NaOH indicator was poured into sample. 0.4 g of Murexide indicator was put into sample and the colour changed to light pink. The solution was titrated with the 0.02 M EDTA. Reddish-brown colour developed at the end of titration.

Calcium concentration in sample (mg/l) = 400.8VM

Where, V = EDTA used, ml

M = molarity of EDTA

400.8 = a factor

(APHA, 1992).

3.6.9 BOD

Special BOD bottles were filled with samples to the brim to expel all air. The bottles containing the samples were fitted to tubes in the incubator (CB-DN model). 0-35 and 0-350 mg/l BOD scales which indicate the amount of oxygen consumed by microorganisms were attached to the bottles. The incubator was set at 20°C. Readings were recorded every 24 h and plotted on a graph. After 5 days, a sum of the values obtained was recorded as the BOD_5 for the sample.

3.6.10 Faecal coliform and *E. coli*

Single strength Mackonkey broth was prepared by adding 40 g of the powder of Mackonkey to 1 litre of distilled water. This was distributed into 5 MacCarthy bottles with durham tubes inside. They were sterilized by autoclaving at 121°C for 15 min. The caps of the 5 bottles were removed one at a time. With a sterile pipette, 10 ml of sample was put into each of the bottles. The screw caps on each bottle were replaced immediately after sample addition. The durham tubes were inverted a few times to thoroughly mix the sample with the nutrient medium. After the last inversion, it was ensured that the durham tubes were upright and full of liquid with no air bubbles. The bottles were kept upright (caps up with the durham tubes inverted) for the rest of the procedure. The bottles were incubated at a temperature of 44 ± 3°C. After 1 h, the durham tubes were examined for trapped air, then incubated further. At the end of 24 ± 2 h, each tube was tapped gently and examined for gas. If the colour of the broth changed from pink to yellow and the durham tubes contained gas bubbles, then coliform bacteria were presumed to be present. If no gas was present, the tubes were returned to the incubator and examined again after 48 ± 3 hours. Formation of gas in any amount constituted a positive test, while its absence constituted a negative test. If gas appeared before 24 h had elapsed, a confirmed test bottle was inoculated without waiting for the entire 48 h.

2% Brilliant Green Lactose Bile Broth was pipetted into each of the MacCarthy bottles for the confirmed test. From each positive presumptive bottle, 5 separate bottles for the confirmed test were inoculated, using a flame-sterilized nichrome wire loop. One loop full from a positive presumptive bottle was transferred to a confirmed test bottle, making sure not to touch the rim of each bottle. Each bottle for the confirmed test was inspected to be certain air was not trapped in the durham tubes. The confirmed tubes were placed upright in the incubator at a temperature of 44 ± 3°C. After 1 h, the tubes were examined for trapped air in the durham tubes, and incubated further. At the end of 24 ± 2 h, the bottles were checked for gas formation. The confirmed test bottles which contained gas in the durham tubes were positive for coliform. Tubes which did not contain gas were returned to the incubator and examined after 48 ± 3 hours. Absence of gas at the end of that period constituted a negative test. Gas present in any amount constituted a positive test.

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

CHAPTER FOUR

4 RESULTS AND DISCUSSION

The presentation of the results and discussion included observations made on site. This was followed by the physical, chemical, and microbiological parameters. The results on the hand-dug wells were compared with that of the boreholes. Data was presented in the form of tables and figures. The hand-dug wells were denoted W, B for the boreholes and T for the treated water from the boreholes.

4.1 Observations on site

Table 4 shows the locations in Kintampo where the wells are located, house number, well site, depth, treatment administration, frequency, and the chemicals used for the treatment.

7 of the hand-dug wells, W1, W5, W8, W9, W10, W11, and W20 were situated outside the yard of the houses while the rest were inside. Most of the hand-dug wells had no locks. This enables children to play around them. For instance, they could throw objects into the wells to contaminate them since no adults may be around to stop them.

22 of the hand-dug wells constituting 73% of the number of wells had not received any form of chemical treatment to the water since they were constructed. Pathogenic organisms which may find their way into the water may continue to multiply under favourable conditions. 8 users (27%), who treat their water periodically, use chemicals like camphor, dettol, or alum for this purpose.

Table 4: Particulars of sampled Hand-dug Wells

Location	Code	House No.	Site	Depth, m	Treatment	Frequency, month	Chemical used
Sunkwa	W1	E329/1	Outside	12.13	No	-	-
Sunkwa	W2	E348/1	In yard	16.46	No	-	-
Modern Preparatory School	W3	E366/1	In yard	11.28	No	-	-
Sewaba	W4	E93/1	In yard	10.5	No	-	-
Dwenewoho	W5	D168/1	Outside	12.4	No	-	-
Dwenewoho	W6	D56/1	In yard	10.2	No	-	-
Kyeremankoma	W7	A124/1	In yard	17.7	Yes	3	Alum
Kyeremankoma	W8	A265/1	Outside	20.4	No	-	-
Kyeremankoma	W9	B58/2	Outside	16.6	No	-	-
Mo-line	W10	A244/2	Outside	12.9	No	-	-
Mo-line	W11	A415/2	Outside	15.2	No	-	-
Mo-line	W12	A342/2	In yard	14.6	No	-	-
K-line	W13	C30/2	In yard	17.1	No	-	-
Location	**Code**	**House No.**	**Site**	**Depth, m**	**Treatment**	**Frequency, month**	**Chemical used**
Market Square	W14	D34/2	In yard	17.6	Yes	6	-
Market Square	W15	D29/2	In yard	15.2	No	-	-
Market Square	W16	D64/2	In yard	16.5	Yes	3	Dettol
Market Square	W17	D53/2	In yard	15.8	No	-	-
Lorry Park	W18	D57/2	In yard	15.5	No	-	-
Pentecost Church Area	W19	D109/2	In yard	14.9	No	-	-
Pentecost Church Area	W20	D150/2	Outside	13.1	Yes	12	Alum
Pentecost Church Area	W21	D129/2	In yard	11.6	Yes	6	Alum
Pentecost Church Area	W22	D166/2	In yard	14.1	No	-	-
Pentecost Church Area	W23	D182/2	In yard	13.1	Yes	12	Alum
Nwoase	W24	G25/2	In yard	12.4	Yes	3	Camphor
Nwoase	W25	E244/2	In yard	15.8	No	-	-
Nwoase	W26	F29/2	In yard	16.5	Yes	3	Alum
Nwoase	W27	E264/2	In yard	15.2	No	-	-
Gruma-line	W28	E226/2	In yard	15.3	No	-	-
Gruma-line	W29	E252/2	Inside	12.5	No	-	-
Gruma-line	W30	E354/2	Inside	11.9	No	-	-

Chemicals like camphor and dettol are for external use only. Camphor and alum are not disinfectants. With the use of alum (a coagulant), consideration is not given to the amount of the chemical in relation to the volume of water. The use of incorrect amount of alum may result in ineffective coagulation. Alum is a coagulant that helps particulate matter to settle and not a disinfectant as some well owners believe. In this situation, the pathogens may settle at the bottom of the well and come up again later.

The deepest hand-dug well (W8) was 20.4 m deep, with 15 of them being less than 15 m deep. Any well below 15 m deep is a shallow well and water from such a well is likely to be contaminated by run-off and infiltrating water.

Table 5 shows the condition of the hand-dug wells. The surroundings of 9 of the hand-dug wells (30%) had greenish colouration on their walls and floors. 15 of the hand-dug wells (50%) had no aprons, and their parapet walls were broken. 3 of the hand-dug wells (10%) had no covers. These could permit run-offs and splashes from entering the wells directly or seeping through the surrounding soil to contaminate the water. Hence, these wells needed reconstruction since their physical states expose their water to contamination. Their water may also expose users to water-borne diseases like cholera, dysentery, or typhoid fever.

19 of the hand-dug wells had no channels to carry water that pours on the ground to a suitable outfall. Where they existed, they were not desilted and these were likely to breed mosquitoes to transmit malaria to the people. The stagnant waters attracted animals like sheep, goats, and cattle which come to drink. The animals urinate and

defaecate to make the place unsightly. Children and animals could fall into the open wells.

Table 5: Condition of Hand-dug Wells

Code	Total No.	Condition
W5, W7, W10, W11, W20, W27, W28, and W29.	8	Had not been scrubbed for a long time. Had greenish colouration (spirogyra) on the walls and floors.
W3, W4, W5, W6, W7, W10, W11, W14, W20, W25, W26, W27, W28, W29, and W30.	15	Had no apron. Parapet walls were broken.
W10, W11, and W28.	3	Had no covers.
W4, W5, W6, W7, W8, W9, W10, W11, W14, W16, W17, W20, W22, W25, W26, W27, W28, W29, and W30.	19	Had no channels to carry water that pours on the ground around them.

The major mode of water lifting system was by the pulley, with a common container attached to a nylon or tyre rope. The lifting containers were not cleaned and hanged either on the pulley or inside the wells. This made the containers easy sources of contamination from dust and hands. This confirms a statement by Morgan (1990) that, "Pollution is carried into the well on buckets and ropes which are used to raise the water, and often lie around the unhygienic rim of the well. Poorly made concrete apron can crack and allow leakage of waste water from the surface back into the well to contaminate it". He said further that, "the most practical approach to the problem of improving and maintaining the quality of water delivered in rural water supply schemes is not to impose a set of standards, but to insist on adequate measures of sanitary protection which significantly improve the quality of water".

Table 6 shows the location of the boreholes, the water treatment facility, depth of the boreholes, frequency of treatment, and chemicals used.

Table 6: Particulars of Boreholes and Treated Water

Location	Code	Designation	Depth, m	Treatment	Frequency	Chemical used
Catholic School	B1	C 110	55	No	-	-
Catholic School	B2	K 290	86	No	-	-
Catholic School	B3	D 460	75	No	-	-
Hill Top	T	Treated water	-	Yes	Daily	$CaOCl_2$; $NaCO_3$

The boreholes were better placed in terms of cleanliness of their surroundings and protection from unauthorised persons. The boreholes, pumping, and treatment sites were fenced with barbed-wires and secured with locks. The surroundings were weeded regularly. There is 24 h guard for these sites. Hence, the water and the facilities are secured.

The Kintampo Water Supply treats the water from the boreholes after it had been pumped into a reservoir. The water is first brought in contact with air by making it to move down a stair case, specially designed for that purpose. This helps to remove some of the iron from the water. Calcium hypochloride ($CaOCl_2$) in the form of granules is used to disinfect the water. Soda ash or sodium carbonate ($NaCO_3$) in the form of powder is added to correct the pH after chlorination.

4.2 Physical Parameters of the Water Samples

The results of the physical parameters of the water samples are presented in Table 7. Generally, the colours of water from the boreholes were higher in Pt Co units than that of the hand-dug wells. The highest value obtained for colour for the water samples was 14.3 Pt Co for the borehole B2. This is only slightly lower than the maximum value of 15 Pt Co recommended by WHO. However, this can be considered high in terms of consumer satisfaction. It may also affect aesthetics which could lead to rejection by consumers.

The highest turbidity of 4 NTU obtained for borehole B1 was lower than the WHO maximum value of 5. The turbidity for most of the well waters may lead to consumer rejection. Aesthetically, it may be unacceptable due to the increase in apparent colour of the water.

The highest temperature of water recorded was 28.5°C in the case of well W1. The water may not be rejected by consumers because there are ways by which the temperature of water can be maintained to make it acceptable. This can be done through refrigeration or keeping the water in earthenware pot. Some people like to drink water in its natural state regardless of its temperature. However, depending on whether it is high or low, may affect other parameters including conductivity and dissolved minerals. The water from the boreholes does not get to consumers directly, but rather the treated water. Hence, the comparison made between the quality of water from the hand-dug wells and the treated water.

