

UNIVERSITY OF GHANA
SCHOOL OF PHYSICAL AND MATHEMATICAL SCIENCES
DEPARTMENT OF CHEMISTRY



**ANALYSIS OF MICROBIAL AND PHYSICO-CHEMICAL PARAMETERS OF
DRINKING WATER FROM BOREHOLES IN THE UPPER EAST REGION**

BY

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INTEGRI PROCEDAMUS

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DECLARATION

I, Tabitha Apegyine Ayillah, the thesis's author, hereby affirm that I alone was responsible for the work contained in this thesis, which was done at the University of Ghana's Department of Chemistry under the supervision of Dr. Bozumah Som and Prof. Louis K. Doamekpor.



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DEDICATION

This work is dedicated to Phoebe-Ann, Jedediah and the Ayillah family. Your love has brought me this far. Thank you.



ACKNOWLEDGEMENT

I want to sincerely thank my supervisors for their assistance in making this effort a reality. I am very appreciative of my supervisor, Dr. Bozumeh Som, for his unwavering support and assistance during my time as a student at the University of Ghana. I would like to thank my co-supervisor, Prof. Louis K. Doamekpor, for all the support she gave me and my research project, as well as for your vast knowledge and prompt guidance that enabled the successful completion of the project. Furthermore, I would like to convey my appreciation to the Senior Members of the Chemistry Department at the University of Ghana, whose significant contributions to this study through several seminar presentations have made it a success.

Lastly, I praise the All-Powerful God for His mercy and strength, which enabled me to finish this program.



ABSTRACT

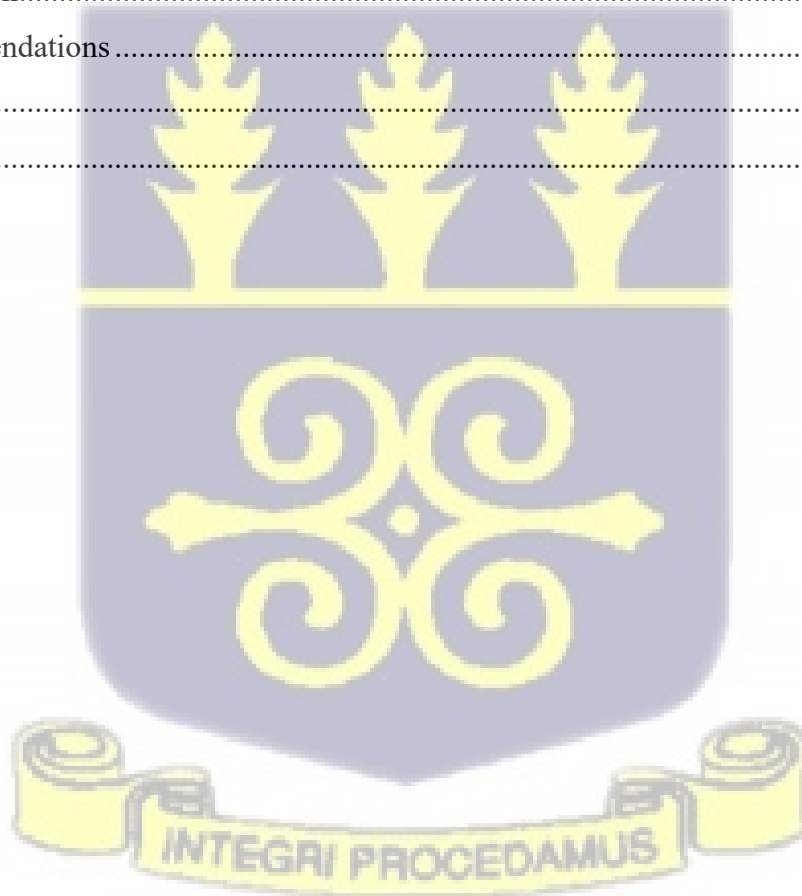
Access to and availability of high-quality water are critical for sustainable development. But in most developing countries, including Ghana, a high percentage of people living in rural areas do not have access to both quantity and quality of water. A significant number of these people rely on alternative water sources such as precipitation, springs, boreholes, and streams. Consequently, during the dry season, water-borne diseases associated with unclean water sources are more common. Fluoride-containing minerals, which are commonly found in sedimentary and igneous rocks, are found in several settlements in Ghana's Upper East region. As such, this work sort to measure the amounts of some metals, physico-chemical and microbial parameters present in the borehole water sources to assess whether the borehole water sources are suitable for drinking and other household applications. The HACH DR 3900 method was employed with some modification in determining the physico-chemical parameters and metals, while the microbial studies were done using the membrane filtration method. The results suggest that the physico-chemical parameters generally are within the accepted limit set by the Ghana Standard Authority (GSA) and the World Health Organization (WHO) water quality recommendations. However, fluoride levels recorded at Bolgatanga and Bongo districts gave concentrations as high as 2.7 mg/L and 2.0 mg/L, respectively, which is above the set limit of 1.5 mg/L. Also, the studied metals Mg, Ca, Fe, Cu, and Zn were within the required limits. Additionally, microbial studies showed the presence of total coliform and E. Coli in all the districts. Levels of total coliform and E. Coli were highest at the Bongo district, 115 CFU/100 mL and 53 CFU/100 mL, respectively. The observed presence of fluoride, E. Coli and total coliform poses significant health risks and calls for proactive measures to check the safety of water to protect human lives.

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LIST OF ABBREVIATIONS

EC - Electrical Conductivity

EDTA - Ethylenediaminetetraacetic acid

GWCL - Ghana Water Company Limited

GSA - Ghana Standard Authority

TDS - Total Dissolved Solids

TSS - Total Suspended Solids

WHO - World Health Organization

CHAPTER ONE

1.0. General Introduction

1.1. Background of the study

Access to and availability of high-quality water are critical for sustainable development, as well as health, food production, and poverty reduction (Abul et al., 2014). However, about twenty (20) percent of the population in most underdeveloped nations, including Ghana, has access to both quality and quantity of water. For their daily activities, most of the population relies on alternative sources of water such as streams, springs, boreholes, and precipitation. As a result, water-borne infections linked to unhygienic water supplies are more prevalent during the dry season. Drinking water that is clean and fresh is crucial for humans and other living things, and every community needs it (Ahmad et al., 2018). A survey by the World Health Organization states that approximately 1.1 billion people lack access to clean drinking water (Ahmad et al., 2018). In terms of good quality drinking water, Ghana shares the same fate as the rest of the world.

Although groundwater is widely regarded as safe drinking water, fast population development, rising urban living standards, and industrialization have resulted in increased demand for high-quality water, while pollution of water sources has continuously increased (Apau et al., 2015).

Water in marshy areas, lakes, and streams is referred to as surface water. Surface water is inherently polluted as much as it is easily accessible (Apau et al., 2015). There is a substantial risk of faecal pollution in streams, lakes, and ponds in some sparsely populated areas because of improper sewage disposal (Ahmad et al., 2018). In addition, as water rushes through the ground's surface, it absorbs a wide range of substances, including organic compounds, mineral deposits, and microorganisms. It becomes nutrient-rich, making it an ideal environment for the growth of all types of microorganisms (Kurup et al., 2010). Maintaining high-quality surface water is critical

to ensuring that it can be used for a variety of purposes. Due to dramatic demographic changes in Ghana, raw water has become increasingly polluted in recent years (Apau et al., 2015).

The primary microbiological concern about surface and groundwater is the potential health risk associated with the faecal contamination of the four categories of pathogens (bacteria, viruses, protozoa, and parasites) found in human excrement (Sakyi et al., 2018). According to Bohara et al., 2015 the main contaminants of groundwater include iron, arsenic, manganese, and pathogenic micro-organisms (Bohara, 2015). Furthermore, nitrates and nitrites, as well as other trace elements, contribute to the contamination of groundwater. It is a well-known fact that drinking contaminated water poses considerable health concerns, primarily due to microbes and chemical contaminants.

The World Health Organization (2006) states that a drop in dissolved oxygen in the water supply could accelerate the microbial conversion of sulfate to sulfide and nitrate to nitrite, which is impacted by the distribution system's chemical or biological processes, raw water temperature, treatment, and source (Sakyi et al., 2018). Maintaining proper levels of alkalinity and calcium in pipes and appliances also helps to stabilize the water and lessen abrasiveness. As said, facultative anaerobes are organisms that can exist in the presence of oxygen (or without it). Obligate anaerobes, on the other hand, are organisms that do not tolerate oxygen.

Water quality includes the chemical, physical, biological, and radiological components and is a measurement of the state of the water concerning the needs of one or more biotic species and any human need. Radiological, biological, and physicochemical characteristics are examples of water quality parameters. Physicochemical parameters are those aspects of water's composition that have an impact on both its biological components and its quality (Oluyemi et al., 2010). Water's physical characteristics include temperature, turbidity, colour, conductivity, suspended solids, odour, and total dissolved solids. These may affect the water's taste and appearance and complicate the process

of eliminating microbiological infections during water treatment. The chemical factors that are considered are pH, COD (chemical oxygen demand) and BOD (biochemical oxygen demand) (O. Sakyi et al., 2018). Many groundwaters with high levels of Physico-chemical characteristics such as fluorides, chlorides, hardness, and sulphites may be dangerous to humans. Unfortunately, this problem occurred as a result of the extraction of groundwater for drinking and other industrial purposes without a thorough chemical study and basic water quality parameter testing. Groundwater is widely regarded as the most important natural and fresh resource on the planet, and it is used for drinking and agriculture.

Where different types of rocks and volcanic activity are related to natural sources, fluoride is a common element of groundwater. It occurs naturally in public water systems due to soil leaching into groundwater and runoff from crumbling rocks containing fluoride. Additionally, fluoride-containing emissions from coal-fired power plants and other industrial sources can either directly increase the amount of fluoride in water or deposition on soil and eventually release it into water. Because of its capacity to prevent dental cavities when fluoride is present at acceptable levels and its potential to produce complications including dental fluorosis, osteoporosis, and skeletal fluorosis (Craig et al., 2015), fluoride concentration is an important measure for the quality assessment of drinking water.

1.2. Problem Statement

The most essential substance for human life, water, is rich in minerals and nutrients. It is one of the most important compounds that significantly affects life. Water quality is typically defined in terms of its physical, chemical, and biological properties. A significant reduction in freshwater availability is observed in today's world; this could be linked to population increase, concentrated

farming methods, urbanization, and industrialization (Cosgrove & Loucks, 2015). People must rely on subsurface water sources to meet their demands because surface water is in short supply. Many towns and cities get the groundwater they need from various underground boreholes. The Upper East region is not an exception to this situation. Most districts and towns in this region get their water from borehole water and other alternative sources of water. Many people rely on water sources, like streams, springs, and boreholes, for their daily activities. Consequently, during the dry season, water-borne diseases associated with unclean water sources are more likely to occur. Additionally, some communities in the Upper East region possess both sedimentary and igneous rocks in which minerals containing fluoride can be found (Sunkari & Abu, 2019). Fluoride concentrations significantly rise when these minerals dissolve and enter neighbouring groundwater. Despite the broad exposure and research on the Upper East region's water quality and other regions in Ghana, there is a need to assess its quality since some water related diseases persist due to poor hygiene in our communities. For the aforementioned rationale, this study aimed to determine the fluoride content as well as other physico-chemical and microbiological characteristics found in borehole water sources in a few chosen districts in the Upper East region to determine whether or not they were suitable for drinking and other domestic uses.

1.3. Research Hypothesis

In certain developing countries, access to clean drinking water is still an important issue, particularly in rural communities. As such, a considerable number of people in these rural communities suffer from water borne related diseases. Throughout Ghana's Upper East region, studies have shown that during the dry season, there is a significant increase in the risk of contracting water-borne diseases as a result of contaminated water sources. Additionally, reports

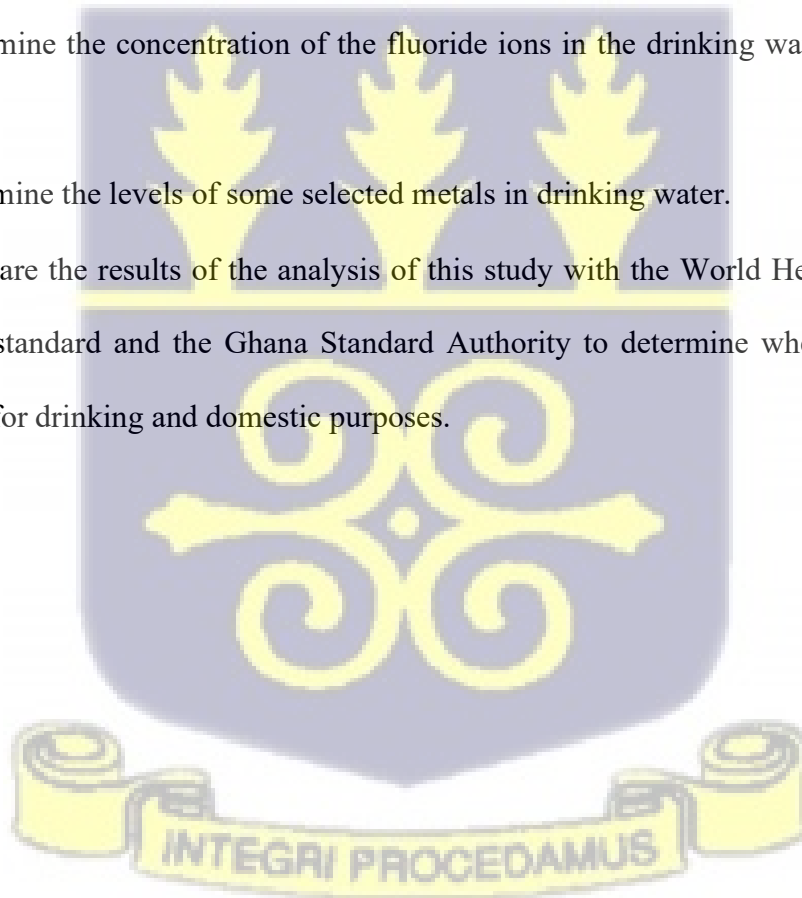
have shown that rocks in the Upper East region contain high levels of fluoride, which may end up in water bodies, posing potential health risks to the populace in the communities found in this region. Consequently, it is hypothesized that borehole water in the Upper East region may contain elevated levels of fluoride, metals and microbes, which may contribute to the rise in waterborne diseases.

1.4. Aims

To evaluate the quality of the drinking water in some selected districts in the Upper East region.

1.4.1. Objectives of the research

- To determine and evaluate the physicochemical properties of the water samples obtained.
- To determine the concentration of the fluoride ions in the drinking water in the selected districts.
- To determine the levels of some selected metals in drinking water.
- To compare the results of the analysis of this study with the World Health Organization (WHO) standard and the Ghana Standard Authority to determine whether the water is suitable for drinking and domestic purposes.



CHAPTER TWO

2.0. LITERATURE REVIEW

2.1. Sources of water

There are several sources of water in the Upper East region of Ghana, which are vital for both domestic and agricultural use. Some amount these include rivers and streams, which provide essential water resources for irrigation and drinking. Groundwater extraction through boreholes is common, thus helping to supply water in areas where surface water is scarce. Collecting rainwater during the wet season helps supplement water supplies, especially in rural communities. Traditional ponds and hand-dug wells also serve as important local water sources. Moreover, dams and reservoirs such as the Pwalugu dam are used for water storage and irrigation purposes (Cornille et al., 2022). These resources are crucial for the livelihoods of the communities in the region, especially given the challenges posed by climate variability and seasonal droughts.

2.2. Groundwater

Groundwater exploitation has increased in Africa over the past ten years to supply water to several rural and urban regions. Groundwater continues to play a vital part in Ghana's socioeconomic growth.

Groundwater from shallow wells, boreholes, and springs continues to be an important supply of water for diverse uses in Sub-Saharan Africa and other regions of the world (Lutterodt et al., 2023). The majority of groundwater is produced by precipitation. Rainwater seeps into the soil layer under the earth's surface. When the soil zone is saturated, water seeps downhill. A saturation zone develops when all of the interstices are filled with water. Water quality issues arise when groundwater is drawn from shallow aquifers, especially when these wells are located close to

beneficiary populations and within dwellings. Properties that are physical, chemical, and biological define the quality of groundwater in a particular place.

