UNIVERSITY OF EDUCATION, WINNEBA

ASSESSING THE QUALITY OF BOREHOLE WATER IN TAFO-AKIM IN THE EASTERN REGION OF GHANA

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ASSESSING THE QUALITY OF BOREHOLE WATER IN TAFO-AKIM IN THE EASTERN REGION OF GHANA

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DECLARATION

Candidates Declaration

I, **Thomas Kwame Dorpe**, hereby declare that this submission, with the exception of quotations and references contained in published works which have all been identified and duly acknowledged in the text, is entirely my own work towards the Mphil in Chemistry Education, and it has not been submitted, either in part or whole, for another degree elsewhere.

Signature: …………………………………………

Date: ……………………………………...…….

Supervisor's declaration

I hereby declare that, the preparation and presentation of this thesis was supervised in accordance with the guidelines for the supervision of thesis laid down by the University of Education, Winneba.

Supervisor's Name: **PROF. RUBY HANSON**

Signature: …………………………………………

Date: ……………………………………...…….

DEDICATION

Dedicated to the Dorpe and the Agumenu families.

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ABSTRACT

Water samples collected from the boreholes in Tafo-Akim were analysed for groundwater quality and its suitability for drinking. The purpose of the study is to determine the quality and hence the health implications of borehole water in Tafo-Akim in the Eastern Region of Ghana. Two sets of samples were taken from each of the four boreholes, Site 1-4, were analysed. One set of samples were taken in the dry season while the other was taken in the raining (wet) season. Major heavy metals, physicochemical and microbial parameters of drinking water were used as quality indicator. All instruments and methods (spectrophotometer, comparator, titrimetric and plate count method) used in this study are based on international standard recommendation, availability, proximity to the laboratory and cost involved. The results obtained from the water samples analysed shows that, all physical parameters analysed except pH, conductivity, colour and turbidity, are within the WHO's standard for drinking water. Heavy metal concentrations observed are also within the WHO's standard for drinking water except for iron at Site 3. All values obtained for phosphate are outside the WHO's standard for drinking water while all other chemical parameters are within the standard. Values observed for microbial analysis are unacceptable considering the WHO's guidelines for drinking water. Statistical comparison of results obtained in the dry and raining season using one way ANOVA shows no significant difference for all parameters measured. The level of probability at which significant difference existed between the groups was set at $p<0.05$ at 95% confidence level. It was concluded that, water at Site 1 is fairly good for drinking while those at Site 2, 3 and 4 are unacceptable. Some form of treatment and monitoring needs to be done on boreholes in the community.

CHAPTER ONE

INTRODUCTION

1.0 Overview

This chapter deals with the background to the study, statement of the problem and research objectives. It further spells out the significance of the study, limitations, delimitations and definition of terms.

1.1 Background to the Study

Water is the wonder of nature which is an essential source of nutrient for all forms of life. It helps in proper digestion, energy metabolism, transport of nutrients and metabolites, cellular functions, and excretion of waste materials from our body and animals (Giri et al., 2020). This explains the importance of water to humans and why it is enshrined in the sustainable development goal.

Water as a universal solvent is able to dissolve most substances, some of which are harmful to living things beyond a certain threshold. These substances can change the levels of physicochemical and microbiological quality of water. Hussain et al. (2013) reported in their studies that physicochemical characteristics of water quality are deteriorating day by day owing to anthropogenic activities. Water quality is affected by increased human population, illegal mining or Galamsey, industrialization, overuse of fertilizers and weedicides in agriculture (Adu-Gyamfi et al., 2020). Rivers, lakes, streams and underground water which usually provide drinking water for most communities have become polluted because of increasing discharge of untreated industrial waste, run off from agriculture fields which contain residues of pesticides and fertilizers.

The use of unsafe drinking water has caused many communities to suffer from a variety of water borne diseases. All over the world, there has been an increase in water related diseases and deaths (WHO, 2004). It is estimated that about half of the world's hospital beds are occupied by patients suffering from diseases associated with lack of access to safe drinking water, inadequate sanitation and poor hygiene (UNICEF/WHO, 2008). It is therefore necessary for every human to consume safe drinking water.

The Government of Ghana, the World Health Organization (WHO), and the Embassy of the Kingdom of the Netherlands in Ghana convened a technical workshop on water quality, with a specific focus on water treatment and water, sanitation and hygiene (WASH) in health care facilities (HCF). The high level meeting highlighted and discussed new tools, data and approaches for addressing Sustainable Development Goal (SDG) 6 on safe water and sanitation and technical workshops to explore specific challenges, approaches and solutions for improving water quality in households and health care facilities (World Health Organization, 2018).