Table 7: Physical Parameters of the Water Samples

Code	Colour, Pt Co	Turbidity, NTU	Temperature, °C
W1	4.7	1	28.5
W2	5	1.7	27.6
W3	5	1.7	27.9
W4	4	1.3	27.7
W5	4.7	1.7	27.7
W6	5	2.3	27.8
W7	5	1.7	27.8
W8	4.3	1	27.6
W9	4.7	1.3	27.5
W10	6.7	2	27.8
W11	4.3	1	26.7
W12	4.3	1.3	26.9
W13	4.7	1.3	27.1
W14	4	1.3	27
W15	3.7	1	26.5
W16	4.3	1	27.2
W17	4.3	1	26.9
W18	4.7	1.3	27
W19	4.7	1.7	26.7
W20	4	1	26.6
W21	4	1	27
W22	4	1	26.6
W23	4	1	26.5
W24	5.3	1.3	26.6
W25	4.7	1	26.2
W26	4.3	1	26.5
W27	8	2	27.3
W28	6.3	1.7	26.8
W29	6	1	26.6
W30	4	1	26.7
B1	11	4	27
B2	14.3	3	27
B3	11.7	3.3	26.8
T	6.7	2.3	26.6

The highest value for colour for the hand-dug wells was 8.0 Pt Co for well W27 and that for the treated water was 6.7 Pt Co. However, 28 of the wells had values between 3.7 and 6.3 Pt Co, which were below that for the treated water. Generally, it can be said that the treated water was more coloured than the water from the wells.

Water from hand-dug well W6 recorded a turbidity of 2.3 (the highest for all the hand-dug wells) and that for the treated water was also 2.3 NTU. Hence, turbidity may not be the determining factor in terms of consumer preferences. The turbidity value is less than half the WHO maximum value of 5 NTU.

The higher temperature recorded was 28.5 °C for the water of hand-dug well W1. Although the hand-dug well had a higher temperature than the treated water, directly, it has no health or any adverse impact on consumers. This may not influence consumers in their choice of drinking water.

4.3 Chemical Parameters of the Water Samples

The results of the chemical parameters of the water samples of the study area are presented in Table 8. Generally, the conductivity of the water from the boreholes was higher than that from the hand-dug wells. B3 and B2 had conductivities of 1116.3 and 1119.7 µS/cm respectively. The wells had lower values between 61.3-1070.7 µS/cm. This is directly related to the salt content of the water. The salts dissociate into positive and negative ions and conduct electric current proportional to their concentration. Hence, a higher conductivity indicates a higher salt concentration of the water. This may result in consumer dissatisfaction and subsequent rejection of the water.

Table 8: Chemical Parameters of the Water Samples

Code	Conductivity, µS/cm	pH	DO, mg/l	TDS, mg/l	TSS, mg/l	Total Hardness, mg/l
W1	229	5.8	4.7	114.5	3.3	77
W2	150.7	5.9	3.6	75.5	2	69
W3	165.7	5.6	5.5	82.7	2	59.3
W4	305.3	6	3.2	153.8	2	87.3
W5	339.7	5.5	4.7	169.7	2	98.7
W6	646.7	5.9	4.1	324	2	207.7
W7	187.7	6.2	4.1	93.6	2	69.3
W8	61.3	6.1	4.5	30.4	2	38.7
W9	422	6.1	5.3	210	2	155.7
W10	257	5.7	2.7	129.3	3	82.3
W11	473.3	6	2.9	236.3	2	96.7
W12	1070.7	5.9	3.5	533.3	2.7	397
W13	326.3	6.1	2.7	161.3	2	119
W14	522	6.2	2.7	261	5.7	184
W15	314.3	6.2	3.1	155.5	2	90
W16	679.7	6	3.4	337.5	2.7	219.3
W17	339.7	6.1	3.4	170.5	2	124
W18	416.3	6.2	3.8	203.2	8	110.3
W19	268	6.1	4.3	132.5	2	83
W20	382	5.9	3	191.2	2	142
W21	262.7	5.7	3.6	129.3	2	76.7
W22	411	5.9	3.8	206	2	116
W23	522.3	5.5	2.8	261	5	138
W24	445.3	6.1	3.3	225.9	2	164.7
W25	520	6.1	2.7	256.7	2	170
W26	146.3	6.4	2.9	73.2	3.7	69.3
W27	95.3	6	4	47.7	2	51.7
W28	174.7	6.2	3.9	86.3	4	85.3
W29	169.7	6	4.4	85.2	2	56.7
W30	695.3	6.5	3.5	346.3	2	259.3
B1	416.7	6.2	2.9	74.1	10	194.3
B2	1116.3	6.6	3.3	694.7	13	313.3
B3	1119.7	6.5	2.6	641.2	15.7	354.7
T	920.7	6.7	3.2	586.3	2	275.7

All the hand-dug wells had pH values between 5.5-6.5. This is an indication that their water is acidic and did not conform to the WHO and GSB pH range of 6.5-8.5. Usually, the pH has no direct impact on consumers; it is one of the most important operational water quality parameters (WHO, 2006). This is because depending on the pH and sometimes the temperature of water, metals may dissolve into ions to increase the salt concentration of the water. Ultimately, it could affect the acceptability of the water by consumers. The boreholes also had water which were slightly acidic (pH between 6.2-6.7), but these waters undergo treatment where the pH is adjusted.

The concentration of dissolved oxygen of the water samples ranged from 2.6-5.5 mg/l. Higher dissolved molecular oxygen in water gives it a good taste and it may be the preferred choice by consumers. These values may be considered low although WHO and GSB do not have any recommendation on it. The low oxygen levels may be attributed to inadequate light penetration. The degree of move, which is a factor may not be much and could be from lifting of the water.

The total dissolved solids of the water from the hand-dug wells ranged from 48-533 mg/l, which is well below the maximum value of 1000 mg/l allowed by the WHO and GSB. Hence, it may be considered acceptable. The boreholes had higher total dissolved solids of 641-695 mg/l except borehole B1, which had 74 mg/l. However, the treated water had TDS of 586 mg/l. The TDS is made up of inorganic salts, principally calcium, magnesium, potassium, sodium, chlorides, and sulphates and small amounts of organic matter. These impart taste to water.

The boreholes had the highest values of TSS, ranging from 10-15.7 mg/l. Consumers are likely to reject water with high concentration of suspended solids and may consider it unwholesome. What is important in this regard is that after treatment, the TSS dropped to 2 mg/l, before distribution to consumers.

The total hardness of water from the hand-dug wells ranged from 38.7-259 mg/l. Apart from well W12 which had 397 mg/l, all the hand-dug wells had less than half of the maximum permissible value of 500 mg/l. The boreholes generally had higher values of 194-355 mg/l. The treated water had a total hardness of 276 mg/l. On the other hand the result is still significant because depending on pH and alkalinity, hardness above 200 mg/l can result in scale deposition, particularly on heating.

Water from all the hand-dug wells had conductivity values from 61.3-695.3 μS/cm, except well W12 which had 1070.7 μS/cm. The treated water had a conductivity of 920.7 μS/cm. Generally, the treated water may have a higher salt content than that of the hand-dug wells. Therefore, consumers may drink from the wells because they have no salty taste as the treated water.

The hand-dug wells had water with dissolved oxygen level between 2.7-5.5 mg/l. Water from nine of the hand-dug wells (Table 8) had values below 3.2 mg/l. That of the treated water was 3.2 mg/l. Since a higher concentration of molecular oxygen level in water gives it a good taste and reduces odour, consumers may prefer the water from most of the hand-dug wells to the treated water.

Water from hand-dug well W12 had the highest total dissolved solids of 533.3 mg/l among the wells; however, W27 had the lowest value of 47.7 mg/l. That of the treated water was 586.3 mg/l, which is higher than any of the values for the hand-dug wells.

Since the treated water had a higher total dissolved solids than the water from the hand-dug wells, it may have a saltier taste than that from the hand-dug wells.

The highest total suspended solids concentration for the water from the hand-dug wells was 8, and that of the treated water was 2 mg/l respectively. Only nine of the hand-dug wells had water with total suspended solids above 2 mg/l. Generally, it may be said that the total suspended solids concentrations for the hand-dug wells and the treated water was not considered in terms of choice.

The dissolved ion concentrations of the water samples are presented in Table 9. The higher values of 0.77 and 0.87 mg/l of iron concentration came from the boreholes, B2 and B3 respectively. This was reduced to 0.29 mg/l after treatment. This concentration is below the WHO and GSB maximum concentration of 0.3 mg/l. Among the hand-dug wells, the ones whose waters had the highest concentration of iron were W26 and W28, with 0.17 mg/l. The treated water may be more coloured than water from the hand-dug wells.

The fluoride concentration of the hand-dug well water samples were generally low, being between 0.01-0.03 mg/l. The exceptions were wells W5, W7, W22, and W23 which had values from 0.11-0.14 mg/l. The boreholes had higher values than the hand-dug wells, but they were still low, between 0.10-0.13 mg/l. These values are far below the maximum allowable concentration of 1.5 mg/l by WHO and GSB and therefore acceptable.

Table 9: Dissolved Ion Concentrations of the Water Samples

Code	Iron, mg/l	Fluoride, mg/l	Chloride, mg/l	Calcium, mg/l	Sulphate, mg/l
W1	0.08	0.08	115.3	24.3	-
W2	0.09	0.01	73.7	102.5	-
W3	0.06	0.01	84.0	21.8	1.67
W4	0.1	0.02	153.7	33.0	-
W5	0.06	0.12	169.3	34.4	2.00
W6	0.12	0.01	322.3	72.9	-
W7	0.08	0.12	94.7	117.6	-
W8	0.08	0.02	37.7	139.0	-
W9	0.1	0.03	210.3	122.0	-
W10	0.08	0.01	128.3	31.4	-
W11	0.1	0.03	237.0	35.8	1.67
W12	0.13	0.03	535.3	158.0	-
W13	0.14	0.02	162.3	133.3	-
W14	0.17	0.02	265.7	135.4	8.67
W15	0.1	0.01	157.3	89.6	1.33
W16	0.09	0.02	338.7	95.5	-
W17	0.13	0.02	171.0	94.2	2.00
W18	0.15	0.01	208.3	96.2	-
W19	0.1	0.01	133.7	94.6	6.67
W20	0.09	0.1	190.7	50.1	-
W21	0.09	0.01	130.3	28.6	9.33
W22	0.1	0.14	206.0	43.7	-
W23	0.15	0.11	274.3	51.4	-
W24	0.15	0.03	222.3	62.8	-
W25	0.1	0.02	260	97.5	-
W26	0.17	0.1	72.3	95.5	-
W27	0.13	0.02	59.3	19.5	4.67
W28	0.17	0.01	87.0	29.9	-
W29	0.11	0.02	85.3	20.8	-
W30	0.1	0.02	343.0	100.1	-
B1	0.16	0.11	208.3	84.6	-
B2	0.77	0.1	572.7	152.9	1.67
B3	0.87	0.1	573.3	158.4	-
T	0.29	0.13	469.0	152.6	1.0

7 of the hand-dug wells (23%), 2 boreholes, and the treated water had chloride concentrations above the maximum value of 250 mg/l recommended by the WHO and GSB. Chloride concentration above 250 mg/l may give water a salty taste. Therefore, the chloride may impart some taste to these waters.

Water from 29 of the hand-dug wells (96%) had chloride concentrations below 344 mg/l, except W12 which got the highest of 535.3 mg/l. That of the treated water was 469 mg/l. In terms of taste, generally, the treated water was likely to impact more taste to its water than that from the hand-dug wells. Therefore, consumers may choose water from the hand-dug wells over the treated water.

The hand-dug wells had calcium concentrations from 19.5-158 mg/l, with well W12 having the highest value of 158 mg/l. The boreholes B2 and B3 had 153 and 158 mg/l respectively. The treated water also had 153 mg/l. Water with $CaCO_3$ concentration of 150 mg/l and above is considered to be hard so water from W12 and the treated water may be treated as such. The hardness of water may affect its acceptability to the consumer in terms of taste and scale deposition. Whether consumers may accept such water may depend on individual preferences.

8 of the hand-dug wells (26%), 1 borehole (B2), and the treated water had sulphate in them, and the concentrations ranged between 1.0-9.3 mg/l. These concentrations may be considered insignificant in relation to the WHO and GSB maximum allowable concentration of 250 mg/l. Only water from 9 hand-dug wells had traces of sulphate, and it ranged from 1.3-9.3 mg/l. That of the treated water was 1 mg/l.

4.4 Bacteriological Parameters of the Water Samples

Table 10 presents the results for the water samples on biochemical oxygen demand, faecal coliform, and *E. coli*.