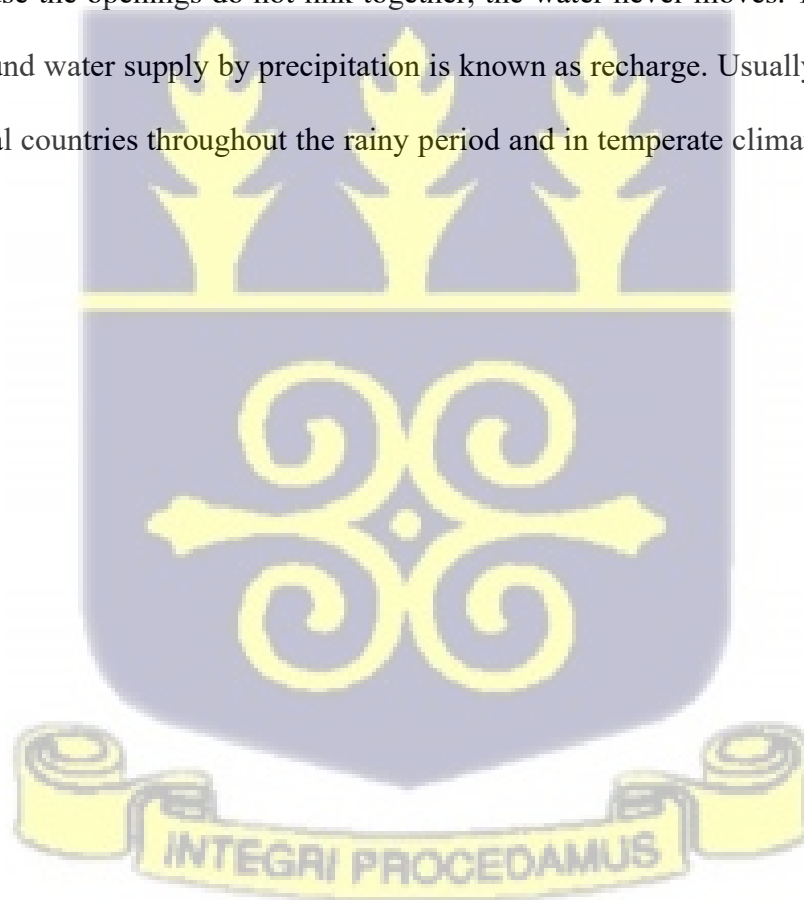
The quality of recharged water, the amount and kind of waste produced, sewage treatment, and subsurface geochemical processes all affect the quality of groundwater (Lutterodt et al., 2021). The variance in groundwater quality in an area is a consequence of physical and chemical factors, which are heavily influenced by geological formations and anthropogenic activity (Qin et al., 2013). Also, Groundwater pollution in urban areas is mostly caused by urban stormwater infiltration, wastewater and septic reservoir leaks, and improper industrial activity (Singh et al., 2022). Because of the increasing rise in population, industrialization, and urbanization in metropolitan cities around the world, groundwater contamination has become a major issue (Lutterodt et al., 2021). Groundwater quality is often defined by a variety of physicochemical factors (Khatri & Tyagi, 2015). According to research findings, Ghana's groundwater resources are under increasing strain as a result of dangers posed by fast population expansion, as well as the development of populated areas devoid of sufficient sanitary facilities and water supplies (Bakobie et al., 2024). Comparing the chemical and biological components of groundwater to international and national standards for potable drinking water is necessary to determine whether it is suitable for domestic use.

2.3. Geochemistry of Groundwater

Groundwater is often tapped in Ghana's Upper East Region through hand-dug wells and boreholes that come into contact with lineaments in foundation rocks (Figure 1.0). Only when cracked or worn are these rocks capable of storing and transporting water. Groundwater resource evaluation necessitates a better understanding of numerous characteristics related to groundwater creation, transport, and distribution in the current hydrogeologic environment. It entails identifying and

characterizing hydrogeologic units, aquifer types, groundwater flow systems, and the interplay of surface and groundwater (Abanyie et al., 2020). Groundwater is mostly derived through precipitation, although its geochemistry is shaped by reactions between water and minerals in the rock.

Rainfall percolates into the layer of soil below the surface. Saturation of the soil zone causes water to seep downwards. A zone develops when water fills up every interstitial space. Also, the interstices have an aeration domain whereby air and water coexist in part. The groundwater keeps declining until it hits a zone of dense rock at a certain height. These rocks have pores that contain water, but because the openings do not link together, the water never moves. The replenishment of the underground water supply by precipitation is known as recharge. Usually, recharging only occurs in tropical countries throughout the rainy period and in temperate climates all through the winter.



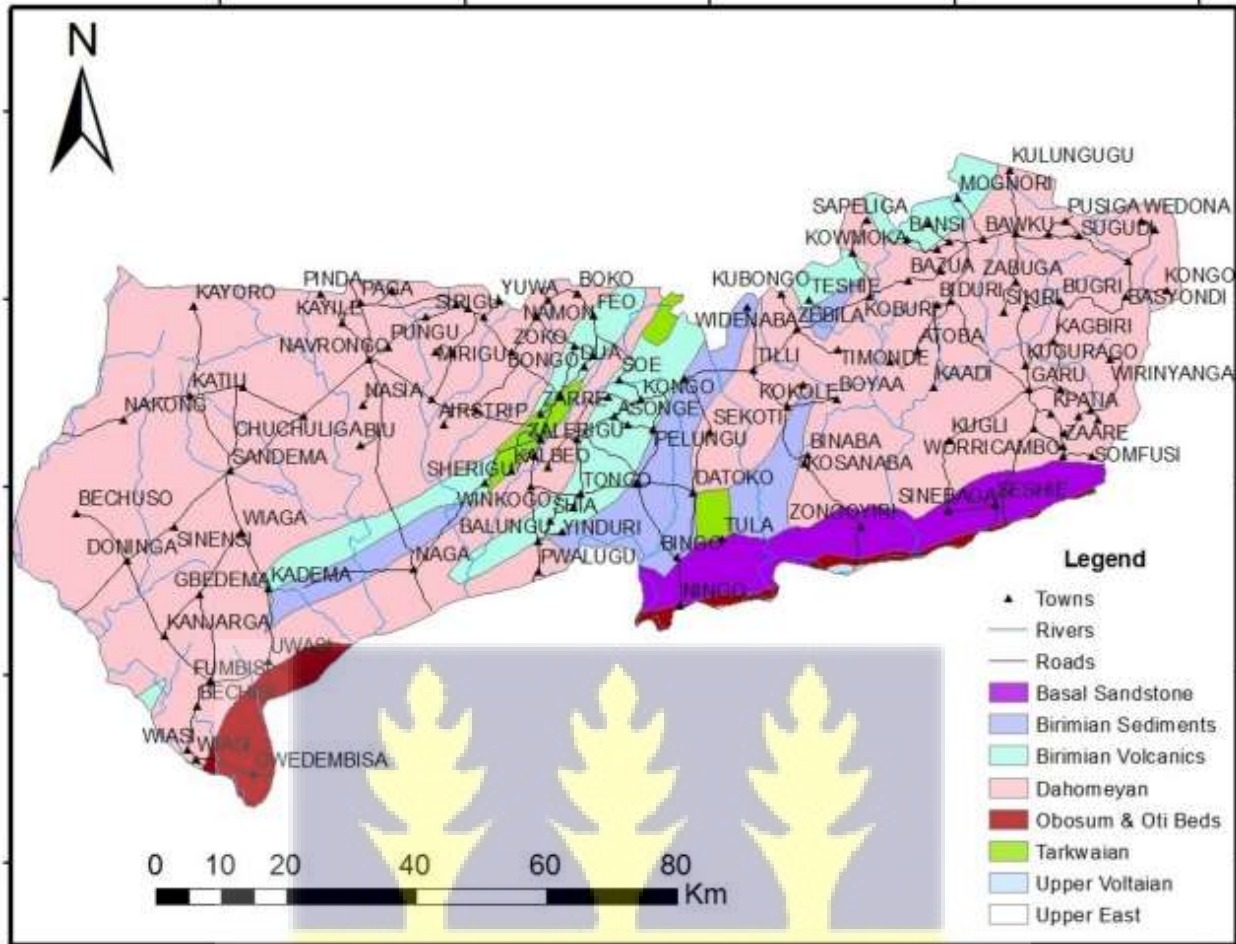


Figure 2.1: An Upper East region geological map that displays all kinds of rocks (Abanyie et al., 2020).

2.4. Principal Pollutants of Groundwater

The World Health Organization report states that the most prevalent types of water contaminants are pathogens (bacteria, viruses, and protozoa), afterwards pesticides, important ions (sulfates, nitrates, phosphates, calcium, magnesium, and fluoride), and inorganic pollutants (salts, acids, and toxic metals) (Kristanti et al., 2022; WHO, 2017). Water is unsafe to drink and may be extremely harmful to one's health if any of these pollutants exceed certain thresholds. When groundwater comes into contact with ore-bearing rocks, components dissolve into the flowing water.

2.5. Borehole

Groundwater, which includes natural springs, wells, and boreholes, is a less expensive form of domestic water supply. In many dry and semi-arid regions of Africa, where surface water is extremely scarce and rainfall is either very seasonal or infrequent, borehole water is a way to deal with water scarcity (Ahmad et al., 2018). Groundwater extracted from an aquifer and drawn out to consumers via pumps is known as borehole water. One of the main problems with boreholes is that the chemical makeup of groundwater must be checked to determine whether these dissolved compounds are below the acceptable limits for consumption. Boreholes frequently have the highest fluoride level in groundwater since the weathering and leaching of rocks of aquifers containing fluoride end up in groundwater (Craig et al., 2018).

2.6. Microbiological quality of water sources

Total and fecal coliform bacteria are commonly found by microbial analysis of water quality. Although coliform bacteria are prevalent in nearly all regions with high human activity, they do not endanger human life (Abanyie et al., 2020). Several studies are being carried out to determine the microbiological level of water for drinking in various regions of the country and the global community. A finding from Ofosu et al., 2014 reported that 73.3% of the samples analyzed in the Sunyani Municipality were contaminated with coliforms. 50% of the samples tested positive for *Escherichia coli* contamination (*E. coli*) (Ofosu et al., 2014). *Salmonella typhi* and *E. coli* were among the microorganisms that Issahaku et al. (2017) found to have polluted water sources in Ghana's Upper East region (Issahaku et al., 2017). Drinking water sources which contain *E. coli* and fecal coliforms typically indicate that the water has been contaminated by human and animal waste (Abanyie et al., 2020). For total and fecal coliforms, the WHO water consumption limit is zero (0) counts per 100 mL (WHO, 2017). Open defecation close to groundwater supplies is one sign of unhygienic circumstances. Overall, the region's water is contaminated by bacteria, which

poses a potential health risk to the public and must concern to stakeholders when creating mitigation strategies. The situation becomes particularly alarming in the Upper East Region as high levels of bacterial contaminants have been detected in both water sources and water treatment facilities (Naabil et al., 2014). Faeces are key sources of many infections (Apau et al., 2015a), and it is the biggest microbiological risk linked with water contamination.

2.6.1. Total Coliform

Among them are cylindrical, gram-negative aerobic and facultative anaerobic bacteria belonging to the Enterobacteriaceae family, which break down lactose in 24 to 48 hours at 35°C to produce gas (Salihu & Bakar, 2018). They produce the lactose-fermenting enzyme β -galactosidase, which is lacking in most bacteria found in soil and water. Despite belonging to the Enterobacteriaceae family and typically including *Escherichia coli* along with members of the genera *Escherichia*, *Klebsiella*, and others, these groupings are not strictly taxonomic. Both human and animal excrement commonly release these coliforms in relatively high concentrations (2x10⁹ coliforms/day/capita) (Bitton, 2005).

2.6.2. Faecal Coliforms

A subset of total coliforms is fecal coliforms. The optimal temperature range for total coliform growth is between 44 and 45°C, which is the only difference between them. They are nearly the same, save for that. They are mostly found in warm-blooded animals' digestive tracts, and their presence in water indicates that the water has been tainted by the animal's excrement. Of all the coliforms discovered in faeces, *E. coli* requires particular consideration. Because it possesses other traits in addition to often meeting all TC and FC standards, this bacterium is a great microbiological indicator of water quality. The most common coliform in warm-blooded animals' gut flora has been demonstrated to be a more reliable indicator of pathogen prevalence (Ahmed et al., 2019).

2.6.3. Escherichia Coli

In many regions, *Escherichia coli* is frequently employed as a water quality indicator. Its presence in bodies of water may be a sign of contamination and unfitness for use as a recreational area. *E. Coli* is a bacterium that is found in human and animal waste. It can enter water bodies such as creeks, rivers, streams, lakes, and groundwater through precipitation events such as rainfall, snowmelt, and other types of precipitation (Kim et al., 2010). *E. Coli* could find its way into drinking water when these sources are exploited, and the water is not properly treated. It is commonly used because it can be a sign of faecal contamination in water and warm-blooded animals' intestines normally contain it. Not all strains of *Escherichia coli* are harmful; in fact, the majority of them are not. But other strains, like *E. Coli* O157:H7, are pathogenic and may result in severe illness, including food poisoning (Mesele & Abunna, 2019).

2.7. Geological background and study zone

Situated in Ghana's northeastern region, the Upper East Region is bounded to the north by Burkina Faso, to the east by Togo, to the west by the Sissala East District of the Upper West Region, and to the south by the West Mamprusi District of the Northern Region. Bolgatanga is the capital, with Bawku, Bongo, Navrongo, Paga, Zebilla, Fumbisi, Naban, Talense, and Sandema, among the prominent cities. The Black Volta, White Volta, Red Volta, Tamne, Siisili, and Tono are the six main rivers in the region (Abanyie et al., 2020). Beginning in July and ending in September, the area has a rainfall pattern that includes heavy storms and intense rains that last only a few hours. The overall land area is 8842 km², which accounts for 4% of Ghana's land size (Abanyie et al., 2020). In today's developing communities of Ghana's Upper East Region, the necessity for and use of water in farming and home settings have expanded significantly. This necessitates regular water monitoring to make it safe for consumption and irrigation.

2.8. Physiochemical Parameters of Water

There are many kinds of chemical compounds in water. Consequently, this might affect water credibility, public health, and operational efficiency. Colour, odour, taste, pH, total hardness, and other dissolved ions (iron, magnesium, calcium, fluoride, and chloride) are among the indicators of water contamination (Bozorg-Haddad et al., 2021). Some other physicochemical parameters include turbidity, conductivity, pH, DO (dissolved oxygen), TS (total solids), BOD (Biological oxygen demand), and TDS (total dissolved solids)(Asami et al., 2021).

The main cause of the problems with drinking water's chemical composition is that certain contaminants, like heavy metals and compounds that cause cancer, can have detrimental impacts on one's health when exposed over time (Jamshaid et al., 2018). The pH range for drinking water should be between 6.50 and 8.80, according to WHO recommendations (WHO, 2017). Water with an excessively low pH can dissolve substances that build up in metal pipes, which might cause illness (Wasim et al., 2018). According to WHO guidelines, water should be suitable for drinking if the BOD and COD levels are less than 6 mg/L and 10 mg/L, respectively (WHO, 2017). Water with TDS levels close to 600 mg/L is acceptable and considered to have a good taste. Drinking water becomes undesirable when the TDS content is above 1000 mg/L (Priyanshi et al., 2023).

2.8.1. Fluoride contamination

Fluoride is one of the essential anions in drinking water that requires routine testing. Although human health depends on the level of these ions in water, larger quantities can be harmful to human health, particularly to the bones and teeth (Kabir et al., 2020). Fluoride ion concentrations in drinking water must be between 0.70 and 1.20 mg/L to avoid dental caries; however, amounts over 1.5 mg/L can cause skeletal and dental fluorosis (Irigoyen-Camacho et al., 2016; Kabir et al., 2020).

As the most electronegative and reactive nonmetal, fluorine (F) is usually found in groundwater and is formed when water reacts with rocks and dirt in the Earth's crust. Fluorine is never found in nature in its elemental condition. Several factors, such as climate, the composition of the host rock and the aquifer, the mixing of different recharge fluids, the geochemical environment, and hydrogeological circumstances, affect the amount of fluoride ions that are inherent in groundwater (Lone et al., 2024; S. M. Zango et al., 2019). Fluoride-bearing minerals, including fluorite, apatite, biotite, phlogopite, muscovite, hornblende, and pyroxene, are thought to alter and dissolve preferentially in igneous, sedimentary, and metamorphic geological terrains, increasing the natural concentration of fluoride ions in groundwater during extended water-rock interaction (Daanoba et al., 2022; Lone et al., 2024).

The most prevalent fluoride-bearing minerals in granitoids are fluorite $[\text{CaF}_2]$ and apatite $[\text{Ca}_5(\text{PO}_4)_3(\text{F},\text{Cl},\text{OH})]$, which are also recognized sources of fluoride in groundwater (M. S. Zango et al., 2019). Moreover, there is an inverse relationship between the concentrations of calcium magnesium and fluoride in groundwater. This suggests that the concentration of fluoride increases in proportion to the ratio between the total concentrations of carbonate and bicarbonate in groundwater and the sum of the concentrations of calcium and magnesium (Salifu et al., 2012; Subba Rao, 2017).

Increased fluoride concentrations in groundwater supplies have only been documented in just a few towns and districts in the northern and eastern parts of the Upper East Region (Onipe et al., 2020). This suggests that one of the main problems in certain parts of the region is the pollution of drinking water sources by fluoride ions. According to Zango et al., the bulk of the boreholes in Ghana's northeast had fluoride ion concentrations of 3.26 mg/L, which were greater than the 1.5 mg/L WHO-established tolerable limit. According to other reports, the Upper East Region's Bongo

District has a significant concentration of fluoride ions (Craig et al., 2018). These elevated results were not in line with recorded findings (Anornu et al., 2017).

According to Craig et al. (2018), the leaching of fluoride from the Bongo granite was responsible for the high concentration of fluoride ions seen in deep subterranean water sources. Additionally, they stated that high rains tended to dilute the chemicals in groundwater, as seen by the low concentration of fluoride ions recorded during those periods (Craig et al., 2018).

2.8.2. Temperature

The average kinetic energy of the particles that make up an object is measured by its temperature. One important factor that influences other quality metrics like pH and TDS is the water's temperature. The physical and chemical properties of water are influenced by its temperature (Haldar et al., 2020). It can affect how quickly chemicals react as well as how soluble gases and solids are in water. The metabolism of aquatic species is influenced by temperature, which is another important factor in aquatic habitats.

2.8.3. pH

The amount of hydrogen ions in water serves as a reference for the pH scale. The dissociation of water molecules or other dissolved molecules containing ionizable hydrogen atoms produces the hydrogen ion (H^+) that is found in water. It shows the degree to which the water is acidic or alkaline. Depending on its pH, water can be classified as basic, neutral, or acidic. Due to the equal proportion of hydroxyl and hydrogen ions, pure water is neither basic nor acidic. Water is classified as basic when its hydroxyl ion concentration is higher and as acidic when its hydrogen ion concentration is higher. Elevated pH levels significantly affect water. Water with a low pH tastes bitter, while water with a high pH tastes soapy (Petersen & Saykally, 2008).