Despite governments efforts to provide safe drinking water for all, some communities do not have access to safe water in Ghana (Appiah et al., 2017). It is therefore appropriate to assess drinking water safety by checking its quality at regular time intervals. In assessing the quality of water for drinking, the physical, chemical and microbiological parameters of water must be measured (Diersing, 2009). The measurement of physical and chemical parameters like turbidity, dissolved oxygen, temperature, total dissolved solids, total suspended solids, pH, free carbon dioxide, total hardness, chlorides, alkalinity, phosphate, nitrites, sulphates, nitrates and bacteriological contaminants provide suitable information for determining the quality of water (WHO, 2011; Ghana Standard Authority (GSA), (2009). Medudhula (2012) asserted that good quality of water resources largely depends on physicochemical and biological characteristics.

The levels of these parameters in water must fall within an acceptable reference range prescribed by World Health Organization to indicate good water quality. This study will give a baseline data on bore-hole drinking water and help policy makers to improve quality and accessibility of potable water which will help reduce the incidence of water borne diseases in the East Akim Municipality.

1.2 Statement of the Problem

More than one billion people out of about seven billion people of the world's population, live without safe water (Sachs et el., 2019). This challenge is more pressing in Ghana, where about one-fifth of the country's population, or close to six million people rely on natural sources of water, leaving them vulnerable to water-related illnesses (Sachs et el., 2019). In the rural areas of Ghana, over 95% of improved water supplies intended for domestic purposes are groundwater supplies – primarily communal boreholes (BHs) (Awuah et al., 2009; Marks et al., 2014). Unfortunately, high levels of minerals and metals in groundwater may preclude extensive exploitation of some of these water sources (Awuah et al., 2009; Siabi, 2003).

In the Eastern Region of Ghana, drilling records indicate that 20–30% of rural boreholes have iron and manganese concentrations well in excess of the WHO water quality (WQ) guidelines (0.3 mg/L and 0.4 mg/L, respectively) (Siabi, 2003;), causing them to be abandoned or marginally used (Kulinkina et al., 2017; Siabi, 2004).

The Abuakwa North Municipal Assembly was carved out of the East Akim Municipal Assembly and established by L.I 2305 of 2017 with Kukurantumi as its capital. The Assembly was inaugurated on 1st June, 2018. (Abuakwa North District Assembly, 2019). The 2019 projected population for the Municipality stands at 101,831 at a growth rate of 1.9%. The youth constitute 35.9% of the entire population thus giving credence to the youthful nature of the municipal population while the workforce population is more than half (57.4%) of the population. (Abuakwa North District Assembly, 2019) According to Ghana Statistical Service (2015), agriculture is the mainstay of the municipal economy employing about 65% of the working population. Thus, more agro-chemicals are used in the municipality.

Water supply has fairly improved over the past few years in the Abuakwa North Municipality (Abuakwa North District Assembly, 2019). The people of Osiem and Anyinasin in the Abuakwa North Municipality have benefited from pipe-borne water and boreholes through the expansion of water distribution systems by the GWCL Network Extension Project. Access to water (in general) in the municipality stands at 72.3%. This means that, 72.3% of the population has continuous supply of sufficient water for drinking, personal and domestic hygiene. The rural water coverage is however a little lower and stands at 62% (Ghana Statistical Service, 2015). The report indicates that about 60% of households in the municipality either use bore-hole (30.4%), river/stream (15.9%) or protected well (13.7%) as the main source of drinking water. Even though water coverage may be high, the source and quality of drinking water available to the population is a worry to the Assembly because not all the sources are potable (Abuakwa North District Assembly, 2019).

In spite of the seemingly good picture of water supply painted by figures above, the capital of the municipality, Kukurantumi (and Tafo) has very limited access to water from the Ghana Water Company Limited. Most households have resorted to the construction of wells and at best boreholes for their water needs owing to their inability to afford and/or limited service lines. (Abuakwa North District Assembly, 2019).