Table 10: Biological Parameters of the Water Samples

Code	BOD, mg/l	Faecal coliform, MPN	*E. coli*, MPN
W1	2.67	3	-
W2	10.00	7	6
W3	11.67	6	5
W4	6.67	4	-
W5	10.00	3	-
W6	8.33	5	-
W7	6.33	3	-
W8	7.67	7	-
W9	8.33	8	7
W10	5.00	9	4
W11	10.67	6	-
W12	19.00	9	-
W13	6.67	5	-
W14	9.67	9	-
W15	5.00	3	-
W16	14.67	8	-
W17	8.33	8	-
W18	17.33	9	-
W19	8.33	4	-
W20	15.00	8	-
W21	17.33	6	-
W22	9.33	4	-
W23	2.00	-	-
W24	5.00	9	-
W25	1.67	-	-
W26	6.00	-	-
W27	10.00	8	6
W28	12.33	3	-
W29	1.33	6	4
W30	3.67	-	-
B1	-	-	-
B2	-	-	-
B3	-	-	-
T	-	-	-

All the hand-dug wells had BOD concentration less than half the WHO maximum of 50 mg/l, the highest being 19 mg/l for well W12. The water from the boreholes and treated water did not have any BOD. There is the need to ensure that the BOD does not go up in future. The people need to understand what makes their water unsafe so that they can take steps to reduce such activities.

All the hand-dug wells were contaminated by faecal coliform W23, W25, and W26. Faecal coliform in drinking water is not permissible. 6 of the hand-dug wells (20%) even had *E. coli* bacterial contamination as well. The presence of faecal coliform in all and *E. coli* in some of the wells is an indication of constant faecal contamination, since the samples were taken about two months interval. *E. coli* causes diarrhoea that ranges from mild and non-bloody to highly bloody, which is indistinguishable from haemorrhagic colitis. These may result from faecal matter coming from poorly constructed and poorly sited latrines, septic tanks, refuse dumps and animal farms. The boreholes and the treated water did not have either faecal coliform or *E. coli*. Water from most of the hand-dug wells contaminated with faecal coliform and *E. coli* bacteria are not safe for drinking.

Figures 1-18 show the hand-dug wells, boreholes, treated water with the corresponding parameters for reference. That is, colour, turbidity, temperature, conductivity, pH, dissolved oxygen, total dissolved solids, total suspended solids, total hardness, iron, fluoride, chloride, calcium, sulphate, BOD, faecal coliform and *E. coli* in that order.