Water's chemical and biological processes are impacted by pH. The pH of water can affect the dissolution of minerals, the accessible amount of nutrients for aquatic animals, and the efficiency

of chemical treatment processes (Pinheiro et al., 2021). It has an impact on the toxicity and solubility of metals in water.

2.8.4. Electrical Conductivity

The conductivity of water indicates its capacity to transmit an electrical current (Yu & Wu, 2021). It serves as a gauge for the quantity of ions in a solution. It has to do with how many dissolved ions, like salts, there are in the water. Chlorides, nitrates, phosphates, sulfates, and positively charged ions like sodium, magnesium, calcium, and iron are the main ions that affect this quality parameter. This is a temperature-dependent parameter. At 25 °C, the measurement unit is ($\mu\text{S}/\text{cm}$). Consumers who consume water with conductivity values above 370 $\mu\text{S}/\text{cm}$ may have negative health consequences; water bodies with values above 1000 $\mu\text{S}/\text{cm}$ are considered contaminated (Kerketta et al., 2013).

2.8.5. Total Dissolved Solids (TDS)

The total concentration of organic and inorganic materials dissolved in water is measured by TDS. It consists of some organic material, ions, salts, and minerals. Water quality, taste, and odour can all be impacted by high TDS levels. The amount of cloudiness or haziness that results from the presence of suspended particles in water is measured as turbidity. Aquatic ecosystems, light penetration, and water clarity can all be impacted by high turbidity.

2.8.6. Total Hardness

This has been described as water's ability to absorb soap (Salihu & Bakar, 2018). Based on its hardness, water can be categorized as soft or hard. Hard water creates scaling on pipes and boilers and needs a lot of soap to make lather (Boyd, 2015). Because of this, users find hard water to be inconvenient and an economic burden. The ions that cause the hardness of water are magnesium and calcium. Because carbonates and bicarbonate salts can be eliminated by boiling, the hardness they create is only momentary (Tóth et al., 2013). Sulfates, chlorides, and nitrates in calcium and

magnesium salts are the sources of permanent hardness. The term "permanent hardness" refers to the fact that this kind of hardness cannot be removed by boiling.

2.8.7. Chloride

Chlorides can be found in underground aquifers or as a consequence of home or industrial waste contaminating saltwater. As sodium, potassium, and calcium salts, they can produce a taste in water that is noticeable and occurs at natural levels higher than 250 mg/L.

2.8.8. Nitrates

It is true that fertilizer application, in particular, can introduce nitrates into the soil through agricultural activities. These nitrates have the potential to contaminate groundwater and surface water if they are not properly controlled. High nitrate levels can cause problems, including eutrophication and the contamination of drinking water sources, which can harm the environment and public health (WHO, 2017). Open defecation, sewage leaks, and septic tank leaks are major causes of nitrate contamination in the environment, as are animal and human wastes. Human waste and sewage that are not properly disposed of can cause nitrates to enter soil and water systems, which can contaminate both surface and groundwater.

Methemoglobinemia, also called "blue baby syndrome," is a disorder that can be fatal for infants caused by high nitrate levels in drinking water. Bacteria can further transform nitrate into the more dangerous form, nitrite. Haemoglobin in the blood can react with nitrite, lowering its ability to deliver oxygen. According to Brender and Weyer (2016), epidemiological research has suggested a possible link between exposure to high nitrate levels in drinking water and problems with reproduction, including specific birth abnormalities in the offspring of exposed pregnant women (Brender & Weyer, 2016).

2.8.9. Hardness

Hardness measures the concentration of calcium and magnesium ions in water. It can be expressed as either temporary hardness (due to bicarbonate ions) or permanent hardness (due to sulfate and chloride ions), and is often reported in milligrams per litre (mg/L)



CHAPTER THREE

3.0 MATERIALS AND METHODS

3.1 Description of study area

This study was done in the Upper East region situated in northeast Ghana. It is located between latitudes $10^{\circ} 30'N$ and $11^{\circ}N$ and longitudes 0° and 1° West (Quaye-Ballard et al., 2020). Burkina Faso borders the region to the north; Togo borders it to the east; and the Northern and Upper West Regions border it to the south and west, respectively. There is only one rainy season and a generally dry climate in the Upper East region. The average annual rainfall occurs between May and October, with a range of 950 to 1100 mm. The dry season, which stretches from November to April, is distinguished by harmattan winds that are cold, dry, and dusty. The highest temperature recorded between March and May is approximately $45^{\circ}C$, while the lowest temperature recorded between December and January is approximately $13^{\circ}C$ (Achana et al., 2015).

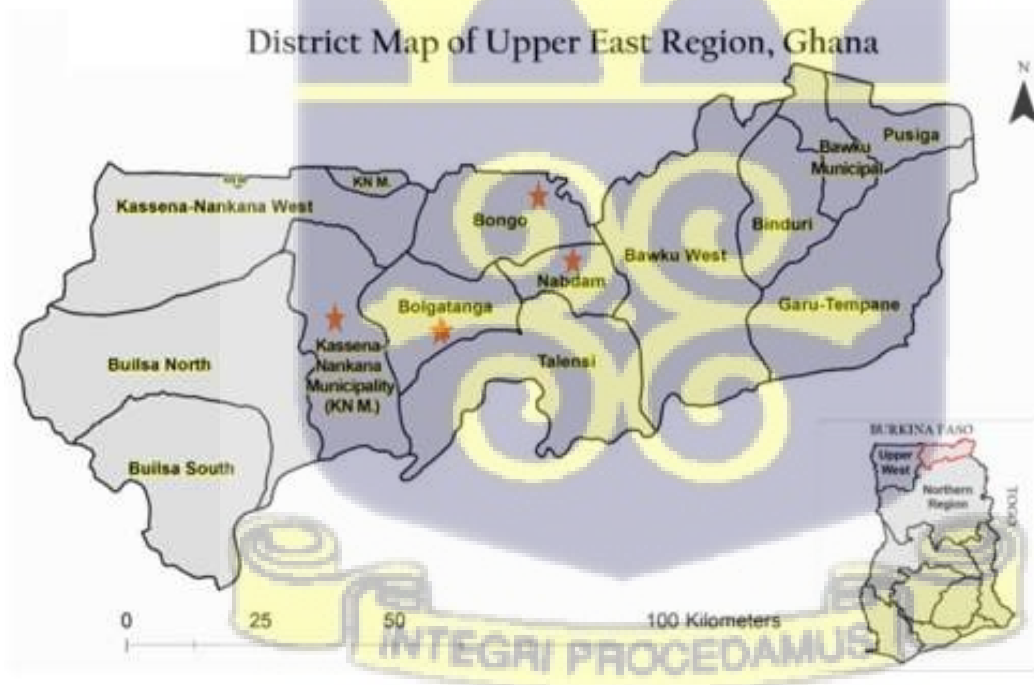


Figure. 3.1. Location map showing all the major districts of the study areas.

3.2. Sampling

Sampling was preceded by the preparation of sampling bottles. Sampling bottles used for the physicochemical and metal analyses were washed and rinsed with deionized water. Bottles for bacterial analyses were washed and autoclaved at 120°C for 30 minutes. A total of 40 borehole water samples were taken from four districts in the Upper East region. Out of the 40 samples, five (5) composite samples were formed for each of the four studied districts. The parameters studied were all analysed in the laboratory. All the samples were analysed for their bacteria and physicochemical parameters. The samples were kept in an ice chest and transported to the lab for analysis.

3.3. Determination of Physicochemical Analyses

3.3.1 pH

The pH meter was calibrated with pH buffers 4.0, 7.0 and 10.0 and it was ensured that a plot of mV versus pH followed the Nernstian relation. A 100ml aliquot of each sample was measured into a beaker and the pH was determined using a Hach pH meter.

3.3.2 Conductivity

The conductivity meter was standardized with 0.01N KCl solution. The conductivity of this solution was found to be 1413 $\mu\text{mhos/cm}$ at 25 °C with a cell constant of 1. A 100ml sample of water was measured into a beaker and its conductivity was determined with the Hach Conductivity meter. The determinations were made after refrigerated samples had been allowed to attain room temperature.

3.3.3 Total dissolved solids (TDS) and Total Suspended Solids (TSS) Determination

TDS was measured using a Hanna Instruments HI 9032 conductivity meter. The water sample was transferred into a beaker and the electrode was rinsed with distilled water and immersed in the sample in the beaker. TDS was measured by selecting the TDS key while the electrode remained

in the water sample. The TDS value in mg/L was displayed on the screen and recorded. The absorbance method was used to determine total suspended solids (TSS). The Spectrometer was set to a wavelength of 630 nm. The sample was shaken to ensure an even distribution of suspended solids, and an aliquot was taken and put in the sample holder. The results were shown digitally in mg/L.

3.3.4 Total Hardness Determination

The hardness was determined by a complexometric titration using Ethylenediaminetetraacetic acid (EDTA), using Erichrome Black dye as an indicator. A 50ml sample was measured in a conical flask. To this was added 1ml portion of ammonium chloride buffer solution, which was then followed by the addition of 30 mg Erichrome black T indicator crystal. The resulting solution was titrated with 0.01M EDTA solution with continuous stirring until the endpoint was reached. The endpoint is when the last reddish tinge disappears. The total hardness was then calculated as follows.

$$\text{Calculations: (total hardness) mg/L CaCO}_3 = \frac{A}{B} \times 1000 \dots\dots\dots 1$$

Where A=ml of titrant, B=Volume of the sample.

3.3.5 Alkalinity Determination

The alkalinity was determined by titration with a standard acid solution. A 50 ml sample was measured in a conical flask. Two drops of methyl orange indicator were added, and the resulting mixture was titrated against the standard 0.1M HCl solution to the first permanent pink colour at pH 4.5. The following equation was used in the calculation.

$$\text{Alkalinity as mgCaCO}_3/\text{L} = \frac{A \times N \times 50 \times 1000}{\text{Volume of water sample}} \dots\dots\dots 2$$

Where A= ml of acid is used.

50 = equivalence of CaCO_3

N = Molarity of standard acid used.

3.3.6 Chloride Determination by Titration

An aliquot of 50ml of the sample was measured into a conical flask. The pH was then adjusted to a range of 7-10 with H_2SO_4 for high pH samples and NaOH for low pH samples. Two drops of K_2CrO_4 indicator were added. A Standard AgNO_3 solution of 0.01M was titrated against the resulting mixture above to an orange-red endpoint. Blank titration with only the reagents and deionised water samples was also performed.

$$\text{Chloride } \left(\frac{\text{mg}}{\text{L}} \right) = \frac{(A-B) \times M \times 35.5 \times 1000}{\text{Volume of sample}} \dots\dots\dots 3$$

Where A = volume of sample

B = volume of BLANK

M = molarity of AgNO_3

35.5 = atomic weight of chloride

3.3.7 Determination of Turbidity.

The samples are allowed to come to room temperature before analysis. The sample bottles were shaken vigorously to ensure thorough mixing. After shaking, time was allowed for all bubbles to disappear, and about 10-15 mL of the sample was poured into the sample cell. The instrument was zeroed with distilled water. The blank was replaced with the sample, and the turbidity was read directly from the instrument readout displayed on Hanna HI 98713 Turbidity meter.

3.3.8 Determination of Nitrates, Nitrites, Sulphate, Phosphates and Fluoride

The above determinations were carried out using the Hach DR 6000 Spectrophotometer. After the instrument was switched on, a wait time was allowed to ensure the instrument does its self-diagnosis and self-calibration. For each parameter, its program number was entered to access it.

Samples were prepared by filling the sample cells with the required volume of the sample according to the test method. Required reagents were added as per the test method. Where necessary reaction times were allowed by engaging the timer on the instrument and waiting for the required period, Blanks were prepared by using distilled water and taking through the same treatment samples for each method. At the end of each reaction period samples are read directly where there are no blanks, for methods that require blanks, the sample blanks are used to zero the instrument after which samples are read for the parameters being analyzed. For each parameter, the Hach reagent specified in the Hach methods manual was used.

3.4 Bacteria Analyses

Enumeration of Total Coliforms, Faecal Coliforms, and E. Coli was done by the membrane filtration method. This Method provides a direct count of bacteria in water based on the development of colonies on the surface of the membrane filter. A water sample is filtered through a membrane that retains the bacteria. The membrane containing the bacteria cells was placed on a selective medium (chromocult agar) and incubated for 18-24h at 35°C. Dark blue to violet colonies were counted and recorded as E. Coli. All salmon red to red and dark blue to violet colonies were counted as total Coliforms.

For faecal coliforms the membrane filter containing the bacteria after filtration is placed in a petri dish containing the MFC agar selective medium and incubated at 37 °C for 24h. All blue colonies were counted as faecal coliforms.

Enumeration of *Pseudomonas aeruginosa* was also by membrane filtration. Here the membrane filter containing the bacteria after filtration was placed on the cetrimide agar selective medium and incubated at 30-35°C for 18-72h. After membranes were examined and pigmented greenish colonies were counted *Pseudomonas aeruginosa*.

3.5. Analysis of metal/metal ion

The levels of metals were determined using HACH DR 3900 with some modifications in the method of operation.

3.5.1. Test for zinc (Zn)

The pH for zinc was adjusted to a pH of 4 – 5 using a 5 N sodium hydroxide (NaOH) solution before the analysis to prevent the zinc from precipitating. Also, test results were corrected for dilution caused by the volume added. The program 780 zinc was started, and a 25 mL graduated measuring cylinder was filled with 20 mL of the samples. One zincoVer 5 Reagent powder pillow was added to the content and covered. The measuring cylinder was shaken vigorously to dissolve the powder completely to prevent inconsistency in the readings. A blank was prepared by pouring 10 mL of the solution into the sample cell. A plastic dropper was used to add 0.5 mL of cyclohexanone to the solution in the measuring cylinder. The reaction timer was started for 30 seconds reaction. The mixture in the measuring cylinder was shaken vigorously during the reaction period. The instrument timer was started for 3 minutes. The sample solution was poured into the second sample cell. After the timer expires, the blank sample cell is cleaned and inserted into the cell holder. The zero button was pressed to display 0.00 mg/L Zn. The prepared sample cell was cleaned and inserted into the cell holder. The read button was pushed to read the level of zinc in mg/L Zn.

3.5.2. Test for Copper (Cu) and Iron (Fe)

The pH for copper was adjusted to a pH of 4 – 6 using 8 N potassium hydroxide (KOH) before the analysis to prevent the copper from precipitating. Also, test results were corrected for dilution caused by the volume added. A 2.0 mL of the sample was added to the test vial using a pipet. The vial was tightened with its cap and inverted until it was completely mixed. The reaction time started

for 3 minutes, when the time expired the vial was cleaned. A program DR 1900 was selected. The vial containing the sample was inserted into the cell holder. The batten labelled read as pushed to record the reading in mg/L Cu.

3.5.3. Test for magnesium (Mg) and calcium (Ca)

A buffer solution A (4.0 mL) was added to the test vial with a pipette. The cap of the vial was used to tighten the vial and inverted until the contents were mixed completely. Reaction time was set for 30 seconds; when the time expired, the vial was cleaned. The program was set to DR 1900 while the vial was inserted into the vial holder. The read batten was pushed to zero for the instrument. The vial was then removed. A pipette was then used to add 0.2 mL of the sample to the test vial. The cap of the vial was then used to tighten the vial and inverted until the contents were mixed completely. The reaction time was set for one (1) minute. After the time expired, the test vial was cleaned and inserted into the vial cell holder, and the read button was pushed to record the level. The vial was then removed, a 0.2 mL of buffer solution B was added to the test vial using a pipette. The cap of the vial was used to tighten the vial and was inverted several times until the contents were mixed completely. The reaction time was set for 30 seconds; after the time expired, the vial was cleaned and inserted into the cell holder. The read batten was pushed to record the level using DR 1900. The readings were shown in mg/L Mg for magnesium and mg/L Ca for calcium.

3.6. Quality Assurance

The sample bottles and glassware used were cleaned with detergent and rinsed thoroughly with deionized water. The glasswares were soaked in 10% HCl for about 24 hours to remove metal particles that adhered to the glass surface. Distilled water was used in the preparation of all solutions and stored in a capped plastic bottle. Before the analysis using the HACH DR 3900 spectrophotometer, the plastic bottles used were cleaned using 6 N hydrochloric acid and water

(1:1) and rinsed with distilled water. The pH was adjusted to less than two (2) using concentrated nitric acid (2%) to preserve the samples for later analysis. However, for those tested immediately, no acid was added. In addition, calculations of precision and accuracy were also done for the analytical method by analysing the certified reference materials.



CHAPTER FOUR

4.0. RESULTS AND DISCUSSION

4.1. Physicochemical analyses

This study was set to identify, assess, and compare water quality from various boreholes at different locations within the Upper East region of Ghana.

4.1.1. pH

pH is a crucial water quality indicator whose value gives a quick picture of how acidic or basic a water body is. Although pH value has no direct impact on consumer health, it is highly important because it influences the toxicity, solubility, and bioavailability of various chemical elements in water, including heavy metals (Sonone et al., 2021). The result from this study showed pH values for the borehole water samples ranging from 6.88 - 7.93 in the four districts, with a mean value of 7.25 ± 0.02 . In the Bolgatanga district, pH values range from 6.60-7.05 and an average value of 6.88 ± 0.01 . Nabdam district recorded a range of 6.75-7.15 and 6.96 ± 0.02 . In the Bongo and Navrongo districts, the pH range of 7.70-8.28, with a mean value of 7.93 ± 0.02 and the pH values range from 6.71- 7.08, 7.26 ± 0.03 as the average pH respectively. Even though there are slight variations across the sampling areas, all the pH values were within the permissible limit of 6.5-8.5 set by the Ghana Standard Authority (GSA) and the World Health Organization (WHO) limit for drinking water. The pH values in this study concur with the pH values (6.90-7.50) reported by Aaniamenga Bowan, et al., 2022 in their study, which assessed the quality of borehole water in Bole District, Ghana. In which the study revealed that the pH values of borehole samples were very low (Aaniamenga Bowan, 2022). A study by Tomno et al., (2020) reported slightly higher pH values in a range of 7.5 – 8.45 (Tomno et al., 2020).