In 2016 and in the first quarter of 2017, the turbidity level of the Birim was very high and the Ghana Water Company Limited was left with no option but to shut down operations after operating at half capacity with high input cost for over a year. The situation exposed residents to water-related diseases as most of them depended on water from streams for domestic uses (Abuakwa North District Assembly, 2019). Meanwhile, one of the cardinal principles of Ghana Water policy formulated in June 2007 states that people without prejudice have the right to safe and adequate supply of water to meet their fundamental human needs. This observation best explains why access to water for all is enunciated in the Sustainable Development Goals (SDGs), Ghana Poverty Reduction Strategy (GPRS), and the "Africa Water Vision" of the New Partnership for Africa's Development (NEPAD). (Ghana Water and Sanitation Sector Performance Report, 2010; Monney & Ocloo, 2017; Safe Water Network, 2020).

According to the June 2003 report of Well Resource Centre for Water, Sanitation and Environment and Environmental Health, incidences of water related diseases accounted for 70% of diseases in Ghana. Contaminants were therefore determined in well and bore hole water at various places in Ghana including the Eastern region. (Apau et al., 2014; Lutterodt et al., 2018; Nkansah et al., 2010; Saana et al., 2016). Shigut et al. (2017), were of the view that, for underground water to be used for drinking, its quality must be determined and monitored from time to time.

W. B. M. Zion S. H. S is situated in Old Tafo where the entire school community depends on borehole water. I (the researcher) observed that, about half of the student population complain of ‘itches and sore throat accompanied by fever’ at different times through the semester especially from March to July. This, I (the researcher) suspected to be caused by their drinking water. In a research conducted in the USA on drinking water, Methicillin-Resistant Staphylococcus Aureus (MRSA), a bacteria which causes sore throat was found in the water (LeChevallier & Seidler, 1980). Water of very low or high pH values can [also] burn mucous membranes of the throat and intestinal mucosa (Fatoki & Muyima, 2003) an effect similar to sore throat. Researchers conducted in Dodowa and Aburi in the Eastern region also found microbial levels of underground water to be higher than WHO standard for drinking water (Apau et al., 2014; Lutterodt et al., 2018). I also observed that, when water from the boreholes stands overnight, brownish precipitates form. I suspect that, these precipitates could be insoluble iron (III). This observation is in line with a report from the Municipal Assembly that, some of these boreholes have high iron content (Abuakwa North District Assembly, 2019) but the levels have not yet been determined. Review of literature on water quality showed that, there is little or no study done on the quality of borehole water in Tafo-Akim. These observations triggered the researcher’s curiosity to determine the correlation between the current observation and findings from previous researches. This present study, therefore seeks to determine and establish the quality of borehole water in Tafo-Akim.

1.3 Purpose of the Study

The purpose of the study is to determine the quality of borehole water in Tafo-Akim in the Eastern Region of Ghana.

1.4 Objectives of the Study

The specific objectives of the study are to:

- determine the physicochemical parameters of borehole water in Tafo-Akim.
- determine the level of heavy metals in borehole water in Tafo-Akim.
- determine the microbial levels of borehole water in Tafo-Akim.
- compare the levels of physicochemical, heavy metals and microbial parameters to the permissible values of Ghana Standard Authority and the World Health Organization.

1.5 Significance of the Study

The outcome of the study will be informative and useful enough for policy makers to develop proper policies towards the development of water resources in Abuakwa North and Ghana as a whole. Also, it will inform the Abuakwa North municipal assembly about the quality of water people use and assist in the provision of potable water in the municipality.

1.6 Abbreviations

BOD	Biological Oxygen Demand
BH	Borehole
COD	Chemical Oxygen Demand
GPRS	Ghana Poverty Reduction Strategy
GWCL	Ghana Water Company Limited
HCF	Health Care Facilities
MRSA	Methicillin-Resistant Staphylococcus Aureus
NEPAD	New Partnership for Africa's Development
SDG	Sustainable Development Goal
TDS	Total Dissolved Solid
UNICEF	United Nations International Children's Emergency Fund
WHO	World Health Organization
WASH	Water, Sanitation and Hygiene
WSP	Water Safety Plan

CHAPTER TWO

LITERATURE REVIEW

2.0 Overview

This chapter reviews literature on safe drinking water, groundwater, groundwater contamination, physicochemical, heavy metals and microbial parameters of drinking water, seasonal variations in Abuakua North municipality and instruments used in water quality determination.

The physicochemical parameters deal with temperature, turbidity, pH, metal ions, phosphates, nitrates, ammonia and sulphates while the microbial parameters deal with total coliform, faecal coliform, *E. coli* and Heterotrophic bacteria count.