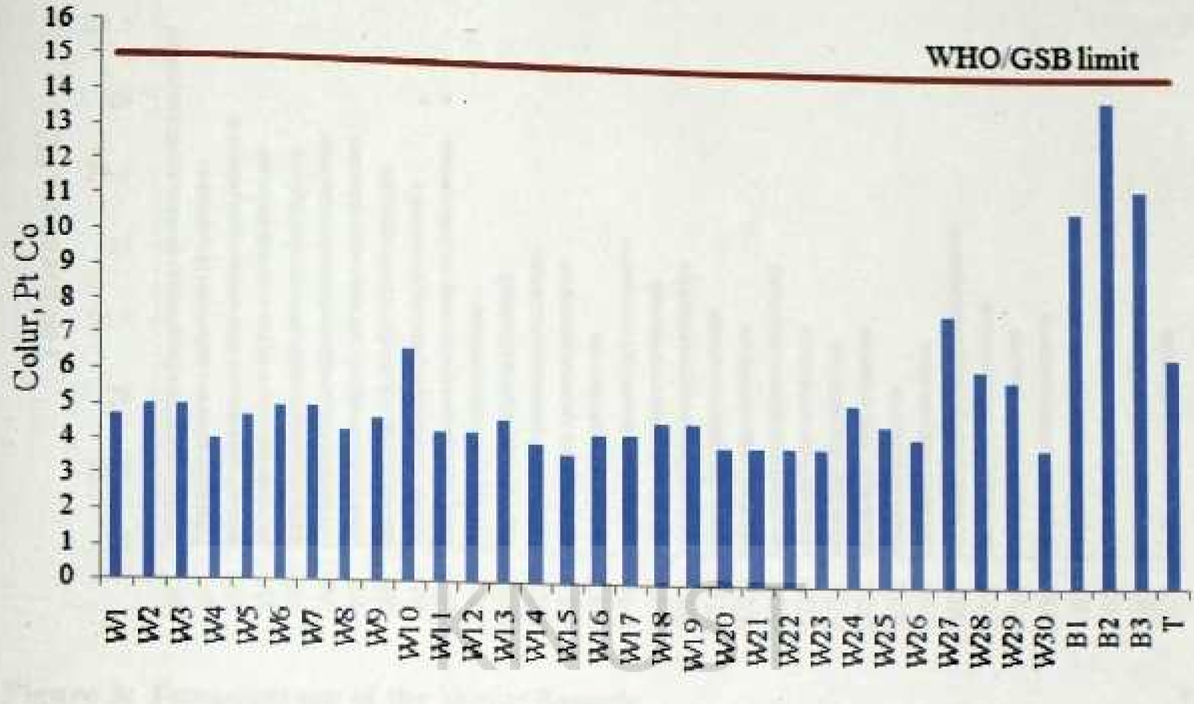

Figure 1: Colour of the Water Samples

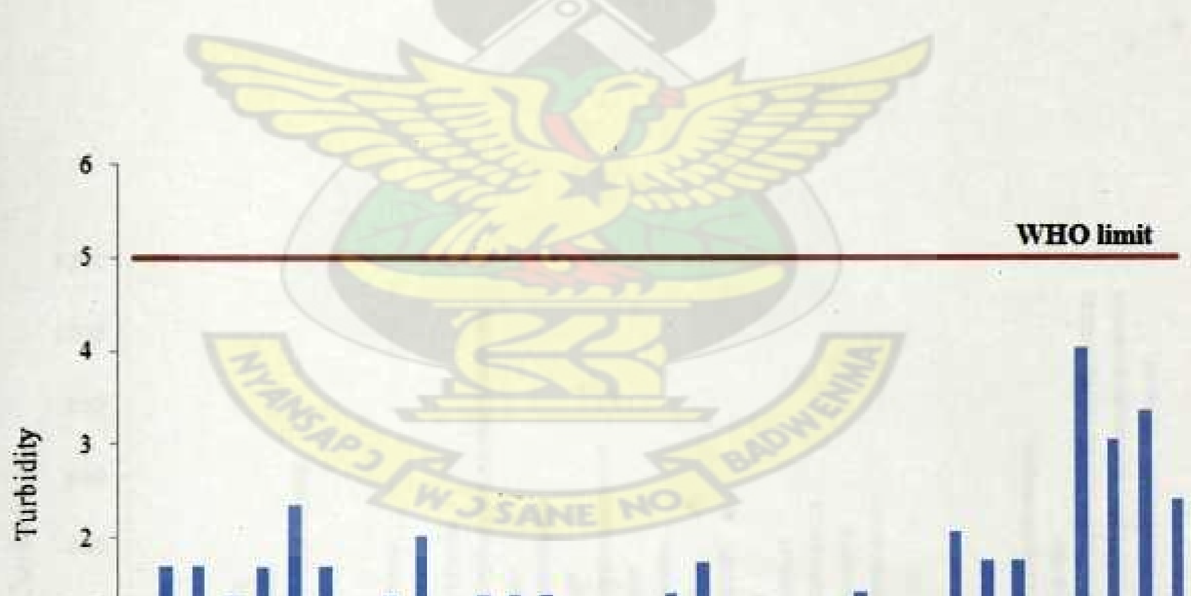

Figure 2: Turbidity of the water samples

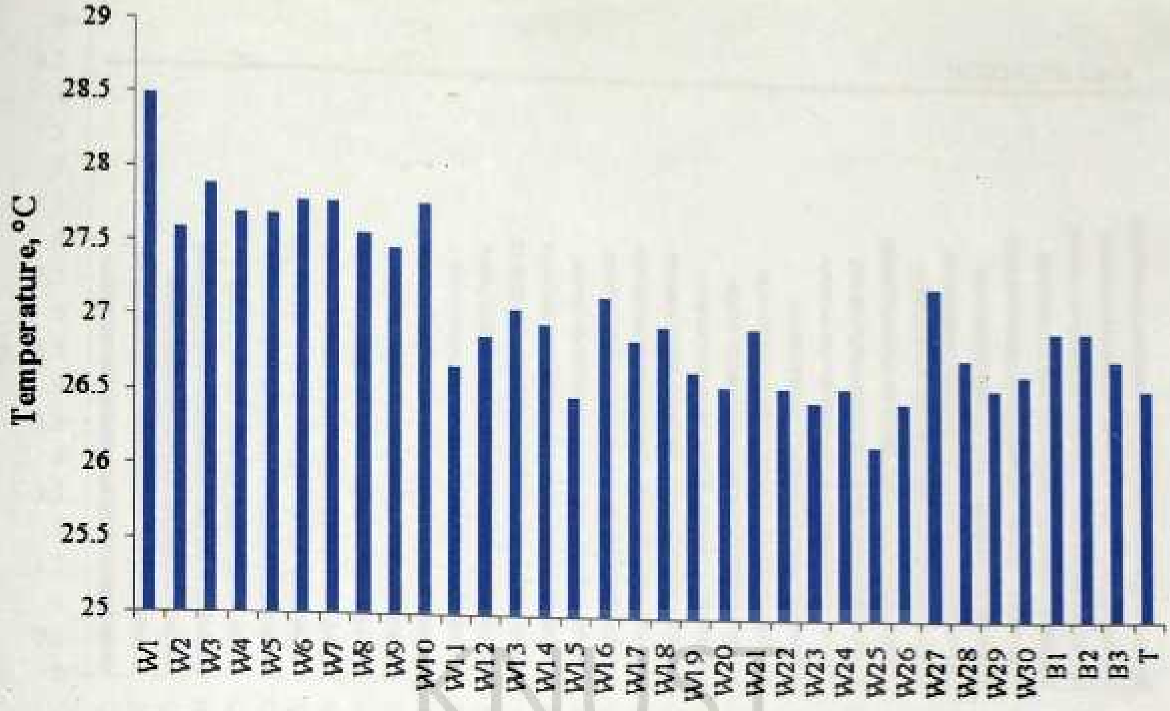

Figure 3: Temperature of the Water Sample

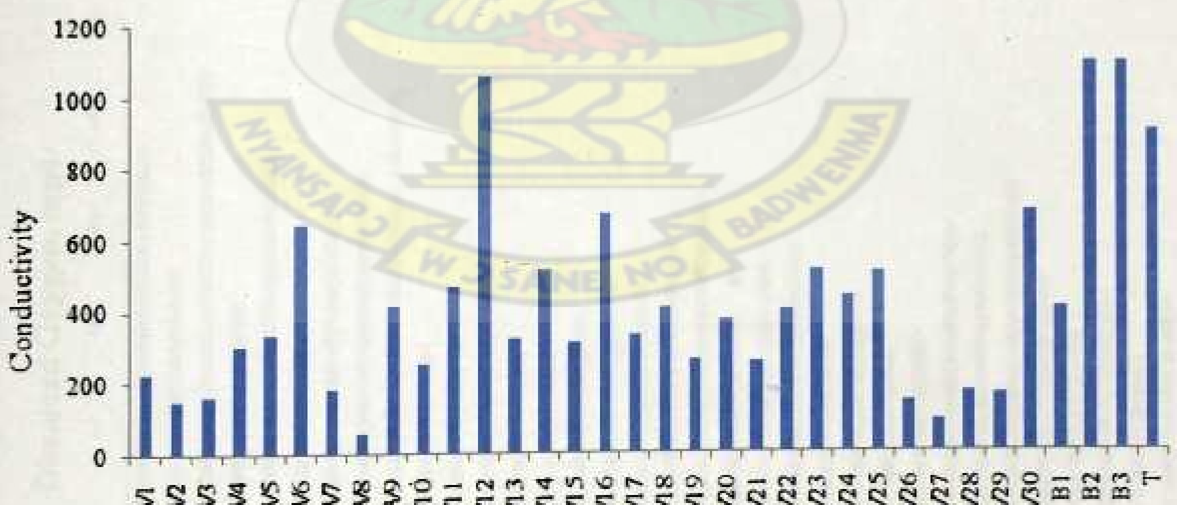

Figure 4: Conductivity of Water Samples

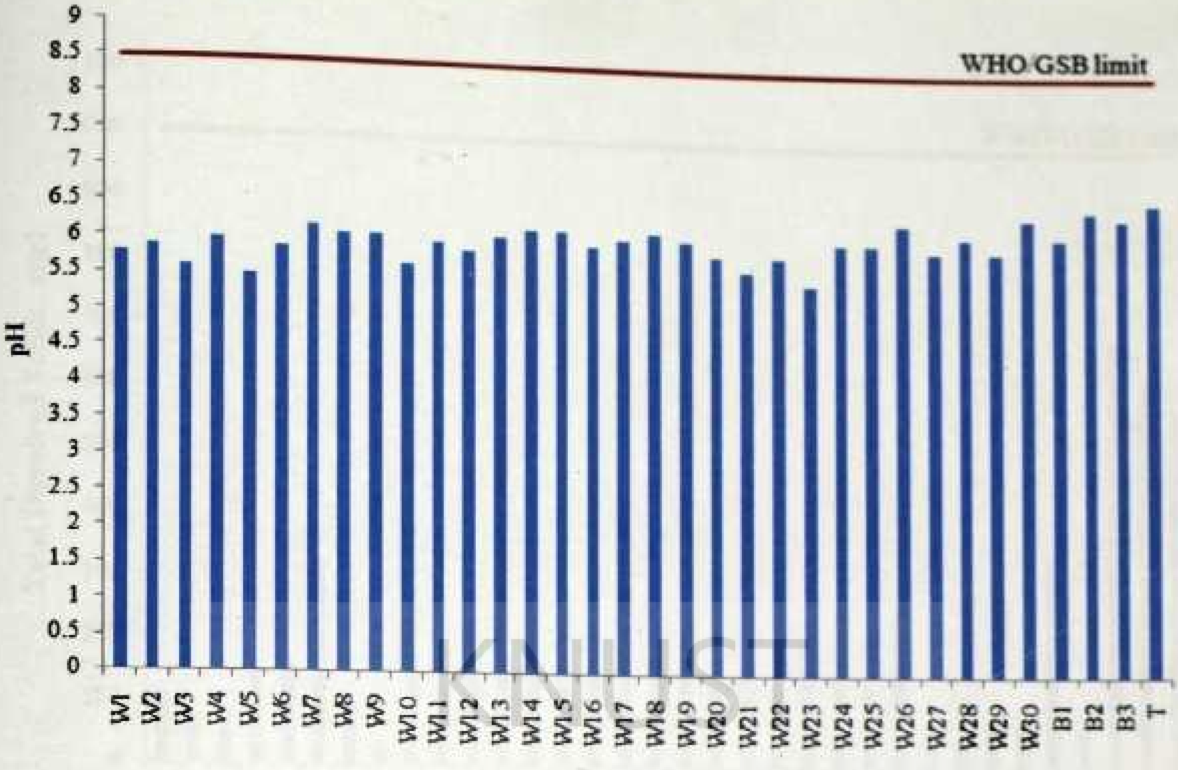

Figure 5: pH of the Water Samples

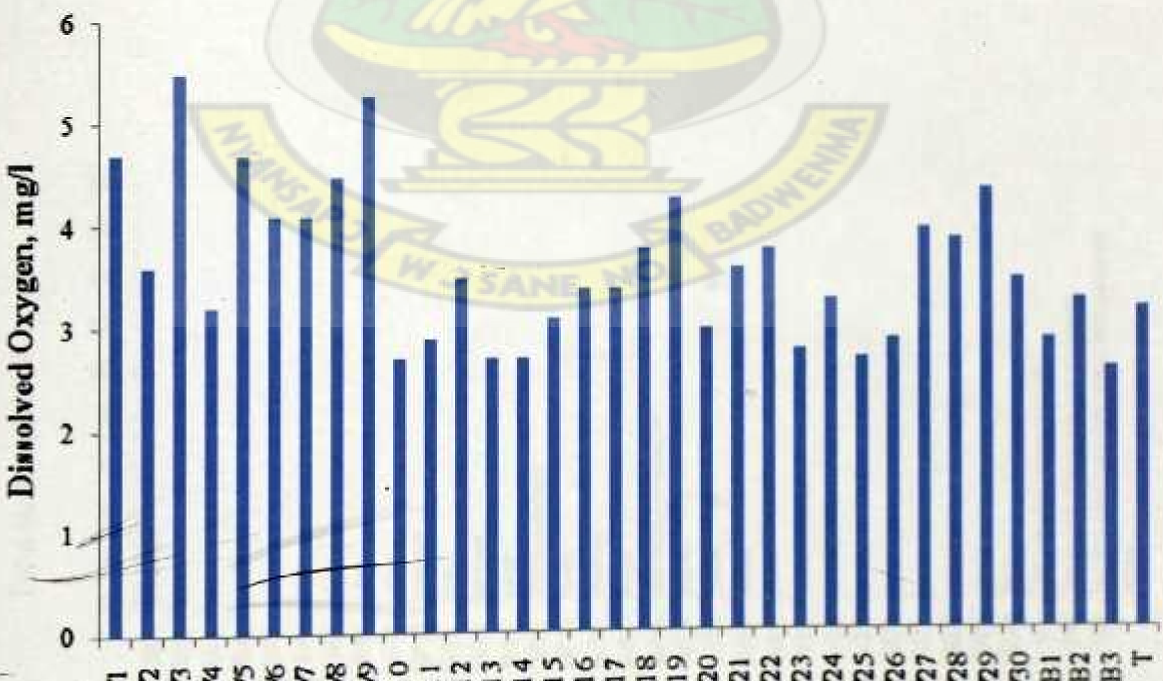

Figure 6: Dissolved Oxygen concentration of the Water Samples

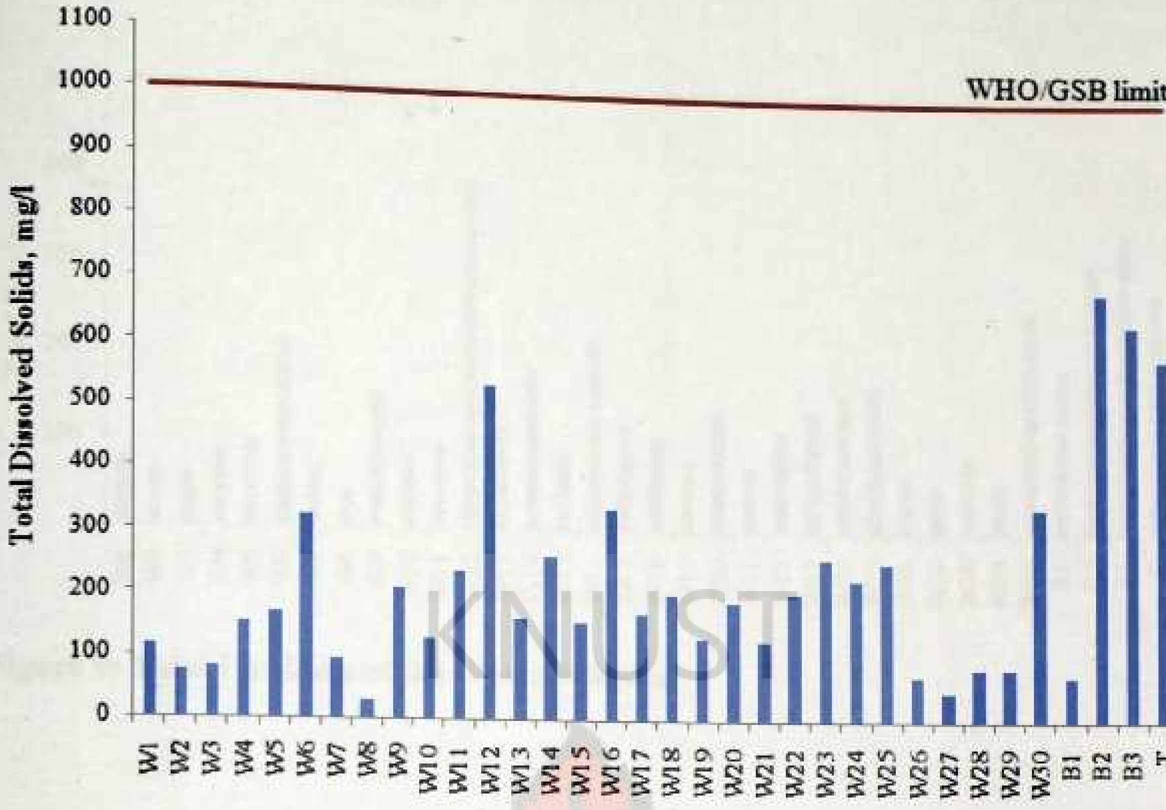

Figure 7 Total Dissolved Solids concentration of the Water Samples