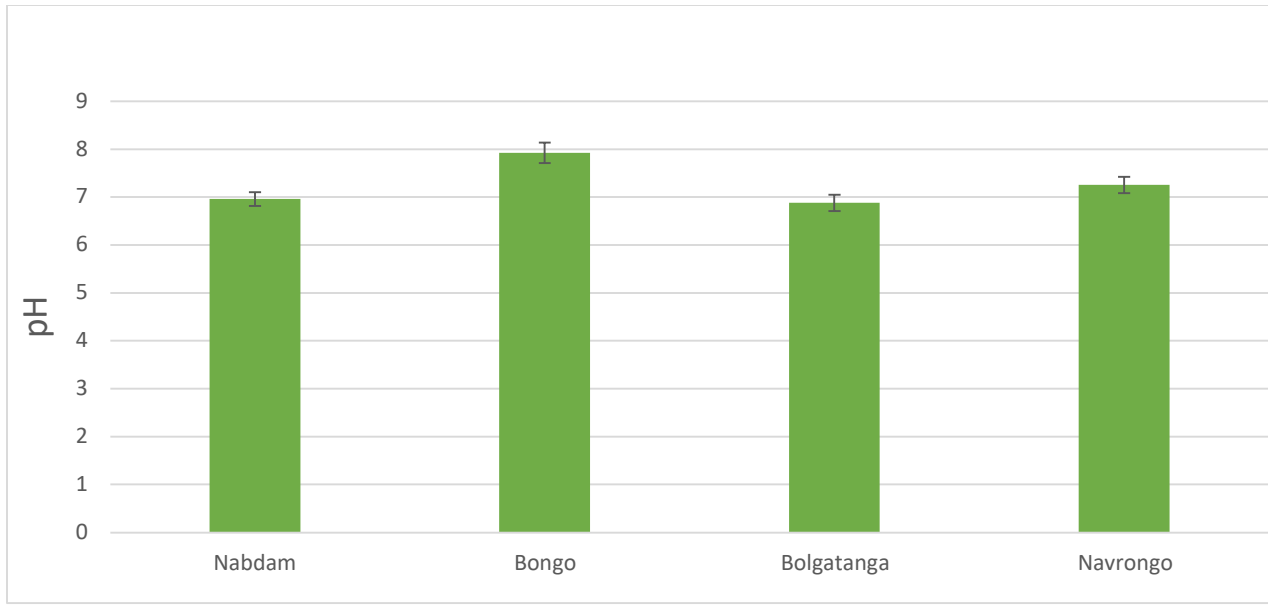


Figure 4.1. Average levels of pH in water samples from the various districts.

4.1.2. Colour

All borehole samples from the four districts (Nabdam, Bongo, Bolgatanga, Navrongo) were clear, colourless and odourless. The colour of borehole samples ranges from 1.00 - 1.10 HU and an average value of 1.03 HU. The recorded colour values were below the threshold limits of the Ghana Standard Authority (GSA) and the World Health Organization (WHO) of 5 HU. A study done to evaluate the physico-chemical parameters in borehole samples in the Upper West region of Ghana gave colour values ranging from 1.44 to 10.0, which is higher than the values recorded in this study (Sebiawu et al., 2014). Though the water samples' colour is reflective of the geology of the areas, there are slight variations in the colour values. This could be because the rate of sand, silt or clay particles being dislodged and washed into the boreholes varies owing to slight geological formations. The swampy nature of certain areas could also aggravate the distortion in colour and turbidity values of samples owing to differences in the depth of the boreholes.

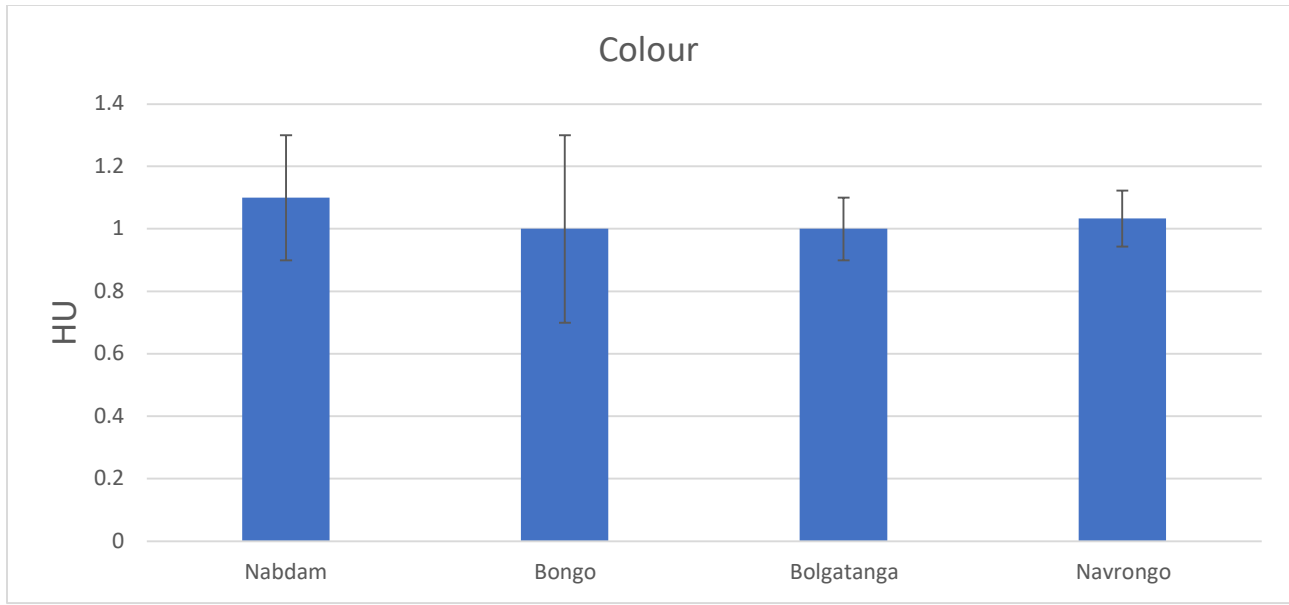


Figure 4.2. Colour of water from the various districts.

4.1.3. Electrical Conductivity (EC)

The average electrical conductivity values recorded in the study districts (Nabdam, Bongo, Bolgatanga and Navrongo) were 295.7, 554.20, 466.6, and 438.83 $\mu\text{s}/\text{cm}$, respectively. The range for EC values for the various regions was Nabdam (28 – 424.5 $\mu\text{s}/\text{cm}$), Bongo (307 – 1186 $\mu\text{s}/\text{cm}$), Bolgatanga (343.5 – 767 $\mu\text{s}/\text{cm}$) and Navrongo (361.5 – 929 $\mu\text{s}/\text{cm}$). The levels of electrical conductivity were below the maximum permissible limit of 1000 $\mu\text{s}/\text{cm}$ set by GSA and WHO for drinking water. However, the EC value was beyond the set limit at Nayire (1186 $\mu\text{s}/\text{cm}$), a study area in the Bongo district. These results agree with the findings of work carried out in the Southern Parts of Bole, Ghana (Aaniamenga Bowan, 2022). This can also be attributed to the fact that both study areas have similar geology. Another study done to determine the safety of borehole water as an alternative to drinking water sources gave an EC value ranging from (6.72 – 143.20 $\mu\text{s}/\text{cm}$). The levels of EC in this study were lower than those recorded in their study (Boadi et al., 2020).

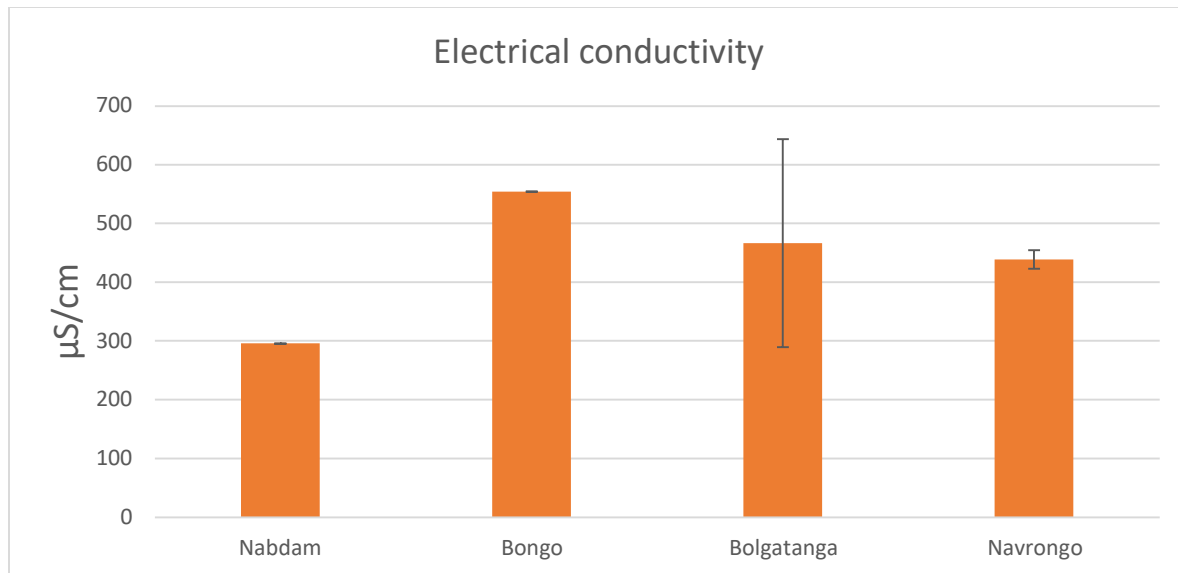


Figure 4.3. Levels of electrical conductivity of water samples from the various studied districts.

4.1.4. Total Hardness

In this study, the total hardness for all the borehole water samples gave an average value of Nabdam (194.9 mg/L), Bongo (233.4 mg/L), Bolgatanga (290.3 mg/L), and Navrongo (239.53 mg/L). All samples had values falling above the maximum permissible limit of 500 mg/L set by GSA. The level of total hardness was below the set limit of GSA and WHO. Nabdam gave a range of 155.5 - 227 mg/L, Bongo recorded a range of 113 – 360 mg/L, Bolgatanga recorded 203 - 503.5 mg/L and Navrongo gave a range of 235 - 486 mg/L. A study done to determine a physico-chemical and bacteriological analysis of borehole water samples from the Wa municipality of the Upper West region, Ghana, gave 65 – 185 mg/L. The levels recorded in this study were lower than those shown in this study (Sebiawu et al., 2014). The results for hardness in this study concur with the findings of Adongo Bobii, *et al.* (2011) in their work titled “An assessment of the groundwater quality in Nabdam and Bole Townships of the Upper East Region of Ghana”, in which the study revealed that borehole water samples in the Bole North district Areas are generally soft.

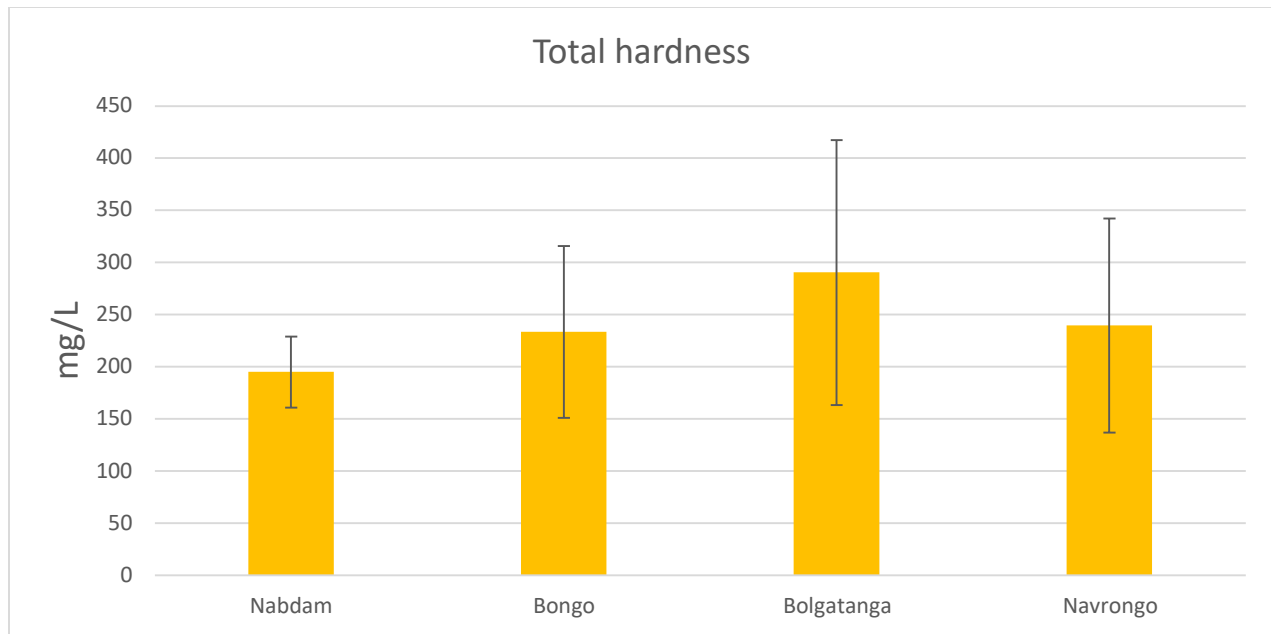


Figure 3.4. Average levels of total hardness of water samples for the various districts.

4.1.5. Total Dissolved Solids (TDS)

Total dissolved solids are used to describe the inorganic salts and small amounts of organic matter present in water. The presence of dissolved solids in water may affect its taste. High TDS values in water may be due to pollution by leaching, especially since the study area is close to lagoons. In this study, the mean TDS values for all the borehole water samples were 206.3, 312.4, 277.7 and 265.5 mg/L for the four districts, respectively. In Nabdam district, the TDS values range from 165 – 264.5 mg/L, Bongo district recorded a range of 131 – 703 mg/L, Bolgatanga gave a range of 207.5 – 430 mg/L, and Navrongo district gave 323 – 562 mg/L. Levels of TDS were below the maximum permissible limit of 500 mg/L and 1000 mg/L, respectively, set by the Ghana Standard Authority (GSA) and World Health Organization (WHO) for drinking water, except for Nayire (703 mg/L) in the Bonga district and 7531 (562 mg/L) in the Navrongo district.

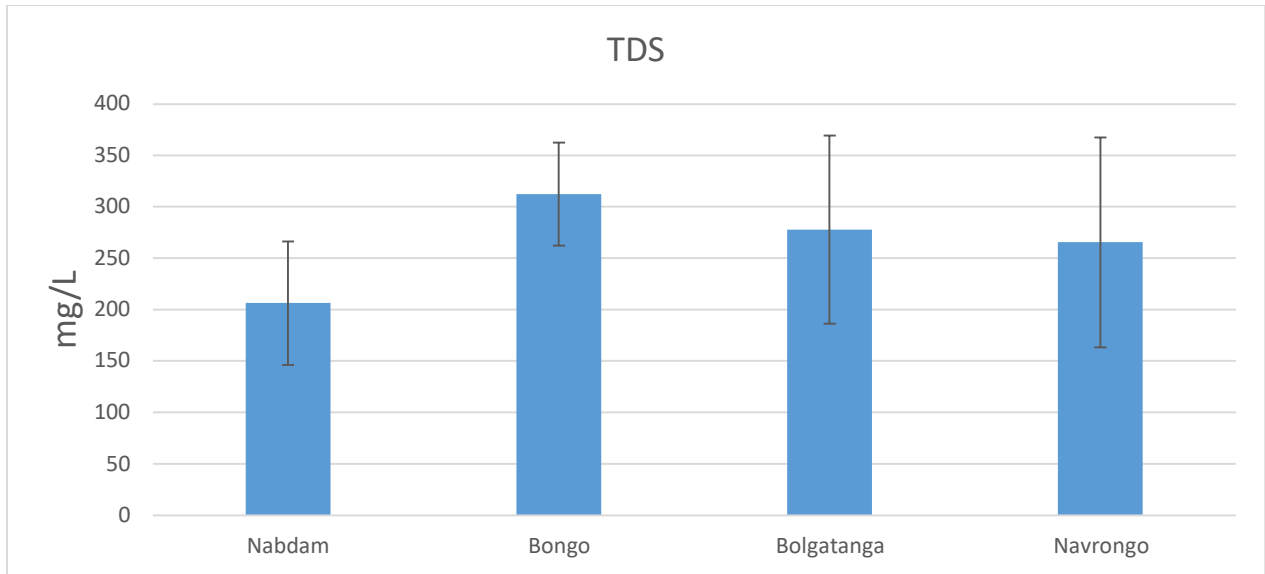
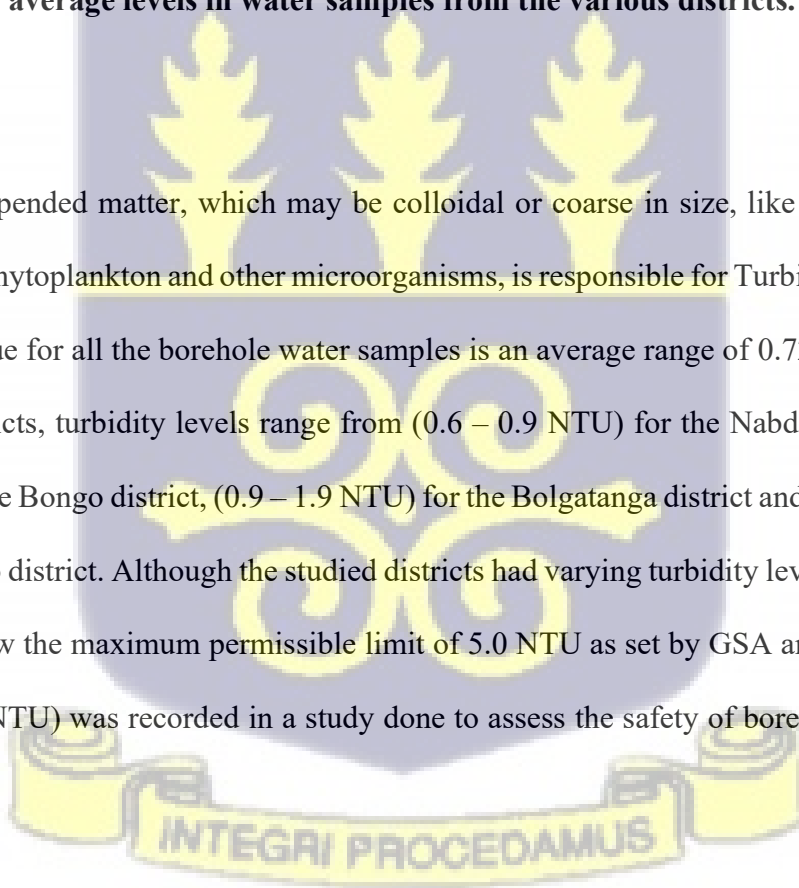


Figure 4.5. TDS average levels in water samples from the various districts.