2.1 Safe Drinking Water

Safe drinking water is the name given to water which is free from contamination by fecal matter and disease-causing organisms. Examples include Boreholes, treated pipe water, protected streams and rainwater (WHO, 2011).

Human beings need water to replenish the amount of water lost by the body through its normal activities. The availability of good drinking water is essential for humans' continuous existence (Sundar & Nirmala, 2015). Good drinking water is needed by man to ensure good health, proper sanitation and national development. Availability of safe and reliable source of water is an essential prerequisite for sustained population growth and development (Hunter et al., 2010). Provision of water for human consumption should be safe to make them healthy.

The WHO (2011) water quality guidelines defined Safe drinking-water, as water which does not pose any significant health risk to people over the period of consumption, not excluding different sensitivities which may be experienced by consumers. This suggests that the heavy metals, physicochemical and microbiological parameters of safe drinking water should not cause any undesirable condition or illness.

This implies that, safe water must be free from pathogens and harmful chemicals to prevent health problems (Lemo, 2002). According to WHO (2011), physical, chemical and biological parameters of drinking water must satisfy either WHO or national standards. The consequences of drinking unsafe, contaminated water are numerous and are still not fully understood (Saana et al., 2016). Consequently, many people have developed the taste for consuming packaged and bottled water because they have become conscious of their health and think that they are reliable and safe (Amit & Pankaj, 2016).

2.2 Groundwater

Groundwater refers to any surface water that occurs beneath the water table in the soil and other geological forms (Rail, 2000). The chemical composition is derived mainly from the dissolution of minerals in the soil and rocks with which it is or has been in contact.

The type and extent of chemical contamination of groundwater is largely dependent on the geochemistry of the soil through which the water flows prior to reaching the aquifers (Pradhan et al., 2022; Subba Rao, 2008). The chemical alteration of groundwater depends on several factors, such as interaction with solid phases, residence time of groundwater, seepage of polluted runoff water, mixing of groundwater with pockets of saline water and anthropogenic impacts (Fujita et al., 2013; Ansari & Umar, 2019).

Ghana's groundwater resources are made up of three geological formations with 54%, 45% and 1% for the basement complex (metamorphic rocks and crystalline igneous), the consolidated sedimentary formations, and the Cenozoic and Mesozoic sedimentary rocks, respectively (Ghana National Water Policy, 2007). Occurrence of groundwater in the basement complex is linked to the development of secondary porosity hence causing the fracturing, jointing, shearing and weathering (Ewusi et al., 2022).

Aquifer's depth normally ranges between 10 and 60 m with yields hardly exceeding 6 cubic metres per hour (Yeleliere et al., 2018). The Cenozoic and Mesozoic formations that usually occur in the extreme South Eastern and Western part of Ghana are also limestone aquifers with depth range of 120 to 300 m. The limestone aquifers have an average yield of about 184 cubic metres per hour (Ghana National Water Policy, 2007).

It is estimated that groundwater makes up 95% of all freshwater available for drinking and remain a significant source of municipal water systems. Rural residents draw water from boreholes/wells (Abinah, 2013). Unfortunately, dangerous chemicals, mainly organic substances and bacteria, contaminate the water we drink. Contamination of water is crucial to our survival and as such, can present significant health risk. The contaminants, many of which are undetectable by sight or taste, can lead to diseases ranging from asthma to the debilitating Parkinson's disease (Araya, 2022; Ramalingam et al., 2022; Zhang et al., 2022).

Research conducted in Accra-Ghana on groundwater used for sachet water ("pure water") by Kwakye-Nuako et al., (2007) indicated that:

> *"Seventy-seven percent (77%) of filtered underground water samples sold as sachet water that were analyzed contained infective stages of pathogenic parasitic organisms. Common pathogens and indicators identified included, Microsporidia spp. (51.2%), Cryptosporidium parvum (63.0%), Cyclosporacayetenens (59.3%), Sarcocystis spp. (66.7%), Rotifers (18.5%), and Charcoat Leyden crystals (evidence of allergies or parasitic infection) (44.4%). Ninety-three (93%) percent of the samples contained unidentified impurities/artifacts. A total of 29.6% of the samples contained at least one type of parasite, 14.8% contained at least two types of parasites, 25.9% contained at least three types of parasites, and 29.6% contained four types of parasites"*

2.3 Groundwater Contamination

Badeenezhad et al. (2020) asserted that two basic factors determine groundwater quality at a specified time. These are:

1. Quality of the infiltrated water – This includes recharging water (rain, dry deposition, evapotranspiration, surface water) as well as added substances (manure, fertilizers and organic contaminants).
2. Post-infiltration reactive processes – These can be split up into various geochemical processes, such as sorption (absorption and adsorption), redox reactions, buffering, degradation, dissolution, etc.