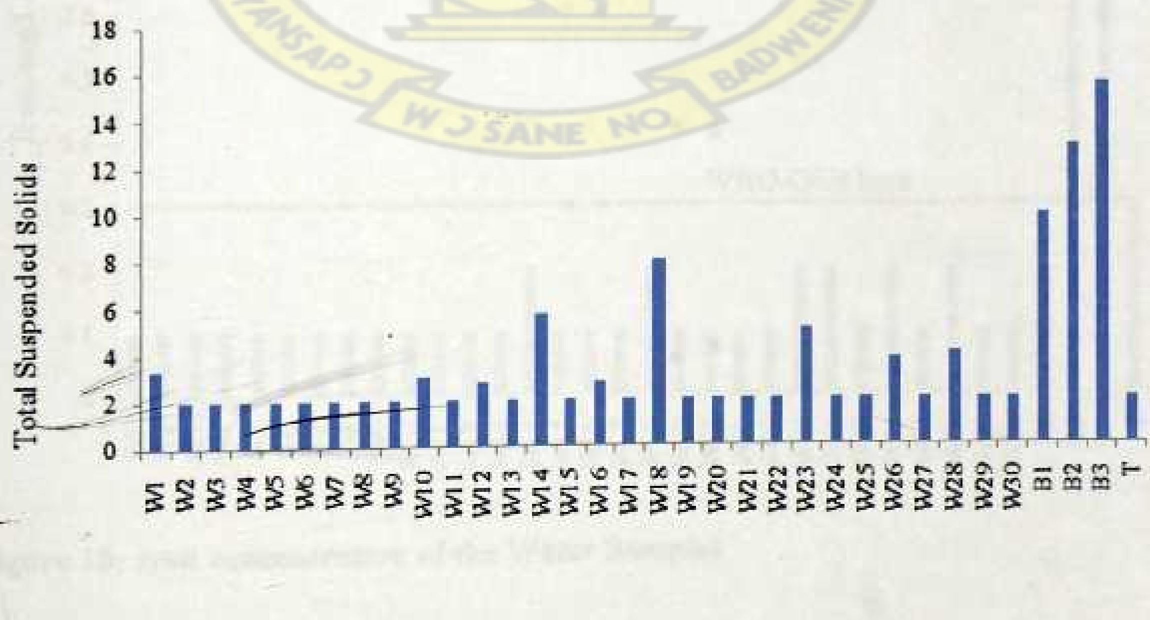

Figure 8: Total Suspended Solids concentration of the Water Samples

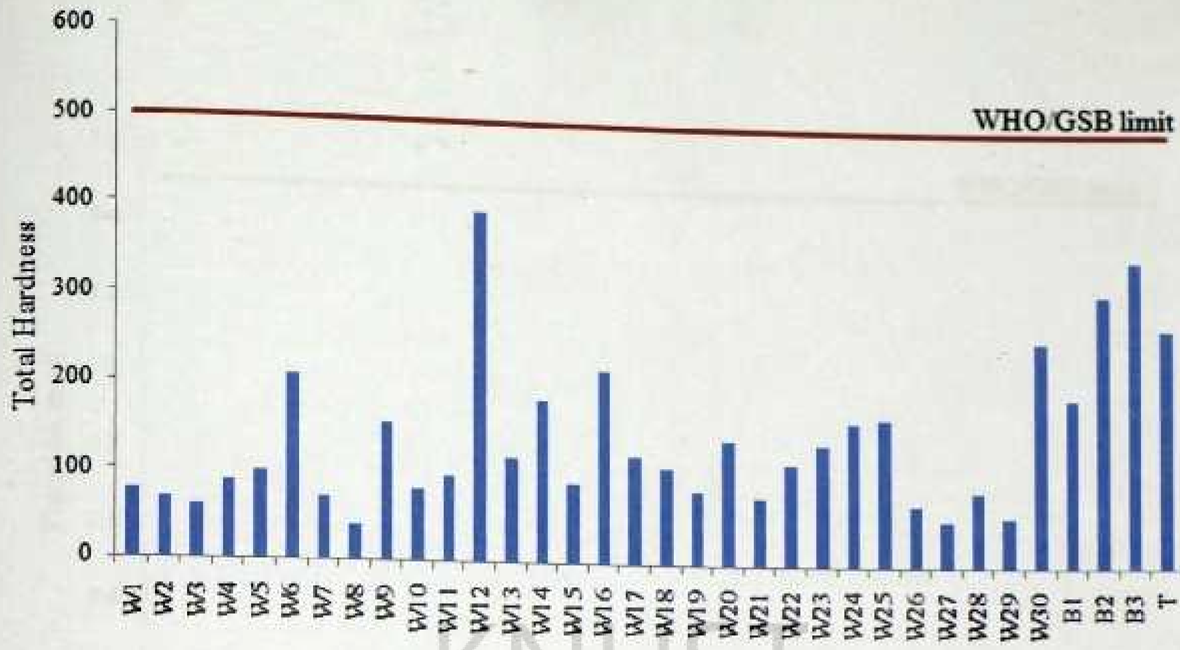

Figure 9: Total Hardness of the Water Samples

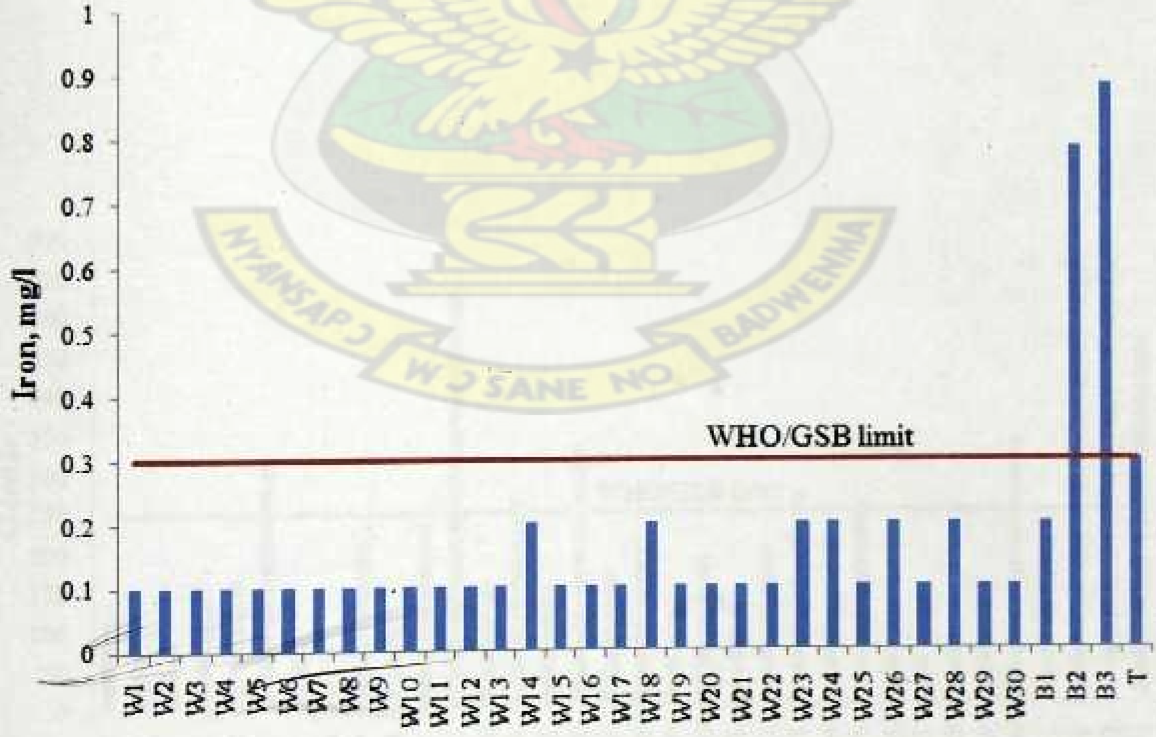

Figure 10: Iron concentration of the Water Samples

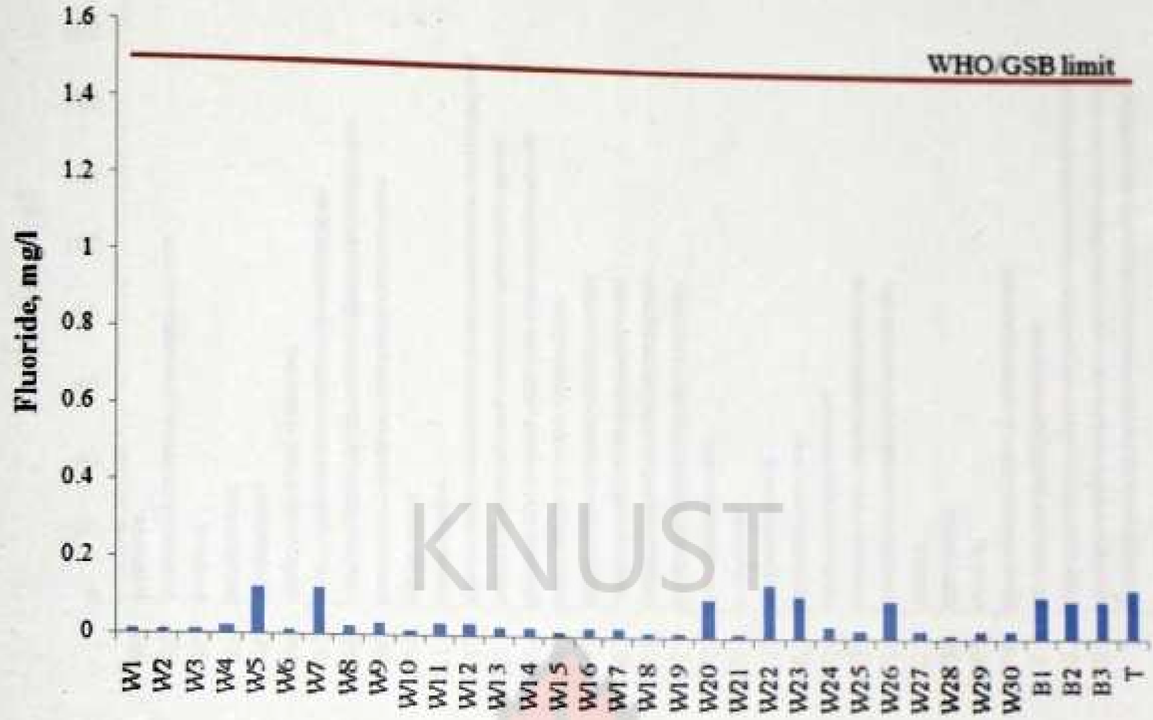

Figure 11: Fluoride concentration of the Water Samples

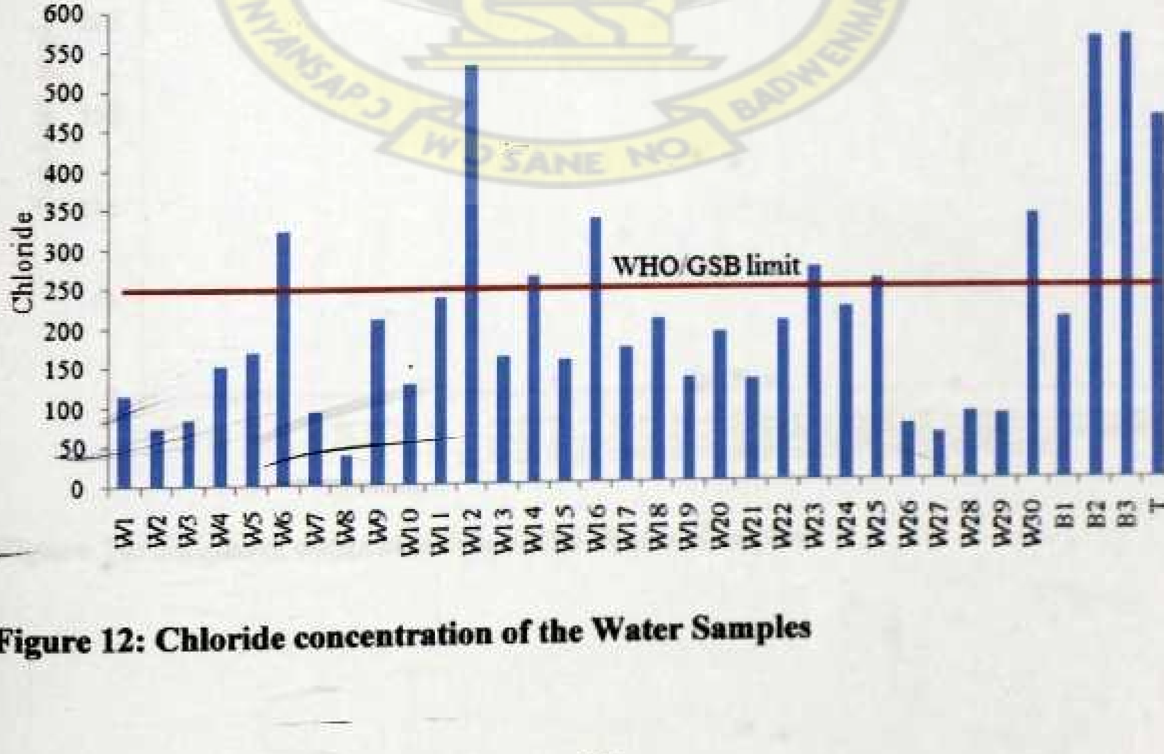

Figure 12: Chloride concentration of the Water Samples

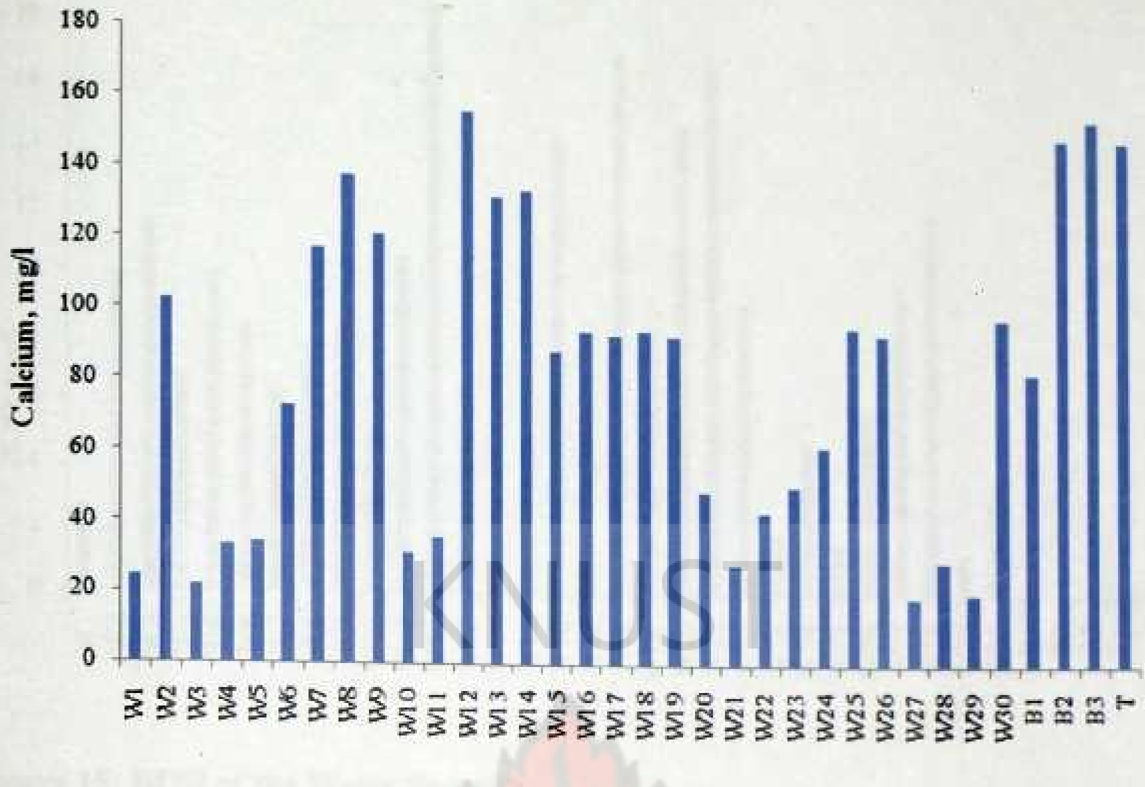

Figure 13: Calcium concentration of the Water Samples

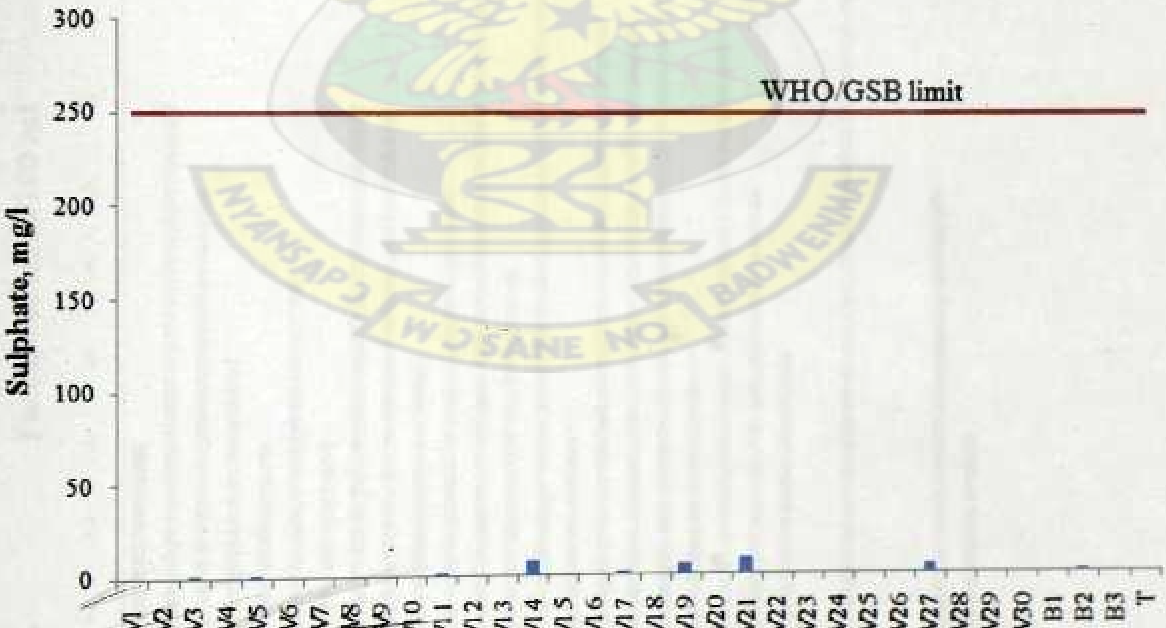

Figure 14: Sulphate concentration of the Water Samples