4.1.6. Turbidity

Most of the suspended matter, which may be colloidal or coarse in size, like clay, silt, organic matter, metals, phytoplankton and other microorganisms, is responsible for Turbidity. In this study, the turbidity value for all the borehole water samples is an average range of 0.72 - 1.17 NTU. For the various districts, turbidity levels range from (0.6 – 0.9 NTU) for the Nabdam district, (0.7 – 1.25 NTU) for the Bongo district, (0.9 – 1.9 NTU) for the Bolgatanga district and (0.8 – 0.85 NTU) for the Navrongo district. Although the studied districts had varying turbidity levels, their turbidity levels were below the maximum permissible limit of 5.0 NTU as set by GSA and WHO. A range of (0.57 – 2.31 NTU) was recorded in a study done to assess the safety of borehole water (Boadi et al., 2020).



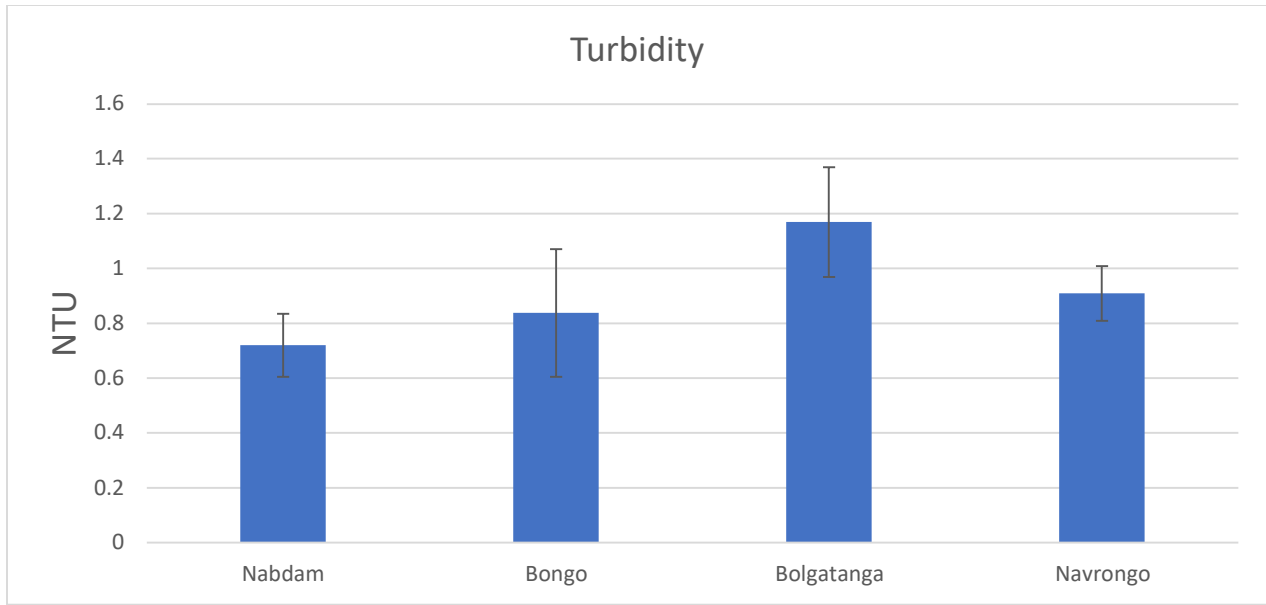


Figure 4.6. Average turbidity levels in water samples for the studied districts.

4.1.7. Chloride

Chloride levels for the borehole water samples recorded mean values ranging from 52.6 -129.8 mg/L for the studied districts. In Nabdam district, chloride levels ranged from 41 – 240 mg/L, and Bongo recorded levels of chloride ranging from 40 – 383 mg/L. (33 – 61.5 mg/L) and (24 – 82 mg/L) for Bolgatanga and Navrongo, respectively. Based on this study, the levels of chloride were highest at Bongo, followed by Nabdam, Navrongo and Bolgatanga being the least. Prior findings from a study done to determine physico-chemical parameters of groundwater samples of borehole waters at Bongo recorded zero levels of chloride in the study (Aaniamenga Bowan, 2022). Another study done by Sebiawu et al., 2014 recorded levels ranging from 10 – 52 mg/L, which is lower than the levels of chloride recorded in this study (Sebiawu et al., 2014). Even though the levels of chloride are lower than the set limit by the Ghana Standard Authority and the World Health Organization, there should be regular monitoring to check their validity.

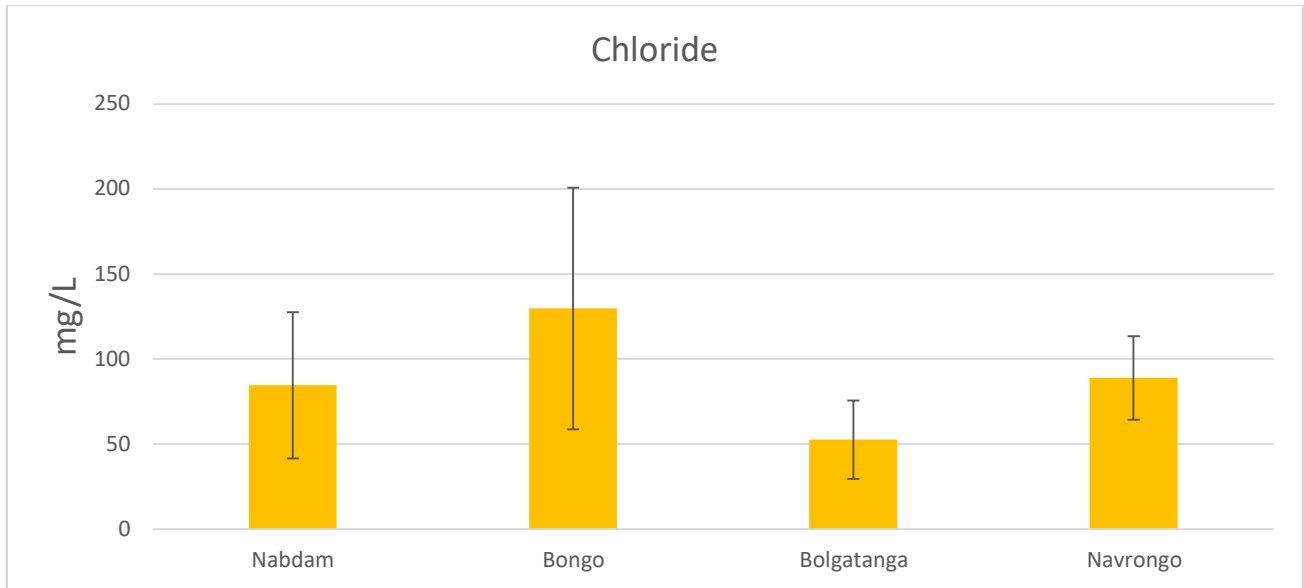


Figure 4.7. Chloride levels of water samples in the various districts.

4.1.8. Fluoride

The presence of fluoride in water is beneficial since it prevents tooth decay; notwithstanding, too much fluoride can induce dental and skeletal fluorosis (Brindha & Elango, 2013). In this study, the average levels of fluoride for all the borehole water samples range from 0.15 - 1.82 mg/L. Fluoride levels determined in the districts were Bolgatanga (0.33 – 2.68 mg/L), Navrongo (0.31 – 0.53 mg/L), Bongo (0.01 – 1.99 mg/L) and Nabdam (0.06 - 0.15 mg/L). Among the four studied districts, the Bolgatanga district recorded higher levels of fluoride than in Bongo, Navrongo and Nabdam districts, respectively. According to Craig et al., (2015), whose work focused on fluoride limits in drinking water in the Upper East Region of Ghana, recorded a range of 0.7 – 4.5 mg/L. The levels of fluoride reported are higher than those recorded in this study (Craig et al., 2015). Another study done to investigate the levels of fluoride in borehole water in the Bongo district reported fluoride values ranging from 0.75 – 2.50, which is higher than those recorded in this study (Ashong et al., 2024).

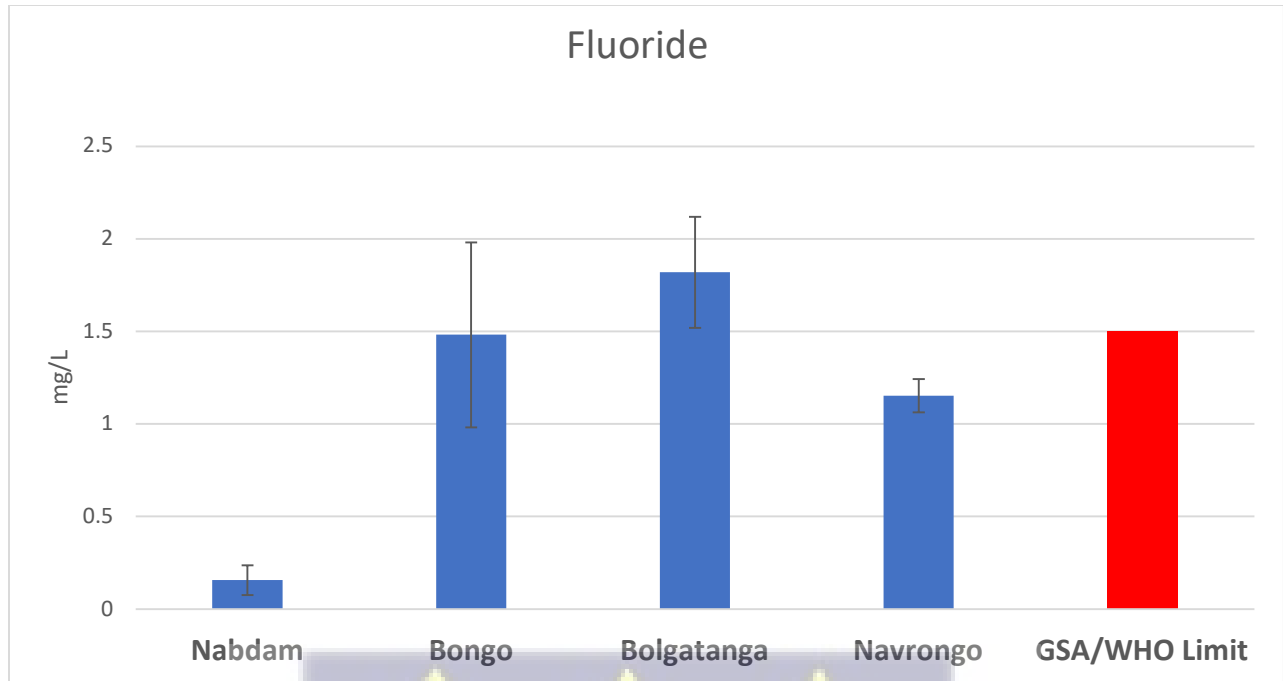


Figure 4.8. Average levels of fluoride in water samples from the various districts.

Table 4.1. Average levels of some physicochemical parameters in borehole water samples from the districts.

| DISTRICTS | pH levels | Colour (HU) | EC ($\mu\text{s}/\text{cm}$) | Total hazard (mg/L) |
|----------------------|------------------|-----------------|--------------------------------|---------------------|
| NABDAM | 6.96 \pm 0.02 | 1.1 \pm 0.2 | 296 \pm 100 | 195 \pm 30 |
| BONGO | 7.93 \pm 0.04 | 1.0 \pm 0.3 | 554 \pm 200 | 233 \pm 80 |
| BOLGATANGA | 6.88 \pm 0.02 | 1.0 \pm 0.1 | 467 \pm 200 | 290 \pm 100 |
| NAVRONGO | 7.26 \pm 0.03 | 1.03 \pm 0.09 | 439 \pm 200 | 240 \pm 100 |
| GSA/WHO LIMIT | 6.5 - 8.5 | 5 | 1000 | 500 |
| DISTRICTS | TDS (mg/L) | Turbidity (NTU) | Chloride (mg/L) | Fluoride (mg/L) |
| NABDAM | 206 \pm 60 | 0.7 \pm 0.1 | 85 \pm 40 | 0.16 \pm 0.06 |
| BONGO | 312 \pm 50 | 0.8 \pm 0.2 | 130 \pm 70 | 1.5 \pm 0.7 |
| BOLGATANGA | 278 \pm 90 | 1.2 \pm 0.5 | 53 \pm 20 | 1.8 \pm 0.9 |
| NAVRONGO | 265 \pm 100 | 0.91 \pm 0.03 | 89 \pm 20 | 1.15 \pm 0.09 |
| GSA/WHO LIMIT | 500/1000 | 5 | 250 | 1.5 |

4.2. The levels of metals in the borehole water.

Iron showed the highest level in the water samples from the Bonga district, with a range; (0.07±0.01 - 0.17±0.03 mg/L). Bolgatanga and Navrongo district recorded levels ranging from (0.03±0.01 - 0.28±0.02 mg/L) and (0.025±0.005 - 0.035±0.007 mg/L), respectively. Nabdam district recorded the lowest concentration (0.025±0.008 - 0.040±0.008 mg/L). The concentrations obtained in this study were below the GSA limit of 0.3 mg/L and the WHO limit of 2 mg/L. The levels of Cr in this study were lower than previous levels (1400 – 110000 µg/kg) reported by Botwe et al., 2020 and results obtained (18600 – 739500 µg/kg) by Akoto et al., 2016 (Akoto et al., 2016; Botwe et al., 2020), but the levels of Cr recorded in sediments at Bontanga, Ghana (320 – 1050 µg/kg) were beneath the levels obtained in this study (Asare et al., 2018).

The levels of zinc (Zn) in the borehole samples range from (0.005±0.001- 0.040±0.008) for the Navrongo district, (0.020±0.004 - 0.10±0.02 mg/L) for the Bolgatanga district, (0.025±0.001 - 0.08±0.02 mg/L) for the Bongo district, and (0.025±0.008 - 0.040±0.008 mg/L) for the Nabdam district. Levels of zinc were highest in the Bolgatanga district, followed by the Bongo district, the Navrongo district and least in the Nabdam district. Comparing the levels of zinc to the GSA and WHO set limit of 3 mg/L, the levels of zinc in the studied borehole samples were lower.

The levels of copper were higher than iron and zinc. Copper concentration ranges from (0.040±0.005 - 0.08±0.02 mg/L) Navrongo district, (0.010±0.008 - 0.020±0.003 mg/L) for Nabdam district, (0.010±0.008 - 0.55±0.05 mg/L) for Bongo district and (0.020±0.004 - 0.72±0.03 mg/L) for Bolgatanga district. Among the four districts, Bolgatanga recorded the highest levels of copper, and the lowest levels of copper were recorded at Nabdam district. The levels of copper recorded were, however, lower than the GSA limit of 1 mg/L and the WHO limit of 2 mg/L

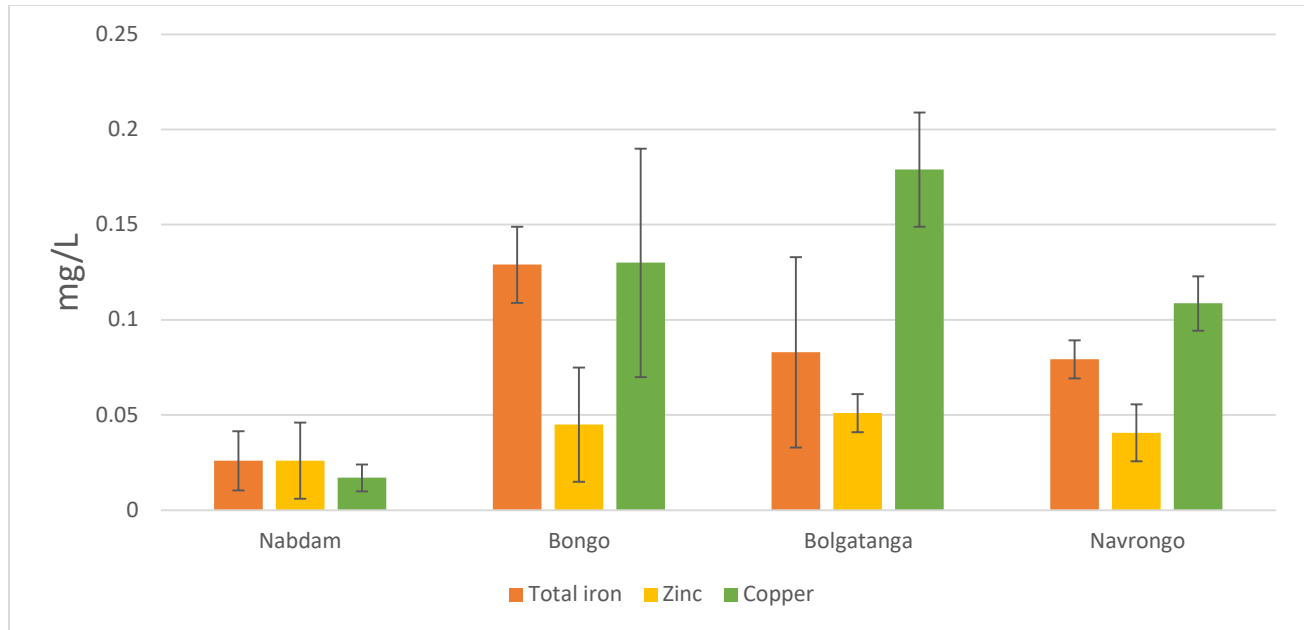


Figure 4.9. Average levels of metals in the various districts.