When the spatial distribution of groundwater quality is taken into account, a third factor is groundwater flow.

In a farming community like Tafo-Akim, groundwater contamination may likely stem from agricultural activities. Fertilizers, pesticides, herbicides and animal wastes all pose a potential threat to groundwater quality. For example, common problems include the spillage of fertilizers and pesticides during handling, runoff from the loading and washing of chemical application equipment, and the use of chemicals uphill from or within a few hundred feet of a well. Contamination may also result from the storage of chemicals in uncovered areas, or in locations where groundwater flows from the direction of the chemical storage to the well (Craig et al., 2008).

Fields with over applied or misapplied chemicals may introduce contaminants such as organic compounds, excess nitrogen, chloride, mercury and selenium into the groundwater. Runoff from animal waste may result in nitrate, coliform bacteria and sulphate contamination. Animal waste and feed fertilizer account for 75 % of the nitrogen and phosphorous content in US rivers, streams and lakes (Craig et al., 2008).

Another major source could be domestic activities. These sources include wastewater from toilets, sinks, showers, and washing machines which are collected in city sewer system. Septic systems are designed to slowly drain away human waste underground at a slow and harmless rate. An improperly designed, located, constructed or unmaintained septic system can leak bacteria, viruses and household chemicals such as paints, oils, detergents and other contaminants into the groundwater causing serious problems. Outflow from improperly functioning sewage systems and cesspools are a major cause of groundwater contamination (Badeenezhad et al., 2020). Residential wastewater can be a source of many types of contaminants, including bacteria, viruses, nitrates and organic compounds. If such chemicals are stored in basements or garages with floor drains, spillage may introduce these chemicals into the groundwater.

Landfills in the residential areas are another major source of contamination. Landfills are the places that our garbage is taken to be buried. The sites are supposed to have a protective bottom layer to prevent contaminants from getting into the water. However, if there is no layer or it is cracked, contaminants from the landfill (car battery acid, paint, household cleaners, etc.) can leach into the groundwater.

Location of boreholes should, thus, be far from any source of potential pollution to avoid water contamination (Akpoveta et al., 2011). Assessment of the type and loads of contaminants transported from landfill site to the adjacent aquifer and the extent of leachate plumes within the groundwater is used for site investigation and borehole positioning based on geophysical measurements and positioning based on the Bayesian expert system for flow field modeling (Abbaspour et al., 2000).

2.4 Water Quality

Water quality according to Diersing (2009) is the combined effect of water characteristics. To ensure water is of good quality there are several parameters that have to be considered. Some of these are the physical, chemical, heavy metals and microbiological parameters. Physical parameters include temperature, colour, total dissolved solids (TDS), electrical conductivity (EC), salinity, turbidity and total suspended solids (TSS). Chemical parameters include pH, alkalinity, total hardness, calcium hardness, magnesium hardness, chlorides, ammonia, nitrates, nitrites, sulphates, phosphates and cyanides. Heavy metals include iron, zinc, lead, manganese and copper.

The values for these parameters can be computed in several ways to show the suitability of water for a particular purpose. The computed value is known as water quality indicator. Water quality index (WQI) is one of the most effective tools used to ascertain the water quality (Banda & Kumarasamy, 2020). Water Quality Index (WQI) is a single number which can be calculated easily and used for overall description of the quality of water bodies. It provides a quick and simple methodology to identify the quality of water by only looking at a single aggregate value and the corresponding scale (Abbasi & Abbasi, 2012). The WQI method has been applied for different purposes, but mainly for surface water quality (especially for river water) (Ghimire et al., 2019; Ma et al, 2020; Nong et al., 2020), groundwater quality (Adimalla & Qian, 2019; Sahoo & Khaoash, 2020; Seifi et al., 2017) and wetland (Yousefi et al., 2018) across the world. Several researchers have used the WQI to assess quality of water resources elsewhere (Shamsudin et al., 2016). Every country is, however, using different WQI including Malaysia, Taiwan and Brazil (Suratman et al., 2015; Yap, 2013).