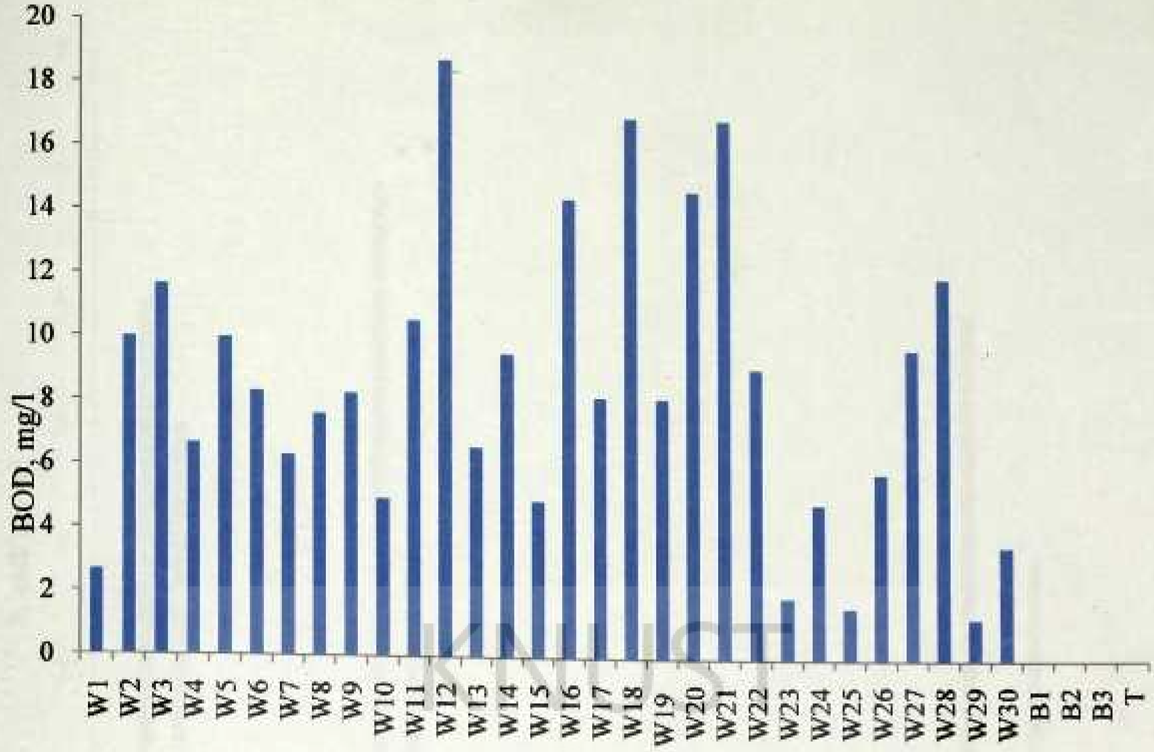

Figure 15: BOD of the Water Samples

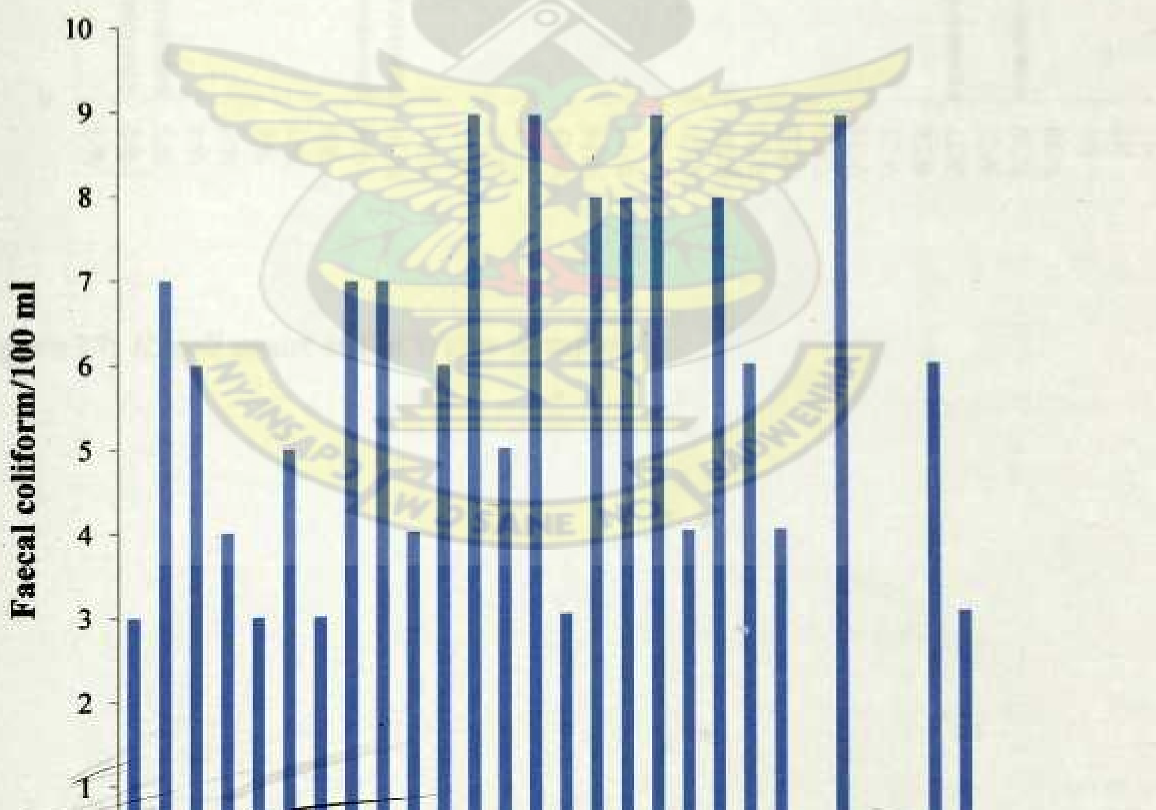

Figure 16: Faecal Coliform count of the Water Samples

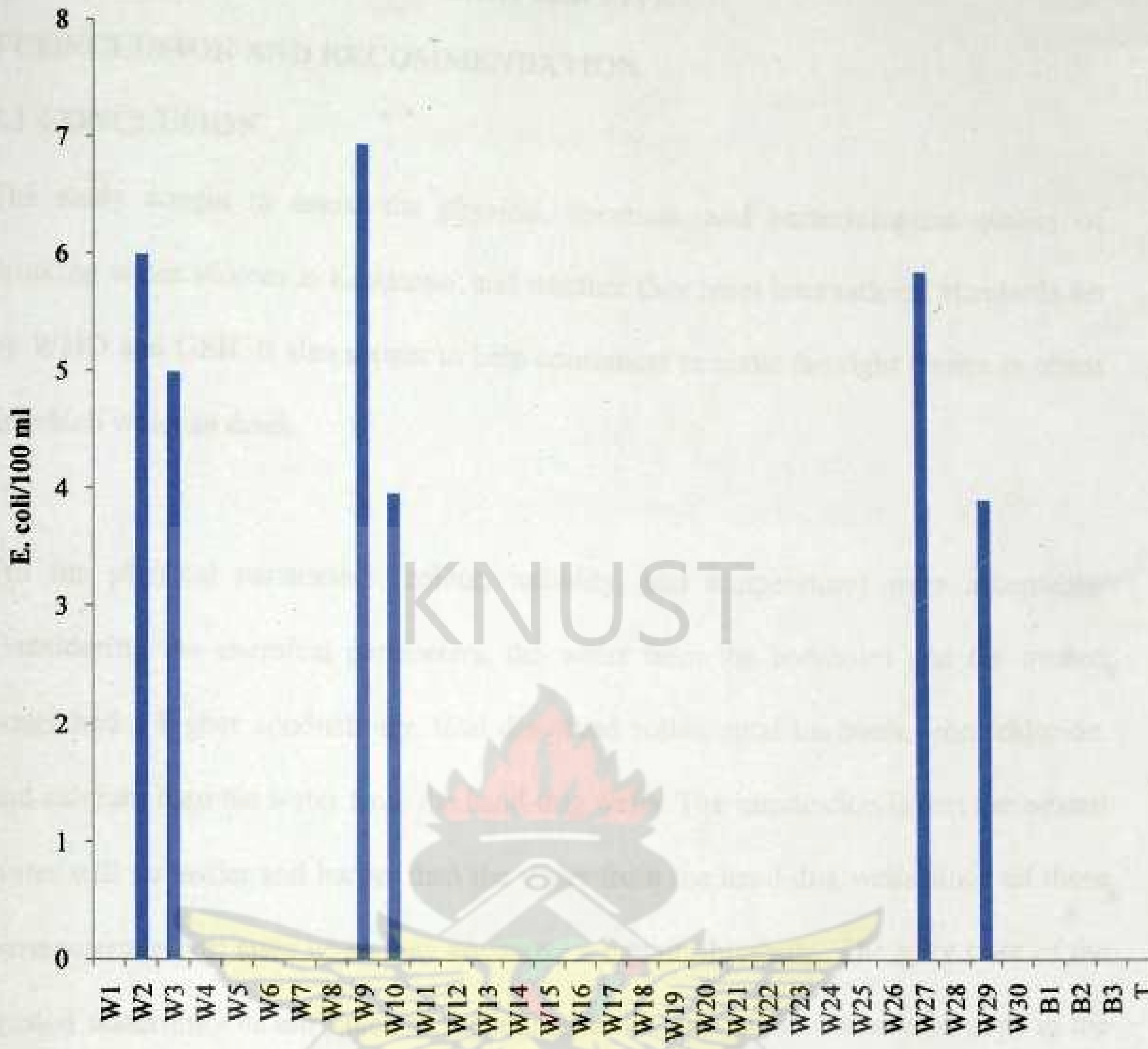

Figure 17: ***E. coli*** **count of the Water Samples**

CHAPTER FIVE

5 CONCLUSION AND RECOMMENDATION

5.1 CONCLUSION

The study sought to assess the physical, chemical, and bacteriological quality of drinking water sources at Kintampo, and whether they meet international standards set by WHO and GSB. It also sought to help consumers to make the right choice in terms of which water to drink.