4.3. Levels of Calcium and Magnesium

The levels of calcium ranges from (32±6 - 82±20 mg/L) for Navrongo, (27±7 - 59±10 mg/L) for Nabdam, (27±10 - 108±10 mg/L) for Bongo, and (31±8 - 103±5 mg/L) for Bolgatanga. The study revealed that the Bongo district recorded the highest level of calcium, and the lowest levels were recorded in the Nabdam district. All the levels of calcium were below the standard limit of GSA and WHO (75 mg/L).

Magnesium ranges from (37±7 - 68±10 mg/L) for Navrongo district, (27±7 - 59±10 mg/L) for Nabdam, (29±6 - 59±7 mg/L) for Bolgatanga district and (6±2 - 67±10 mg/L) for Bongo district. The highest levels of magnesium were recorded in the Bolgatanga district, and the lowest level was reported in the Nabdam district. The levels of magnesium reported were below the standard limit set by GSA and WHO (50 mg/L). A study done to evaluate borehole water quality in the Bole district of Ghana gave the range of (16 – 31.2 mg/L) for magnesium and calcium levels,

ranging from 23 – 27 mg/L (Aaniamenga Bowan, 2022). Similarly, a study done by Boadi et al., 2020 reported 0.6 – 60.7 mg/L for calcium and 0.5 – 3.7 mg/L for magnesium (Boadi et al., 2020), which is lower than the levels recorded in this study

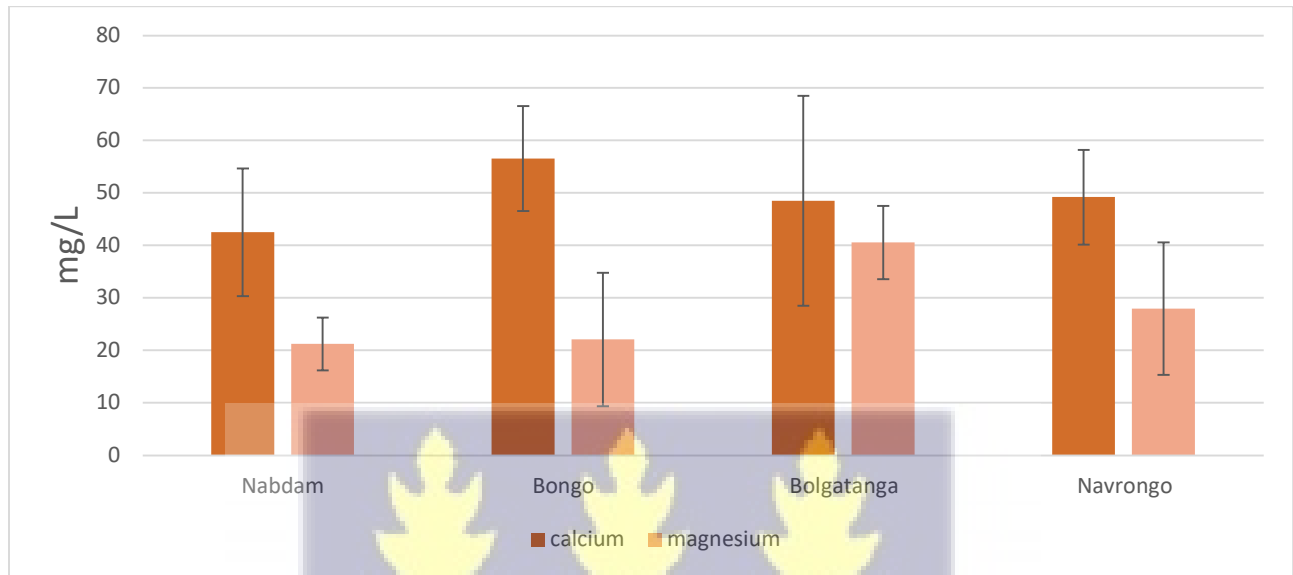


Figure 4.10. Levels of metals in water samples from the various districts.

Table 4.2. Average levels of metals in borehole water samples from the districts.

| DISTRICTS | Ca (mg/L) | Mg (mg/L) | Fe (mg/L) | Zn (mg/L) | Cu (mg/L) |
|----------------------|-----------|-----------|-------------|-----------|-------------|
| NABDAM | 43±10 | 21±5 | 0.03±0.01 | 0.03±0.02 | 0.017±0.004 |
| BONGO | 57±10 | 22±10 | 0.13±0.04 | 0.05±0.01 | 0.13±0.07 |
| BOLGATANGA | 49±20 | 41±7 | 0.08±0.03 | 0.05±0.04 | 0.18±0.06 |
| NAVRONGO | 49±9 | 28±10 | 0.080±0.004 | 0.04±0.02 | 0.11±0.06 |
| GSA/WHO LIMIT | 75 | 50 | 0.3 | 3 | 1 |

4.4. Results of Microbial Analyses

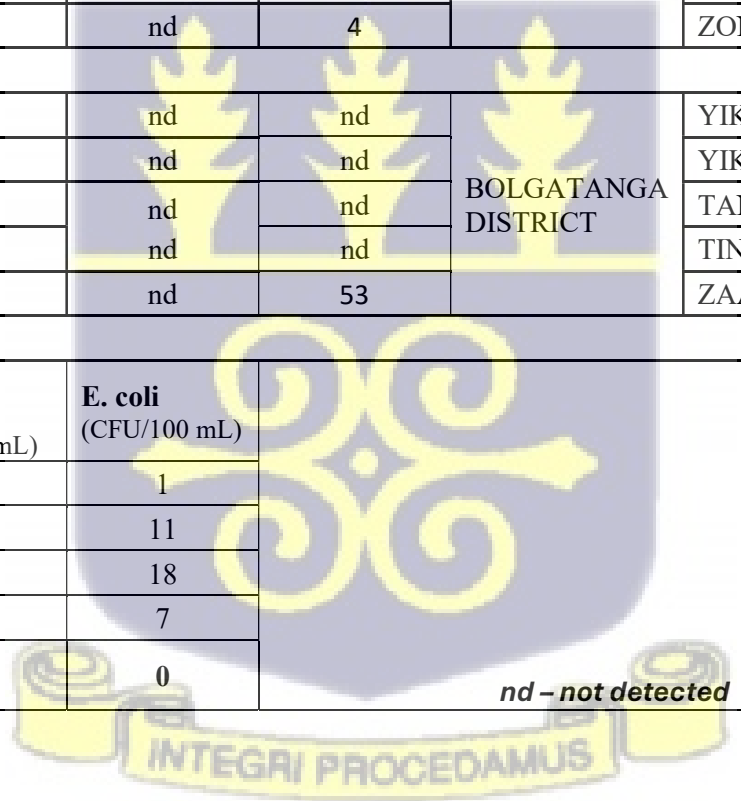
The microbial analyses performed on the samples for this study included faecal coliforms, Escherichia coli (E. Coli), and total coliforms. The results showed that all the studied borehole water samples do not contain faecal coliforms in the districts. In Navrongo, the levels of total

coliforms range from 14 – 109 CFU/100 mL, with a mean value of 22 CFU/100 mL. Nabdam district recorded total coliform levels ranging from (48 – 61 CFU/100 mL) and an average value of 22 CFU/100 mL. A range of (53 – 115 CFU/100 mL) and an average of 83 CFU/100 mL of total coliforms for the Bongo district. Bolgatanga district gave total coliform levels ranging from (15 - 51 CFU/100 mL) and a mean of 32 CFU/100 mL. Most of the studied areas recorded levels of total coliforms above the set limits of GSA (0 CFU/100 mL). Bongo district recorded the highest levels of total coliform, and the lowest levels were at Nabdam and Navrongo districts.

E. Coli were also recorded in the borehole water samples from the districts. In the Bongo district, E. Coli levels ranged from 0 - 53 CFU/100 mL, with an average level of 11 CFU/100 mL. Navrongo district gave a range of E. Coli (0 – 29 CFU/100 mL) and a mean of 7 CFU/100 mL. E. Coli levels ranged from (0 - 5 CFU/100 mL) and an average of 1 CFU/100 mL for the Nabdam district. Bolgatanga district gave E. Coli levels ranging from (0 – 45 CFU/100 mL) and an average level of 18 CFU/100 mL. Although the E. Coli and total coliform recorded were above the threshold limits set by GSA (0 CFU/100 mL), the levels of total coliform were higher than the levels recorded in E. Coli. For E. Coli, Bolgatanga district recorded the highest levels, followed by Bongo district, Navrongo district and the least being Nabdam district. A study done to assess the quality of borehole water in the Upper-East region of Ghana gave a range of (1.8 – 20 CFU/100 mL) for total coliform and a range of (1.8 – 14 CFU/100 mL) for faecal coliform (Adetunde & Glover, 2010). Although their levels of total coliform were lower than was recorded in this study, there were no faecal coliform recorded in our study.

Table 4.3. Levels of some microbes in borehole water samples from the districts.

| DISTRICTS | SAMPLING AREAS | Total coliform (CFU/100 mL) | Faecal coliform (CFU/100 mL) | E. coli (CFU/100 mL) | DISTRICTS | SAMPLING AREAS | Total coliform (CFU/100 mL) | Faecal coliform (CFU/100 mL) | E. coli (CFU/100 mL) |
|----------------------|-----------------------------|------------------------------|------------------------------|--------------------------|---------------------|----------------|-----------------------------|------------------------------|----------------------|
| NAVRONGO DISTRICT | NOGESENIA A | nd | nd | nd | NABDAM DISTRICT | SAKOTI | nd | nd | 2 |
| | SSNIT HOESTEL | 109 | nd | 29 | | ATOFGAE | 61 | nd | nd |
| | SABORO | nd | nd | nd | | KPALE | nd | nd | nd |
| | NOGESENIA B | nd | nd | nd | | KPATIA | 48 | nd | 5 |
| | TECH CENTRE | 14 | nd | 4 | | ZONNO | nd | nd | nd |
| BONGO DISTRICT | ZOBOKINE | 83 | nd | nd | BOLGATANGA DISTRICT | YIKENE A | 51 | nd | 45 |
| | ADOBOBISI | 86 | nd | nd | | YIKENE B | 45 | nd | 45 |
| | ANAFOBISI | 80 | nd | nd | | TANZUI | 15 | nd | 8 |
| | BONGO GURIGU | 53 | nd | nd | | TINDONMOLIGO | nd | nd | nd |
| | NAYIRE | 115 | nd | 53 | | ZAARE | 48 | nd | nd |
| DISTRICTS | Total coliform (CFU/100 mL) | Faecal coliform (CFU/100 mL) | E. coli (CFU/100 mL) | | | | | | |
| NABDAM | 22 | nd | 1 | | | | | | |
| BONGO | 83 | nd | 11 | | | | | | |
| BOLGATANGA | 32 | nd | 18 | | | | | | |
| NAVRONGO | 22 | nd | 7 | | | | | | |
| GSA/WHO LIMIT | 0 | 0 | 0 | <i>nd – not detected</i> | | | | | |



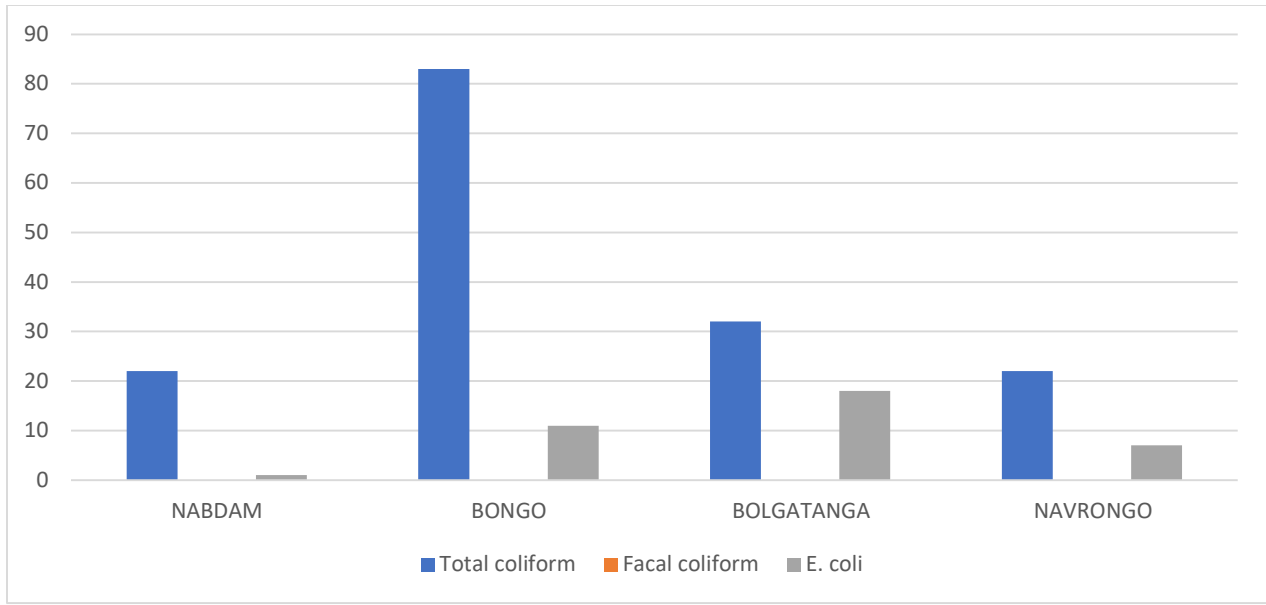


Figure 4.11. Average levels of microbes in borehole water samples from the studied districts.

4.5. Discussion on microbial, physico-chemical parameters and some selected metals.

The study revealed that most of the borehole samples from the studied areas were contaminated with total coliform and E. Coli. As a result, before drinking, these water samples need to be cooked and clear-filtered. The elevated bacterial counts in the water samples may be caused by the boreholes' location in the communities, as domestic animals often visit the borehole site to drink water. These animals usually urinate and defecate around the borehole and lick the mouth of the valve after drinking. These practices might encourage bacterial spores to enter the water through the outlet of the borehole and contaminate it. Additionally, some children using untidy hands to handle the valves of the borehole could increase the possibility of water contamination levels. Total coliform bacteria are sometimes called "indicator organisms," which means that their presence enhances the chance that there are other pathogens present in the water bodies. The rate of microorganism multiplication is influenced by temperature (Bello, 2013). Although there is little information regarding the depth of the boreholes, the height of the borehole may be another

possible source of microbial contamination (Seth & Tagbor, 2013). Packed sand and unfractured rock allow groundwater to pass through; therefore, a borehole must be at least 40 meters deep to exclude surface-level microbial contamination. It might not take more than three meters in an unsaturated zone to clean up groundwater. Microbial pollutants, however, can quickly cross the unsaturated zone of a fractured aquifer and reach the water table. *Escherichia coli* was found in borehole water meant for human consumption is worrying. It has been demonstrated that both domestic and wild animals cause the uncontrolled release of faeces into the environment, leading to the natural reservoirs of the Enterobacteriaceae family of bacteria (Livares & Ood, 2004).

Most of the studied physico-chemical parameters measured, such as pH, colour, turbidity, total hardness, electrical conductivity, total dissolved solids and chloride, were generally within the accepted range of GSA and WHO set standards. However, the levels of fluoride were above the threshold limit set by GSA and WHO. The levels of fluoride range from 0.01 – 2.70 mg/L. Novrango and Nabdam districts recorded levels of fluoride within the GSA and WHO set standard (1.5 mg/L). On the contrary, in the Bongo and Bolgatanga districts, the levels of fluoride were above the GSA and the WHO set standards. Both districts have 80% of the studied samples above the GSA and WHO set limits. The fluctuation in fluoride levels may be attributed to variations in anthropogenic activities such as agricultural practices that release fluoride into groundwater, and geological variables, such as the weathering of minerals containing fluoride. According to their research in the Upper East Region, the Bongo district is situated in a prominent high-fluoride granite called Bongo granite, which might contribute to the high levels of fluoride in those areas.

All the studied heavy metals (Cu, Zn, Fe) were within the threshold limit for drinking water according to Ghana Standard Authority (GSA) and World Health Organization (WHO), thus 3 mg/L, 1 mg/L and 0.3 mg/L, respectively. This could be ascribed to the geology of the studied

areas, not made up of minerals that contain iron, copper and zinc. Also, mining and industrial activities that may lead to the exposure of some of these metals are not found in these communities. Even though the levels of these heavy metals are low, there should be regular monitoring to check their levels in drinking water. In comparison to other studies, a study done assessing the quality of groundwater in the Upper East region gave levels of Fe (0.14 – 5.13 mg/L) and Zn (0.013 – 1.031 mg/L), which are higher than the ranges reported in this study (Asare-Donkor & Adimado, 2020). The levels of magnesium and calcium were within the accepted limits as suggested by GSA and WHO. This agrees with the result recorded for total hardness since high levels of calcium and magnesium contribute to higher levels of total hardness.



CHAPTER FIVE

5.0. CONCLUSION AND RECOMMENDATION

5.1. Conclusion

The study suggests significant levels of fluorides and microbial contaminants were recorded in the borehole water from the districts. In compliance with the findings from this study, microbial contaminants, particularly total coliforms and E. Coli, were recorded in 65% and 40% of the studied samples, respectively, thus exceeding the zero (0 CFU/100 mL) set limit of Ghana Standard Authority (GSA) and the World Health Organization (WHO). The levels of total coliform show concentrations ranging from 0 - 115 CFU/100 mL and E. Coli reporting levels ranging from 0 - 53 CFU/100 mL. Bongo district recorded the highest levels of microbial contaminants, followed by Bolgatanga district, Nabdam district and Navrongo district, respectively. Also, fluoride levels reported in the Bongo and Bolgatanga districts were above the GSA limit (1.5 mg/L). Additionally, the concentrations of the studied metals (Mg, Ca, Fe, Cu, and Zn) were within the accepted limit of the Ghana Standard Authority (GSA) and the World Health Organization (WHO) for drinking water. Treatment is necessary before drinking, given the wide range of physicochemical and biological characteristics within the same region. The GSA standard for drinking water quality was exceeded by most microbiological indicators (E. coli and coliform) from every monitoring area.

5.2. Recommendations

To ensure the safety of the people in the Upper East region, precautionary measures should be put in place to monitor the levels of physico-chemical and microbial parameters all year round. In addition, there should be education to the public to create awareness about the treatment of water from borehole sources before being used and keeping the surroundings of borehole stations clean. To monitor the contaminated water sources, the region's decentralized government institutions

must have sufficient resources and the necessary logistics for water treatment. Some treatment methods such as the use of chlorine, ultraviolet light and reverse osmosis filters can be employed.



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Zango, S. M., Daanoba, E., Abu, M., & Lermi, A. (2019). Hydrogeochemical controls and human health risk assessment of groundwater fluoride and boron in the semi-arid North East region of Ghana. *Journal of Geochemical Exploration*, 207(September), 106363. <https://doi.org/10.1016/j.gexplo.2019.106363>



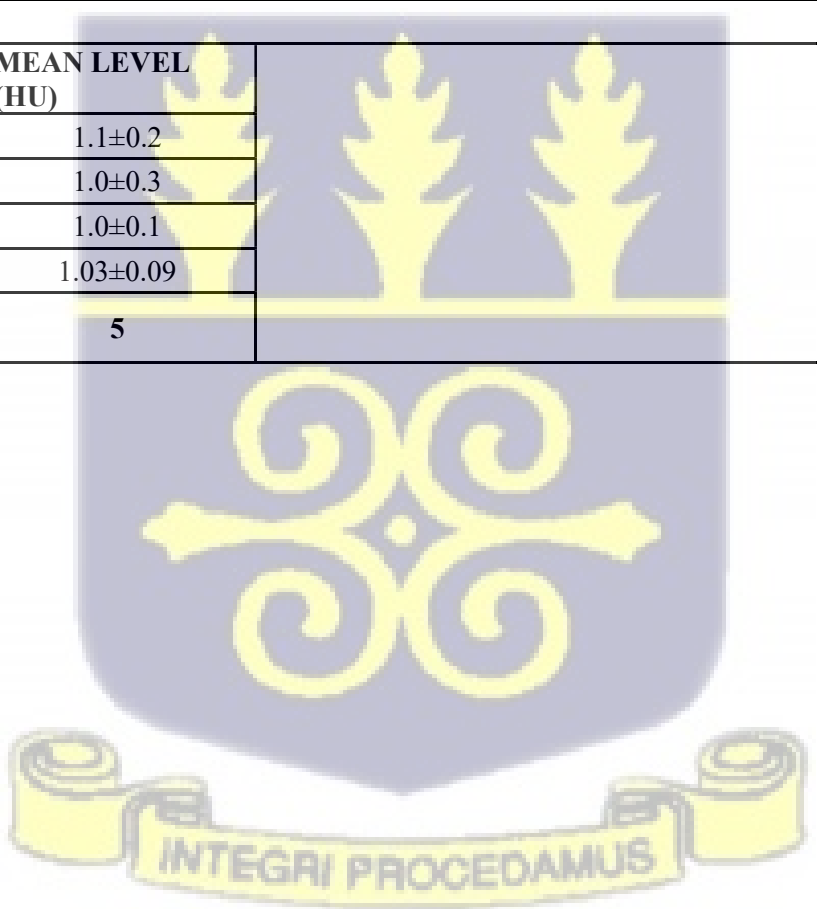
APPENDIX

pH readings of the districts borehole water samples.

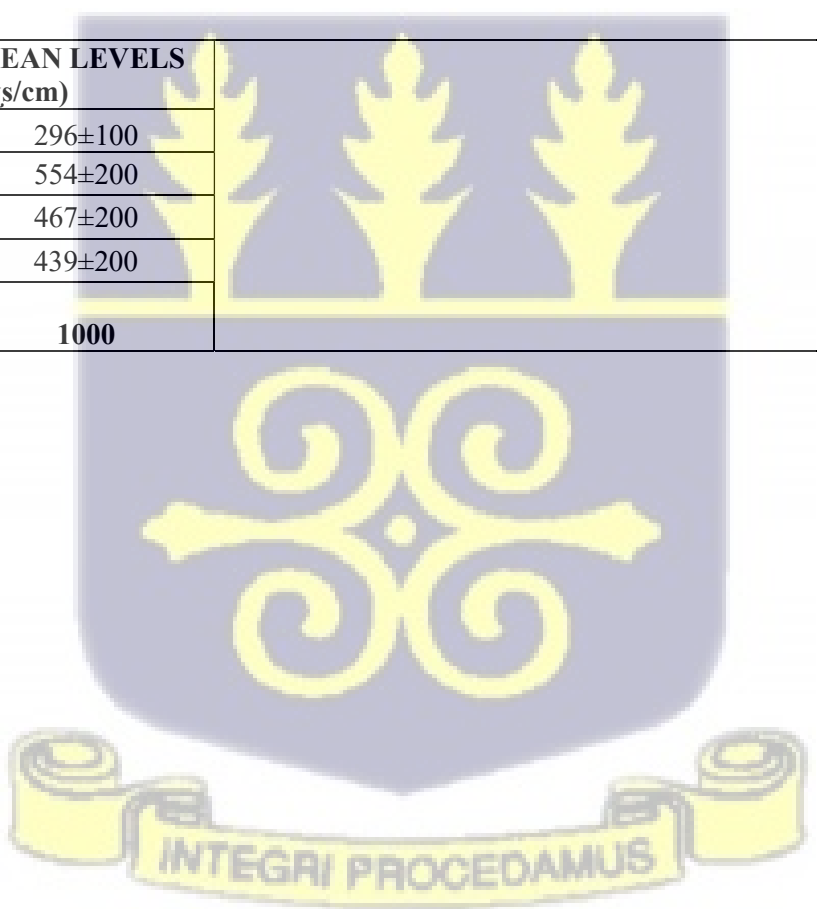
| DISTRICTS | SAMPLING AREAS | LEVELS | DISTRICTS | SAMPLING AREAS | LEVELS |
|----------------------|--------------------|-----------|---------------------|----------------|-----------|
| NAVRONGO DISTRICT | NOGESENIA A | 7.08±0.05 | NABDAM DISTRICT | SAKOTI | 6.95±0.09 |
| | SSNIT HOESTEL | 7.08±0.06 | | ATOFGAE KPATIA | 6.75±0.03 |
| | SABORO | 6.71±0.09 | | KPALE | 7.12±0.09 |
| | NOGESENIA B | 6.90±0.04 | | KPATIA | 6.95±0.05 |
| | TECH CENTRE | 6.76±0.05 | | ZONNO | 7.00±0.08 |
| BONGO DISTRICT | ZOBOKINE | 8.28±0.05 | BOLGATANGA DISTRICT | YIKENE A | 7.05±0.05 |
| | ADOBOBISI | 7.85±0.09 | | YIKENE B | 6.95±0.09 |
| | ANAFOBISI | 7.90±0.07 | | TANZUI | 6.95±0.05 |
| | BONGO GURIGU | 7.90±0.09 | | TINDONMOLIGO | 6.85±0.08 |
| | NAYIRE | 7.70±0.08 | | ZAARE | 6.60±0.09 |
| DISTRICTS | MEAN LEVELS | | | | |
| NABDAM | 6.96±0.02 | | | | |
| BONGO | 7.93±0.04 | | | | |
| BOLGATANGA | 6.88±0.02 | | | | |
| NAVRONGO | 7.26±0.03 | | | | |
| GSA/WHO LIMIT | 6.5 - 8.5 | | | | |



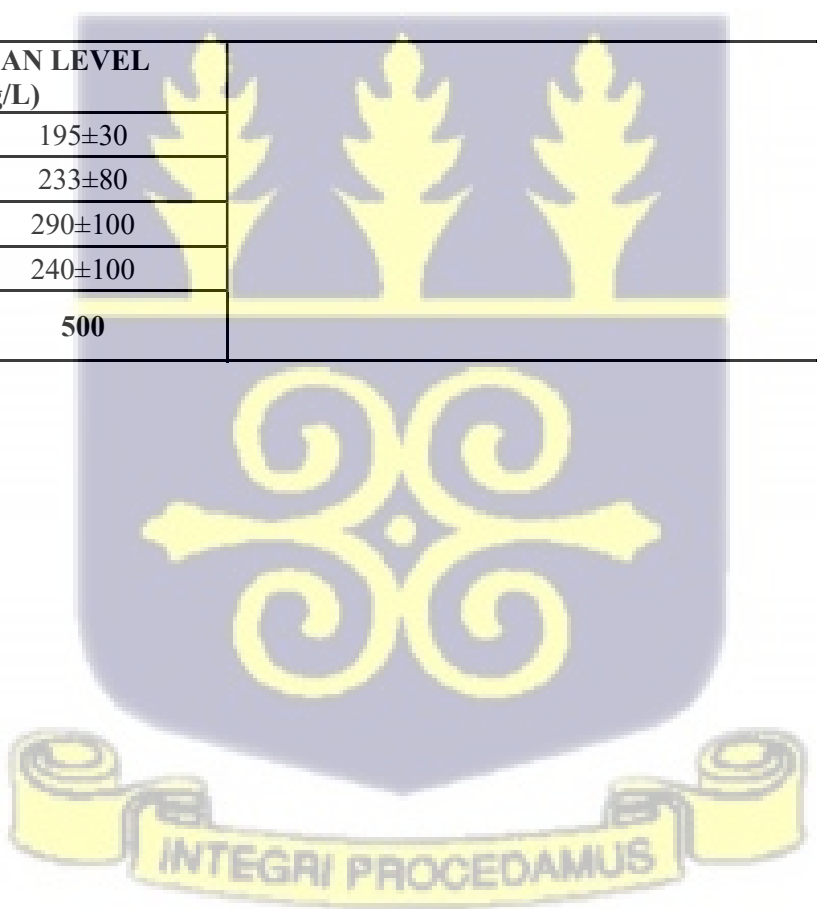
Colour values for the borehole water samples from the various districts.

| DISTRICTS | SAMPLING AREAS | LEVEL (HU) | DISTRICTS | SAMPLING AREAS | LEVEL (HU) |
|----------------------|-----------------|---|---------------------|----------------|------------|
| NAVRONGO DISTRICT | NOGESENIA A | 1.0±0.2 | NABDAM DISTRICT | SAKOTI | 1.0±0.1 |
| | SSNIT HOESTEL | 1.0±0.1 | | ATOGLAE KPATIA | 1.0±0.2 |
| | SABORO | 1.0±0.2 | | KPALE | 1.0±0.3 |
| | NOGESENIA B | 1.00±0.004 | | KPATIA | 1.0±0.1 |
| | TECH CENTRE | 1.00±0.08 | | ZONNO | 1.5±0.1 |
| BONGO DISTRICT | ZOBOKINE | 1.0±0.3 | BOLGATANGA DISTRICT | YIKENE A | 1.0±0.1 |
| | ADOBOBISI | 1.00±0.09 | | YIKENE B | 1.0±0.2 |
| | ANAFOBISI | 1.0±0.2 | | TANZUI | 1.00±0.08 |
| | BONGO GURIGU | 1.0±0.1 | | TINDONMOLIGO | 1.0±0.2 |
| | NAYIRE | 1.0±0.2 | | ZAARE | 1.0±0.1 |
| DISTRICTS | MEAN LEVEL (HU) |  | | | |
| NABDAM | 1.1±0.2 | | | | |
| BONGO | 1.0±0.3 | | | | |
| BOLGATANGA | 1.0±0.1 | | | | |
| NAVRONGO | 1.03±0.09 | | | | |
| GSA/WHO LIMIT | 5 | | | | |

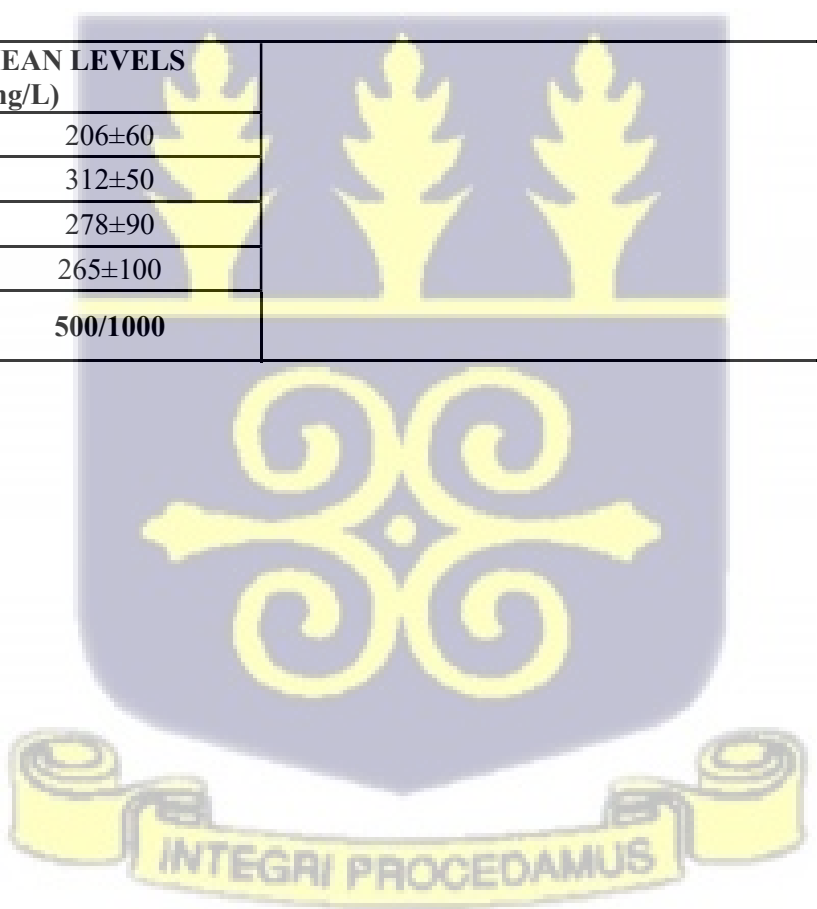
Levels of electrical conductivity in borehole samples from the districts

| DISTRICTS | SAMPLING AREAS | LEVELS ($\mu\text{s}/\text{cm}$) | DISTRICTS | SAMPLING AREAS | LEVELS ($\mu\text{s}/\text{cm}$) |
|----------------------|---|---|---------------------|----------------|------------------------------------|
| NAVRONGO DISTRICT | NOGESENIA A | 362±100 | NABDAM DISTRICT | SAKOTI | 28±10 |
| | SSNIT HOESTEL | 361±70 | | ATOFAE KPATIA | 403±70 |
| | SABORO | 542±100 | | KPALE | 271±90 |
| | NOGESENIA B | 929±50 | | KPATIA | 353±100 |
| | TECH CENTRE | 695±70 | | ZONNO | 425±60 |
| BONGO DISTRICT | ZOBOKINE | 441±90 | BOLGATANGA DISTRICT | YIKENE A | 344±90 |
| | ADOBOBISI | 473±100 | | YIKENE B | 348±70 |
| | ANAFOBISI | 307±100 | | TANZUI | 767±50 |
| | BONGO GURIGU | 365±200 | | TINDONMOLIGO | 483±100 |
| | NAYIRE | 1186±100 | | ZAARE | 393±80 |
| DISTRICTS | MEAN LEVELS ($\mu\text{s}/\text{cm}$) |  | | | |
| NABDAM | 296±100 | | | | |
| BONGO | 554±200 | | | | |
| BOLGATANGA | 467±200 | | | | |
| NAVRONGO | 439±200 | | | | |
| GSA/WHO LIMIT | 1000 | | | | |