For the physical parameters (colour, turbidity, and temperature) were acceptable. Considering the chemical parameters, the water from the boreholes and the treated water had a higher conductivity, total dissolved solids, total hardness, iron, chloride, and calcium than the water from the hand-dug wells. The implication is that the treated water will be tastier and harder than the water from the hand-dug wells since all these parameters impart taste when they are above a certain threshold. The salty taste of the treated water may be attributed to the high chloride and calcium concentrations in the water from the boreholes.

With regards to the biological parameters, the water from the boreholes and treated water had no BOD nor were they contaminated with faecal coliform or *E. coli* bacteria, while the water from most of the hand-dug wells had all. This could be attributed to the general insanitary conditions around most of them. The dilapidated structures like broken parapet walls, lack of aprons and channels to carry waste water from the surroundings of the hand-dug wells made it possible for their water to be contaminated. A few of the hand-dug wells, which were closer to ventilated improved pit latrines may have been contaminated with *E. coli* bacterial from them. However, water from the boreholes and the treated water are healthier than the water from most of the hand-dug wells since the later has BOD and are contaminated with faecal coliform and *E. coli* bacteria. Chemicals like camphor and dettol are not meant for oral consumption. Hence, the use of these chemicals by some hand-dug well owners to treat their water may lead to adverse health effects (especially, cancer for the consumption of camphor) on the consumers of such water.

5.2 Recommendation

The health officials in Kintampo Municipality should embark on a health education programme to educate the people on sanitary protection of all water sources, including appropriate siting of latrines.

The use of camphor and dettol to treat water in hand-dug wells should be discouraged by health official because of their adverse effects on health.

The Municipal Assembly should pass a bye-law to ensure that all hand-dug wells are completely covered and fitted with simple hand pumps to reduce contamination of the water.

The Kintampo Water Supply should take steps to reduce the chloride and calcium concentrations in their water since these ions contribute to the taste and hardness in the water.

The aeration facility, which serves to reduce iron concentration in the water, should be expanded to further reduce the iron concentration of the treated water.

DEFINITION OF TERMS AND ACRONYMS

APEC..................	Advance Purification Engineering Corporation
APHA..................	American Public Health Association
AWWA..................	American Water Works Association
CWSA..................	Community Water and Sanitation Agency
UNEP..................	United Nations Environment Programme
USEPA................	United States Environmental Protection Agency
USGS..................	United States Geological Survey
WHO....................	World Health Organisation
Haemochromatosis...	A genetic disorder in which there is excess accumulation of iron in the body leading to damage of many organs, especially the liver and pancreas (Microsoft Encarta, 2008)
Methemoglobinemia..	An altered form of haemoglobin that cannot bind oxygen produced by some poisons or genetic disorder (Microsoft Encarta, 2008).
Uraemic Syndrome...	A form of blood poisoning caused by the accumulation in the blood of products that are normally eliminated in the urine. (Microsoft Encarta, 2008)

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APPENDIX

Table 1: Physical Parameters of the Water Samples for October 15, 2008

Code	Colour, Pt Co	Turbidity, NTU	Temperature, °C
W1	4.2	1	28.2
W2	4.5	1.6	27.1
W3	4.6	1.6	27.6
W4	3.8	1.2	27.5
W5	4.2	1.5	27.4
W6	4.7	2.2	27.6
W7	4.6	1.6	27.7
W8	4.0	0.8	27.5
W9	4.0	1.2	27.4
W10	6.5	1.9	27.6
W11	4.1	0.9	26.6
W12	4.0	1.2	26.7
W13	4.4	1.2	26.9
W14	3.8	1.1	26.9
W15	3.6	1	26.2
W16	4.1	0.9	27.1
W17	4.2	0.9	26.7
W18	4.4	1.2	26.9
W19	4.6	1.5	26.6
W20	3.9	0.8	26.5
W21	3.7	0.9	26.7
W22	3.8	0.9	26.4
W23	3.8	0.9	26.3
W24	5.0	1.2	26.5
W25	4.2	0.9	26.1
W26	4.1	0.7	26.2
W27	7.8	1.9	27.2
W28	6.1	1.6	26.7
W29	5.7	0.8	26.5
W30	3.5	0.9	26.5
B1	10.8	3.9	26.9
B2	14.1	2.9	26.7
B3	11.4	3.2	26.5
T	6.5	2.2	26.5

Table 2: Physical Parameters of the Water Samples for December 20, 2008

Code	Colour, Pt Co	Turbidity, NTU	Temperature, °C
W1	5.2	1	28.8
W2	5.5	1.9	28.1
W3	5.4	1.8	28.2
W4	4.2	1.4	28.0
W5	5.2	1.9	28.0
W6	5.3	2.5	28.0
W7	5.4	1.9	27.9
W8	4.6	1.2	27.7
W9	5.4	1.4	27.6
W10	6.9	2.1	28.0
W11	4.5	1.1	26.9
W12	4.6	1.4	27.1
W13	5.0	1.4	27.3
W14	4.2	1.5	27.1
W15	3.8	1	27.0
W16	4.5	1.1	27.3
W17	4.4	1.1	27.1
W18	5.0	1.4	27.1
W19	4.8	2.1	26.8
W20	4.1	1.2	26.7
W21	4.3	1.1	27.3
W22	4.2	1.1	26.8
W23	4.2	1.1	26.8
W24	5.6	1.4	26.7
W25	5.2	1.1	26.3
W26	4.5	1.	26.9
W27	8.2	2.1	27.5
W28	6.5	1.8	26.9
W29	6.3	1.2	26.7
W30	4.5	1.1	26.9
B1	11.2	4.1	27.2
B2	14.5	3.1	27.3
B3	12.0	3.6	27.1
T	6.9	2.4	26.8

Table 3: Physical Parameters of the Water Samples for February 14, 2009

Code	Colour, Pt Co	Turbidity, NTU	Temperature, °C
W1	4.7	1	28.5
W2	5	1.6	27.6
W3	5	1.7	27.9
W4	4	1.3	27.6
W5	4.7	1.7	27.7
W6	5	2.2	27.8
W7	5	1.6	27.8
W8	4.3	1	27.6
W9	4.7	1.3	27.5
W10	6.7	2	27.8
W11	4.3	1	26.6
W12	4.3	1.3	26.9
W13	4.7	1.3	27.1
W14	4	1.3	27
W15	3.7	1	26.3
W16	4.3	1	27.2
W17	4.3	1	26.9
W18	4.7	1.3	27
W19	4.7	1.5	26.7
W20	4	1	26.6
W21	4	1	27
W22	4	1	26.6
W23	4	1	26.4
W24	5.3	1.3	26.6
W25	4.7	1	26.2
W26	4.3	1	26.4
W27	8	2	27.2
W28	6.3	1.7	26.8
W29	6	1	26.6
W30	4	1	26.7
B1	11	4	26.9
B2	14.3	3	27
B3	11.7	3.1	26.8
T	6.7	2.3	26.5

Table 4: Chemical Parameters of the Water Samples for October 15, 2008

Code	Conductivity, µS/cm	pH	DO, mg/l	TDS, mg/l	TSS, mg/l	Total Hardness, mg/l
W1	227	6.2	4.8	114.3	3.2	76
W2	149.7	6.1	3.8	75.3	1.8	67
W3	164.7	5.7	5.6	82.6	1.9	57.3
W4	303.3	6.1	3.4	153.7	1.8	86.7
W5	339	5.7	4.9	169.5	1.8	97.7
W6	645.7	6	4.2	323.7	1.9	205.7
W7	186.7	6.3	4.2	93.4	1.7	67.3
W8	60.3	6.2	4.6	30.2	1.9	36.7
W9	421	6.3	5.4	209.8	1.9	153.7
W10	256	5.8	2.9	129.1	2.9	80.3
W11	471.3	6.1	3	236.2	1.9	94.7
W12	1070.2	6	3.6	533.1	2.4	396
W13	324.3	6.2	2.8	161.1	1.9	117
W14	521.2	6.3	2.8	260.8	5.5	182.4
W15	313.3	6.3	3.4	155.3	1.9	88
W16	678.7	6.1	3.5	337.3	2.5	217.3
W17	337.7	6.2	3.5	170.4	1.8	121
W18	415.3	6.3	3.9	203	7.7	109.3
W19	266.1	6.2	4.4	132.3	1.9	81
W20	380	6.1	3.1	191	1.9	140
W21	260.7	5.8	3.7	129.1	1.9	74.7
W22	411	6	3.9	205.9	1.8	114
W23	521.3	5.8	2.9	260.8	4.9	136
W24	442.3	6.2	3.4	225.7	1.8	162.7
W25	519	6.2	2.8	256.5	1.8	168
W26	145.3	6.5	3	73	3.4	67.3
W27	94.3	6.2	4.1	47.5	1.9	49.7
W28	171.7	6.3	4	86.1	3.9	83.3
W29	167.7	6.2	4.5	85.1	1.9	54.7
W30	693.3	6.8	3.7	346.1	1.9	257.3
B1	414.7	6.5	3	73.9	9.7	191.3
B2	1115.3	6.8	3.4	694.5	12.8	311.3
B3	1118.7	6.7	2.8	641	15.6	352.7
T	919.7	6.7	3.3	586.2	1.9	274.7

Table 5: Chemical Parameters of the Water Samples for December 20, 2008

Code	Conductivity, µS/cm	pH	DO, mg/l	TDS, mg/l	TSS, mg/l	Total Hardness, mg/l
W1	231	5.4	4.6	114.9	3.5	80
W2	151.7	5.7	3.4	75.9	2.3	72
W3	166.7	5.5	5.4	82.9	2.2	62.3
W4	307.3	5.9	3	154.1	2.3	89.2
W5	340.4	5.3	4.5	170.2	2.2	101.7
W6	647.7	5.8	4	324.2	2.2	210.7
W7	188.7	6.1	4	93.9	2.4	73.3
W8	62.3	6	4.4	30.8	2.1	42.7
W9	423	5.9	5.2	210.5	2.1	160.7
W10	258	5.6	2.5	129.7	3.2	87.3
W11	475.3	5.9	2.8	236.5	2.2	99.7
W12	1071.2	5.8	3.4	533.7	3.4	400
W13	328.3	6	2.6	161.8	2.2	123
W14	522.8	6.1	2.6	261.5	6.1	186.8
W15	315.3	6.1	2.8	155.9	2.2	93
W16	680.7	5.9	3.3	337.9	3	223.3
W17	341.7	6	3.3	170.7	2.3	129
W18	417.3	6.1	3.7	203.6	8.6	113.3
W19	269.9	6	4.2	133	2.2	86
W20	384	5.7	2.9	191.6	2.2	146
W21	264.7	5.6	3.5	129.7	2.2	81.7
W22	411	5.8	3.7	206.2	2.3	120
W23	523.3	5.2	2.7	261.4	5.2	142
W24	448.3	6	3.2	226.3	2.3	168.7
W25	521	6	2.6	257.1	2.3	173
W26	147.3	6.3	2.8	73.5	4.3	73.3
W27	96.3	5.8	3.9	48.2	2.1	55.7
W28	177.7	6.1	3.8	86.7	4.2	89.3
W29	171.7	5.8	4.3	85.5	2.2	59.7
W30	697.3	6.2	3.3	346.6	2.2	263.3
B1	418.7	5.9	2.8	74.4	11.2	200.3
B2	1117.3	6.4	3.2	695	13.3	318.3
B3	1120.7	6.3	2.4	641.6	16	358.7
T	921.7	6.7	3.1	586.6	2.2	277.7