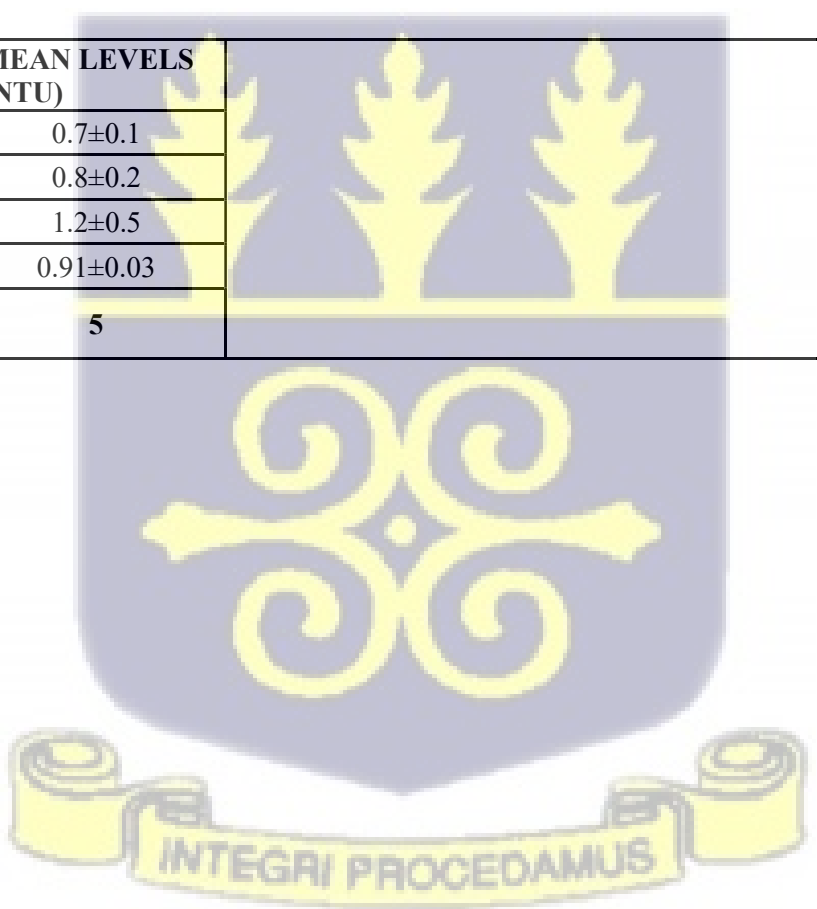
Levels of total hardness of borehole water samples from the districts.

| DISTRICTS | SAMPLING AREAS | LEVEL (mg/L) | DISTRICTS | SAMPLING AREAS | LEVEL (mg/L) |
|----------------------|-------------------|---|---------------------|----------------|--------------|
| NAVRONGO DISTRICT | NOGESENIA A | 235±50 | NABDAM DISTRICT | SAKOTI | 162±30 |
| | SSNIT HOESTEL | 235±40 | | ATOFGAE KPATIA | 227±20 |
| | SABORO | 316±60 | | KPALE | 156±80 |
| | NOGESENIA B | 486±100 | | KPATIA | 206±40 |
| | TECH CENTRE | 335±70 | | ZONNO | 224±60 |
| BONGO DISTRICT | ZOBOKINE | 236±50 | BOLGATANGA DISTRICT | YIKENE A | 219±40 |
| | ADOBOBISI | 133±30 | | YIKENE B | 214±40 |
| | ANAFOBISI | 201±40 | | TANZUI | 504±30 |
| | BONGO GURIGU | 360±70 | | TINDONMOLIGO | 312±70 |
| | NAYIRE | 237±60 | | ZAARE | 203±60 |
| DISTRICTS | MEAN LEVEL (mg/L) |  | | | |
| NABDAM | 195±30 | | | | |
| BONGO | 233±80 | | | | |
| BOLGATANGA | 290±100 | | | | |
| NAVRONGO | 240±100 | | | | |
| GSA/WHO LIMIT | 500 | | | | |

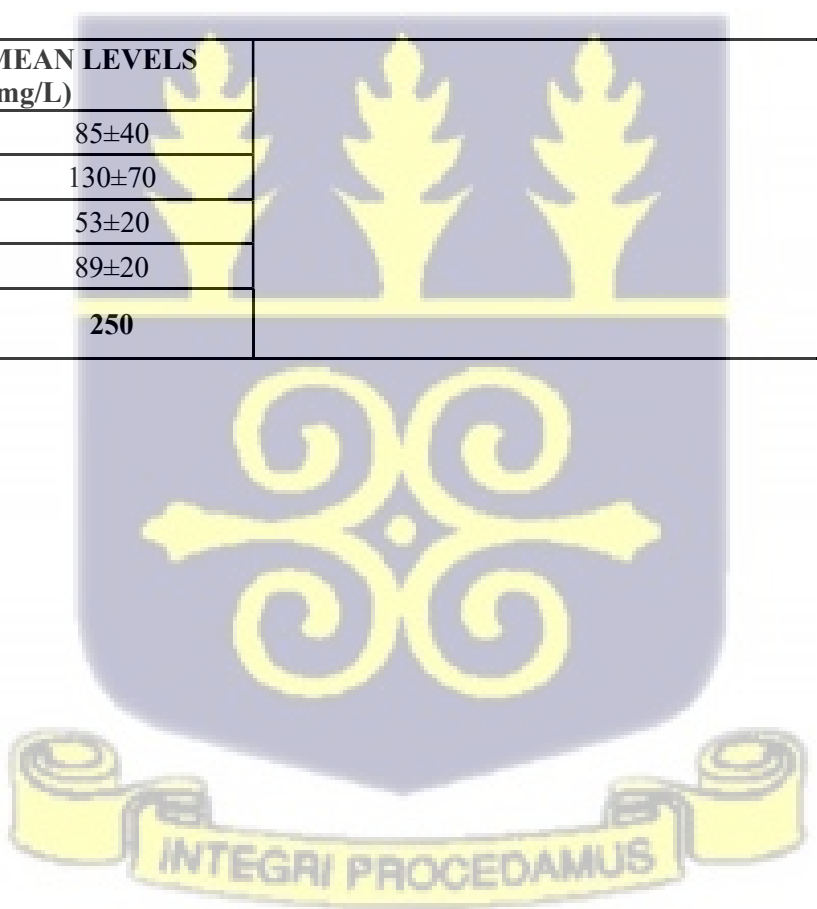
Levels of total dissolved solids in the borehole water samples from the studied districts.

| DISTRICTS | SAMPLING AREAS | LEVELS (mg/L) | DISTRICTS | SAMPLING AREAS | LEVELS (mg/L) |
|----------------------|--------------------|---|---------------------|-----------------|---------------|
| NAVRONGO DISTRICT | NOGESENIA A | 323±60 | NABDAM DISTRICT | SAKOTI | 165±30 |
| | SSNIT HOESTEL | 323±50 | | ATOOGFAE KPATIA | 215±20 |
| | SABORO | 343±30 | | KPALE | 174±30 |
| | NOGESENIA B | 562±100 | | KPATIA | 214±60 |
| | TECH CENTRE | 423±80 | | ZONNO | 265±20 |
| BONGO DISTRICT | ZOBOKINE | 131±70 | BOLGATANGA DISTRICT | YIKENE A | 212±100 |
| | ADOBOBISI | 298±90 | | YIKENE B | 208±40 |
| | ANAFOBISI | 198±40 | | TANZUI | 430±40 |
| | BONGO GURIGU | 232±100 | | TINDONMOLIGO | 291±60 |
| | NAYIRE | 703±90 | | ZAARE | 249±70 |
| DISTRICTS | MEAN LEVELS (mg/L) |  | | | |
| NABDAM | 206±60 | | | | |
| BONGO | 312±50 | | | | |
| BOLGATANGA | 278±90 | | | | |
| NAVRONGO | 265±100 | | | | |
| GSA/WHO LIMIT | 500/1000 | | | | |

Levels of turbidity in the borehole water samples from the various districts.

| DISTRICTS | SAMPLING AREAS | LEVELS (NTU) | DISTRICTS | SAMPLING AREAS | LEVELS (NTU) |
|----------------------|-------------------|---|---------------------|----------------|--------------|
| NAVRONGO DISTRICT | NOGESENIA A | 0.8±0.3 | NABDAM DISTRICT | SAKOTI | 0.7±0.1 |
| | SSNIT HOESTEL | 0.8±0.1 | | ATOFAE KPATIA | 0.75±0.09 |
| | SABORO | 0.85±0.09 | | KPALE | 0.90±0.05 |
| | NOGESENIA B | 0.9±0.2 | | KPATIA | 0.65±0.03 |
| | TECH CENTRE | 0.8±0.1 | | ZONNO | 0.6±0.1 |
| BONGO DISTRICT | ZOBOKINE | 0.8±0.2 | BOLGATANGA DISTRICT | YIKENE A | 1.0±0.2 |
| | ADOBOBISI | 0.7±0.4 | | YIKENE B | 1.3±0.1 |
| | ANAFOBISI | 1.3±0.1 | | TANZUI | 1.9±0.2 |
| | BONGO GURIGU | 0.8±0.2 | | TINDONMOLIGO | 0.8±0.2 |
| | NAYIRE | 0.7±0.3 | | ZAARE | 0.9±0.3 |
| DISTRICTS | MEAN LEVELS (NTU) |  | | | |
| NABDAM | 0.7±0.1 | | | | |
| BONGO | 0.8±0.2 | | | | |
| BOLGATANGA | 1.2±0.5 | | | | |
| NAVRONGO | 0.91±0.03 | | | | |
| GSA/WHO LIMIT | 5 | | | | |

Levels of chloride in the borehole water samples from the studied districts.

| DISTRICTS | SAMPLING AREAS | LEVELS (mg/L) | DISTRICTS | SAMPLING AREAS | LEVELS (mg/L) |
|----------------------|--------------------|---|---------------------|----------------|---------------|
| NAVRONGO DISTRICT | NOGESENIA A | 24±5 | NABDAM DISTRICT | SAKOTI | 41±10 |
| | SSNIT HOESTEL | 24±4 | | ATOGFAE KPATIA | 240±50 |
| | SABORO | 40±8 | | KPALE | 37±20 |
| | NOGESENIA B | 82±20 | | KPATIA | 53±10 |
| | TECH CENTRE | 29±6 | | ZONNO | 52±20 |
| BONGO DISTRICT | ZOBOKINE | 72±10 | BOLGATANGA DISTRICT | YIKENE A | 41±4 |
| | ADOBOBISI | 96±10 | | YIKENE B | 39±8 |
| | ANAFOBISI | 58±20 | | TANZUI | 89±3 |
| | BONGO GURIGU | 40±20 | | TINDONMOLIGO | 62±10 |
| | NAYIRE | 383±50 | | ZAARE | 33±9 |
| DISTRICTS | MEAN LEVELS (mg/L) |  | | | |
| NABDAM | 85±40 | | | | |
| BONGO | 130±70 | | | | |
| BOLGATANGA | 53±20 | | | | |
| NAVRONGO | 89±20 | | | | |
| GSA/WHO LIMIT | 250 | | | | |

Levels of fluoride in the borehole water samples from the districts.

| DISTRICTS | SAMPLING AREAS | LEVEL (mg/L) | DISTRICTS | SAMPLING AREAS | LEVEL (mg/L) |
|----------------------|--------------------------|--------------|---------------------|----------------|--------------|
| NAVRONGO DISTRICT | NOGESENIA A | 0.41±0.08 | NABDAM DISTRICT | SAKOTI | 0.16±0.03 |
| | SSNIT HOESTEL | 0.41±0.06 | | ATOGFAE KPATIA | 0.21±0.03 |
| | SABORO | 0.5±0.1 | | KPALE | 0.21±0.02 |
| | NOGESENIA B | 0.31±0.06 | | KPATIA | 0.06±0.03 |
| | TECH CENTRE | 0.30±0.06 | | ZONNO | 0.15±0.03 |
| BONGO DISTRICT | ZOBOKINE | 1.9±0.2 | BOLGATANGA DISTRICT | YIKENE A | 2.7±0.2 |
| | ADOBOBISI | 1.8±0.4 | | YIKENE B | 2.4±0.3 |
| | ANAFOBISI | 2.0±0.2 | | TANZUI | 0.30±0.04 |
| | BONGO GURIGU | 0.01±0.002 | | TINDONMOLIGO | 1.8±0.2 |
| | NAYIRE | 1.8±0.2 | | ZAARE | 1.8±0.3 |
| DISTRICTS | MEAN LEVEL (mg/L) | | | | |
| NABDAM | 0.16±0.06 | | | | |
| BONGO | 1.5±0.7 | | | | |
| BOLGATANGA | 1.8±0.9 | | | | |
| NAVRONGO | 1.15±0.09 | | | | |
| GSA/WHO LIMIT | 1.5 | | | | |



| DISTRICTS | SAMPLING AREAS | Fe (mg/L) | Zn (mg/L) | Cu (mg/L) | DISTRICTS | SAMPLING AREAS | Fe (mg/L) | Zn (mg/L) | Cu (mg/L) |
|-------------------|----------------|-------------|-------------|-------------|-----------------|----------------|-------------|-------------|-------------|
| NAVRONGO DISTRICT | NOGESENIA A | 0.030±0.006 | 0.040±0.008 | 0.040±0.008 | NABDAM DISTRICT | SAKOTI | 0.040±0.008 | 0.010±0.002 | 0.020±0.004 |
| | SSNIT HOESTEL | 0.030±0.008 | 0.040±0.006 | 0.040±0.005 | | ATOGFAE KPATIA | 0.030±0.006 | 0.010±0.007 | 0.020±0.003 |
| | SABORO | 0.025±0.005 | 0.020±0.004 | 0.08±0.02 | | KPALE | 0.025±0.008 | 0.025±0.005 | 0.020±0.004 |
| | NOGESENIA B | 0.030±0.009 | 0.020±0.005 | 0.05±0.01 | | KPATIA | 0.035±0.007 | 0.010±0.006 | 0.015±0.003 |
| | TECH CENTRE | 0.035±0.007 | 0.005±0.001 | 0.05±0.02 | | ZONNO | - | 0.075±0.005 | 0.010±0.008 |

| | | | | | | | | | |
|----------------|--------------|-----------|-------------|-------------|---------------------|--------------|-------------|-------------|-------------|
| BONGO DISTRICT | ZOBOKINE | 0.12±0.09 | 0.040±0.008 | 0.020±0.004 | BOLGATANGA DISTRICT | YIKENE A | 0.03±0.01 | 0.035±0.007 | 0.06±0.01 |
| | ADOBOBISI | 0.14±0.03 | 0.040±0.009 | 0.010±0.008 | | YIKENE B | 0.040±0.008 | 0.020±0.006 | 0.020±0.004 |
| | ANAFOBISI | 0.07±0.01 | 0.040±0.003 | 0.04±0.01 | | TANZUI | 0.040±0.006 | 0.08±0.01 | 0.72±0.03 |
| | BONGO GURIGU | 0.16±0.03 | 0.025±0.001 | 0.025±0.002 | | TINDONMOLIGO | 0.28±0.02 | 0.020±0.004 | 0.05±0.01 |
| | NAYIRE | 0.17±0.03 | 0.08±0.02 | 0.55±0.05 | | ZAARE | 0.030±0.002 | 0.10±0.02 | 0.05±0.02 |

| DISTRICTS | Fe (mg/L) | Zn (mg/L) | Cu (mg/L) |
|----------------------|--------------|-----------|-------------|
| NABDAM | 0.03±0.01 | 0.03±0.02 | 0.017±0.004 |
| BONGO | 0.13±0.04 | 0.05±0.01 | 0.13±0.07 |
| BOLGATANGA | 0.08±0.03 | 0.05±0.04 | 0.18±0.06 |
| NAVRONGO | 0.080±0.004 | 0.04±0.02 | 0.11±0.06 |
| GSA/WHO LIMIT | 0.3/2 | 3 | 1/2 |



| DISTRICTS | SAMPLING AREAS | Ca (mg/L) | Mg (mg/L) | DISTRICTS | SAMPLING AREAS | Ca (mg/L) | Mg (mg/L) |
|----------------------|------------------|------------------|-----------|---------------------|----------------|-----------|-----------|
| NAVRONGO DISTRICT | NOGESENIA A | 32±6 | 37±7 | NABDAM DISTRICT | SAKOTI | 27±7 | 23±3 |
| | SSNIT HOESTEL | 32±8 | 37±8 | | ATOFGAE KPATIA | 49±3 | 25±5 |
| | SABORO | 42±10 | 50±10 | | KPALE | 39±4 | 14±6 |
| | NOGESENIA B | 82±20 | 68±10 | | KPATIA | 39±9 | 26±8 |
| | TECH CENTRE | 48±10 | 51±10 | | ZONNO | 58.8±10 | 18±4 |
| BONGO DISTRICT | ZOBOKINE | 108±10 | 8±3 | BOLGATANGA DISTRICT | YIKENE A | 34±4 | 33±9 |
| | ADOBOBISI | 42±5 | 6±2 | | YIKENE B | 31±8 | 32±10 |
| | ANAFOBISI | 27±10 | 32±9 | | TANZUI | 103±5 | 59±7 |
| | BONGO GURIGU | 33±8 | 67±10 | | TINDONMOLIGO | 42±9 | 49±3 |
| | NAYIRE | 72±10 | 13±4 | | ZAARE | 32±3 | 29±6 |
| DISTRICTS | Ca (mg/L) | Mg (mg/L) | | | | | |
| NABDAM | 43±10 | 21±5 | | | | | |
| BONGO | 57±10 | 22±10 | | | | | |
| BOLGATANGA | 49±20 | 41±7 | | | | | |
| NAVRONGO | 49±9 | 28±10 | | | | | |
| GSA/WHO LIMIT | 75 | 50 | | | | | |