Table 6: Chemical Parameters of the Water Samples for February 14, 2009

Code	Conductivity, µS/cm	pH	DO, mg/l	TDS, mg/l	TSS, mg/l	Total Hardness, mg/l
W1	229	5.8	4.7	114.3	3.2	75
W2	150.7	5.9	3.6	75.3	1.9	68
W3	165.7	5.6	5.5	82.6	1.9	58.3
W4	305.3	6	3.2	153.6	1.9	86
W5	339.7	5.5	4.7	169.4	2	96.7
W6	646.7	5.9	4.1	324.1	1.9	206.7
W7	187.7	6.2	4.1	93.5	1.9	67.3
W8	61.3	6.1	4.5	30.2	2	36.7
W9	422	6.1	5.3	209.7	2	152.7
W10	257	5.7	2.7	129.1	2.9	79.3
W11	473.3	6	2.9	236.2	1.9	95.7
W12	1070.7	5.9	3.5	533.1	2.3	395
W13	326.3	6.1	2.7	161	1.9	117
W14	522	6.2	2.7	260.7	5.5	182.8
W15	314.3	6.2	3.1	155.3	1.9	89
W16	679.7	6	3.4	337.3	2.6	217.3
W17	339.7	6.1	3.4	170.4	1.9	122
W18	416.3	6.2	3.8	203	7.7	108.3
W19	268	6.1	4.3	132.2	1.9	82
W20	382	5.9	3	191	1.9	140
W21	262.7	5.7	3.6	129.1	1.9	73.7
W22	411	5.9	3.8	205.9	1.9	114
W23	522.3	5.5	2.8	260.8	4.9	136
W24	445.3	6.1	3.3	225.7	1.9	162.7
W25	520	6.1	2.7	256.5	1.9	169
W26	146.3	6.4	2.9	73.1	3.4	67.3
W27	95.3	6	4	47.4	2	49.7
W28	174.7	6.2	3.9	86.1	3.9	83.3
W29	169.7	6	4.4	85	1.9	55.7
W30	695.3	6.5	3.5	346.2	1.9	257.3
B1	416.7	6.2	2.9	74	9.1	191.3
B2	1116.3	6.6	3.3	694.6	12.9	310.3
B3	1119.7	6.5	2.6	641	15.5	352.7
T	920.7	6.7	3.2	586.1	1.9	274.7

Table 7: Dissolved Ion Concentrations of the Water Samples for October 15, 2008

Code	Iron, mg/l	Fluoride, mg/l	Chloride, mg/l	Calcium, mg/l	Sulphate, mg/l
W1	0.06	0.06	113.6	23.3	-
W2	0.07	0.01	73	102	-
W3	0.05	0.01	82.0	20.8	1.65
W4	0.1	0.01	150.7	31.0	-
W5	0.05	0.11	167.3	33.4	2.00
W6	0.11	0.01	320.3	69.9	-
W7	0.06	0.1	93.7	115.6	-
W8	0.06	0.01	35.7	137.0	-
W9	0.1	0.02	209.3	121.0	-
W10	0.07	0.01	126.3	30.4	-
W11	0.1	0.02	235.0	34.8	1.64
W12	0.12	0.02	533.3	155.0	-
W13	0.12	0.01	160.3	131.3	-
W14	0.15	0.01	264.7	133.4	8.66
W15	0.09	0.01	156.3	88.6	1.32
W16	0.06	0.01	338.3	94.5	-
W17	0.11	0.01	169	92.2	1.98
W18	0.12	0.01	207.3	94.4	-
W19	0.1	0.01	131.7	92.6	6.66
W20	0.07	0.09	188.7	48.1	-
W21	0.07	0.01	128.3	25.6	9.31
W22	0.1	0.12	205.0	41.7	-
W23	0.12	0.1	272.3	49.4	-
W24	0.13	0.02	220.3	60.8	-
W25	0.1	0.01	258	69.9	-
W26	0.14	0.1	69.3	93.5	-
W27	0.11	0.01	57.3	17.5	4.64
W28	0.15	0.01	85.0	28.9	-
W29	0.08	0.01	82.3	18.8	-
W30	0.1	0.02	341.0	97.1	-
B1	0.14	0.1	206.3	82.6	-
B2	0.75	0.1	569.7	150.9	1.66
B3	0.84	0.1	571.3	157.4	-
T	0.27	0.11	468	150.6	0.1

Table 8: Dissolved Ion Concentrations of the Water Samples for December, 2008

Code	Iron, mg/l	Fluoride, mg/l	Chloride, mg/l	Calcium, mg/l	Sulphate, mg/l
W1	0.11	0.12	116.3	26.3	-
W2	0.13	0.01	76.4	104	-
W3	0.08	0.01	87	23.5	1.73
W4	0.1	0.04	157.7	36.0	-
W5	0.08	0.15	173.3	36.4	2.03
W6	0.14	0.01	326.3	78.9	-
W7	0.1	0.15	97.7	120.6	-
W8	0.1	0.04	40.7	143.0	-
W9	0.1	0.05	213.3	124.0	-
W10	0.1	0.01	133.3	34.4	-
W11	0.1	0.05	240.0	38.8	1.71
W12	0.15	0.05	538.3	162	-
W13	0.17	0.04	165.3	138.3	-
W14	0.21	0.04	268.7	138.4	8.7
W15	0.12	0.01	160.3	92.6	1.36
W16	0.13	0.03	339.2	97.5	-
W17	0.17	0.03	175	97.2	2.03
W18	0.19	0.01	210.3	98.3	-
W19	0.11	0.01	136.7	99.6	6.7
W20	0.12	0.11	194.7	55.1	-
W21	0.11	0.01	133.3	34.6	9.36
W22	0.1	0.17	209.0	47.7	-
W23	0.19	0.13	278.3	54.4	-
W24	0.19	0.05	225.3	65.8	-
W25	0.1	0.04	264	99.7	-
W26	0.22	0.1	77.3	98.5	-
W27	0.16	0.04	63.3	24.5	5
W28	0.22	0.01	90.0	33.9	-
W29	0.14	0.04	90.3	23.8	-
W30	0.1	0.03	347.0	105.1	-
B1	0.19	0.13	211.3	89.6	-
B2	0.81	0.1	577.7	155.9	1.7
B3	0.92	0.1	576.3	161.4	-
T	0.32	0.17	472.0	155.6	1.6

Table 9: Dissolved Ion Concentrations of the Water Samples for February, 2009

Code	Iron, mg/l	Fluoride, mg/l	Chloride, mg/l	Calcium, mg/l	Sulphate, mg/l
W1	0.07	0.06	116	23.3	-
W2	0.07	0.01	71.7	101.5	-
W3	0.05	0.01	83.0	21.1	1.63
W4	0.1	0.01	152.7	32	-
W5	0.05	0.1	167.3	33.4	1.97
W6	0.11	0.01	320.3	69.9	-
W7	0.08	0.11	92.7	116.6	-
W8	0.08	0.01	36.7	137.0	-
W9	0.1	0.02	208.3	121.0	-
W10	0.07	0.01	125.3	29.4	-
W11	0.1	0.02	236.0	33.8	1.66
W12	0.12	0.02	534.3	157.0	-
W13	0.13	0.01	161.3	130.3	-
W14	0.15	0.01	263.7	134.4	8.65
W15	0.09	0.01	155.3	87.6	1.31
W16	0.08	0.02	338.6	94.5	-
W17	0.11	0.02	169.0	93.2	1.99
W18	0.14	0.01	207.3	95.9	-
W19	0.09	0.01	132.7	91.6	6.65
W20	0.08	0.1	188.7	47.1	-
W21	0.09	0.01	129.3	25.6	9.32
W22	0.1	0.13	204.0	41.7	-
W23	0.14	0.1	272.3	50.4	-
W24	0.13	0.02	221.3	61.8	-
W25	0.1	0.01	258	95.9	-
W26	0.15	0.1	70.3	94.5	-
W27	0.12	0.01	57.3	16.5	4.64
W28	0.14	0.01	86	26.9	-
W29	0.11	0.01	83.3	19.8	-
W30	0.1	0.01	341.0	98.1	-
B1	0.15	0.1	207.3	81.6	-
B2	0.75	0.1	570.7	151.9	1.65
B3	0.85	0.1	572.3	156.4	-
T	0.28	0.11	467.0	151.6	1.3

Table 10: Biological Parameters of the Water Samples for October 15, 2008

Code	BOD, mg/l	Faecal coliform, MPN	*E. coli*, MPN
W1	2.62	3	-
W2	9.97	6	6
W3	11.63	6	3
W4	6.64	3	-
W5	9.97	3	-
W6	8.3	3	-
W7	6.31	3	-
W8	7.61	6	-
W9	8.31	6	6
W10	4.96	8	3
W11	10.65	6	-
W12	18.97	9	-
W13	6.66	3	-
W14	9.64	9	-
W15	4.98	3	-
W16	14.65	6	-
W17	8.31	7	-
W18	17.3	9	-
W19	8.32	3	-
W20	14.96	8	-
W21	17.3	6	-
W22	9.3	4	-
W23	1.98	-	-
W24	4.95	8	-
W25	1.62	-	-
W26	5.96	-	-
W27	9.98	7	6
W28	12.3	3	-
W29	1.3	5	3
W30	3.65	-	-
B1	-	-	-
B2	-	-	-
B3	-	-	-
T	-	-	-

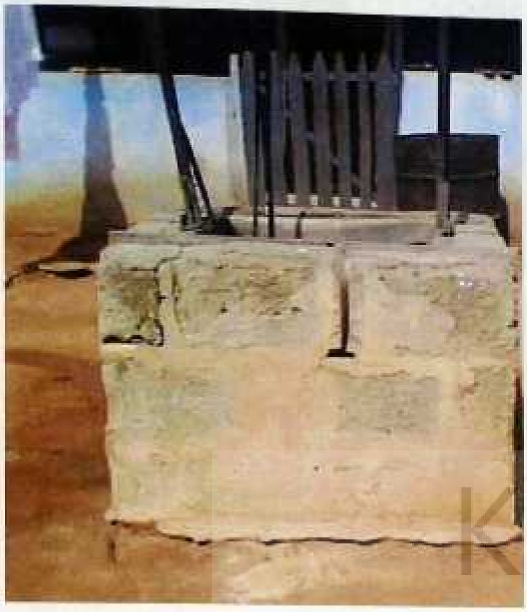
Table 11: Biological Parameters of the Water Samples for December 20, 2008

Code	BOD, mg/l	Faecal coliform, MPN	*E. coli*, MPN
W1	2.74	3	-
W2	10.06	9	7
W3	11.72	7	9
W4	6.71	6	-
W5	10.05	3	-
W6	8.37	9	-
W7	6.36	3	-
W8	7.75	9	-
W9	8.38	12	9
W10	5.04	10	6
W11	10.7	6	-
W12	19.04	10	-
W13	6.69	8	-
W14	9.71	10	-
W15	5.04	3	-
W16	14.71	12	-
W17	8.36	10	-
W18	17.37	10	-
W19	8.35	5	-
W20	15.07	9	-
W21	17.39	6	-
W22	9.39	5	-
W23	2.04	-	-
W24	5.07	10	-
W25	1.73	-	-
W26	6.05	-	-
W27	10.03	10	8
W28	12.37	3	-
W29	1.38	7	6
W30	3.7	-	-
B1	-	-	-
B2	-	-	-
B3	-	-	-
T	-	-	-

Table 12: Biological Parameters of the Water Samples for February 14, 2009

Code	BOD, mg/l	Faecal coliform, MPN	*E. coli*, MPN
W1	2.65	3	-
W2	9.97	6	5
W3	11.66	5	3
W4	6.66	3	-
W5	9.98	3	-
W6	8.32	3	-
W7	6.32	3	-
W8	7.65	6	-
W9	8.3	6	6
W10	5.00	9	3
W11	10.66	6	-
W12	18.99	8	-
W13	6.66	4	-
W14	9.66	8	-
W15	4.98	3	-
W16	14.65	6	-
W17	8.32	7	-
W18	17.32	8	-
W19	8.32	4	-
W20	14.97	7	-
W21	17.3	6	-
W22	9.3	3	-
W23	1.98	-	-
W24	4.98	9	-
W25	1.66	-	-
W26	5.99	-	-
W27	9.99	7	4
W28	12.32	3	-
W29	1.31	6	3
W30	3.66	-	-
B1	-	-	-
B2	-	-	-
B3	-	-	-
T	-	-	-

SOME OF THE SAMPLED HAND-DUG WELLS




HAND-DUG WELLS WITH SIMPLE HAND PUMPS


IRON REMOVAL PROCESS AT THE KINTAMPO WATER TREATMENT SITE