There are many techniques on water quality assessments and some of them are regression analysis, fuzzy reasoning, support vector machine (SVM) and artificial neural network (ANN) (Shamsudin et al., 2016). In all these techniques however, one thing is key. The physical, chemical, heavy metals and microbiological parameters of the water must be determined (Akter et al., 2016; Christine et al., 2018; Nkansah et al., 2010; William, 2014). This is in line with Medudhula (2012), who stated that safe water resources largely depend on physical, chemical, heavy metals and biological characteristics. Among all, ANN is the most popular technique in recent researches (Shamsudin et al., 2016).

In Ghana, however, the values of physical, chemical, heavy metals and microbial parameters are compared to Ghana Standard Authority (2009), water permissible guidelines which is in conformity with the WHO guidelines for drinking water quality. Ghana Standard Authority (GSA) is the regulating body ensuring that water companies comply with these standards. In this regard, the study will compare the physicochemical, heavy metals and microbial levels to GSA/WHO standard for drinking water.

2.5 Physical Parameters of Drinking Water

Measurement of the physical attribute of water can serve as indicators of some form of pollution. For example, changes in pH may indicate the presence of certain effluents like metals, while changes in turbidity may indicate dredging in the area (Kortatsi, 2007). When physical properties of water changes to the extreme (e.g., high turbidity and pH) it affects the palatability and acceptance as good drinking water (Twumasi, 2017).

Other commonly physical characteristics of water include temperature, colour, and total dissolved solids. Florez-Yepes et al. (2022), added that alteration of waters physical chemistry includes acidity, conductivity and temperature.

2.5.1 Temperature

Temperature a measure of how cold/hot a body is (Agudelo-Vera et al., 2020). Water temperature is critical because it is an important quality in environmental parameters. It is important to measure water temperature. By doing so, we can see the characteristics of the water such as the chemical, biological and physical properties of the water, as well as the possible health effects (Qin et al., 2017). Water temperature is an important factor in determining whether a body of water is acceptable for human consumption and use.

Temperature regulates the maximum dissolved oxygen concentration of the water. Temperature influences the rate of chemical and biological reactions. It affects the dissolved oxygen level in water and the sensitivity of parasites and disease (Qin et al., 2017).

Though WHO/GSA did not put much emphasis on temperature for drinking water, the aesthetic objective for water temperature in the Guidelines for Canadian Drinking Water Quality is 15°C (Dunn et al., 2014). The intensity of taste is greatest for water at room temperature and is significantly reduced by chilling or heating the water. Increasing the temperature will also increase the vapour pressure of trace volatiles in drinking water and therefore, could lead to increased odour (Herschy, 2012; Qin et al., 2017).

In the Water Quality Guidelines, it states, “the temperature dependence of most chemical reactions stems from the activation energy associated with them. The rates of chemical reactions decrease with decreasing temperature. The relative concentrations of reactants and products in chemical equilibria can also change with temperature. Temperature can, therefore, affect every aspect of the treatment and/or the delivery of water.” (APHA, 2005; Herschy, 2012).

2.5.2 Turbidity

Turbidity is the cloudiness or haziness of a fluid caused by individual particles (suspended solids). Turbidity in water may be caused by growth of phytoplankton, human activities which lead to high sediment levels entering water bodies during rain storms (USEPA, 2005).

Turbidity is an extremely useful indicator that can yield valuable information quickly, relatively cheaply and on an ongoing basis. Measurement of turbidity is applicable in a variety of settings, from low-resource small systems all the way through to large and sophisticated water treatment plants.

Turbidity, which is caused by suspended chemical and biological particles, can have both water safety and aesthetic implications for drinking-water supplies. Turbidity itself does not always represent a direct risk to public health; however, it can indicate the presence of pathogenic microorganisms and be an effective indicator of hazardous events throughout the water supply system, from catchment to point of use (Herschy, 2012).

Turbidity can be easily, accurately and rapidly measured, and is commonly used for operational monitoring of control measures included in water safety plans (WSPs), the recommended approach to managing drinking-water quality in the WHO Guidelines for Drinking-water Quality (WHO, 2017). It can be used as a basis for choosing between alternative source waters and for assessing the performance of a number of control measures, including coagulation and clarification, filtration, disinfection and management of distribution systems.

Turbidity is also an important aesthetic parameter. Turbidities of 4 nephelometric turbidity units (NTU) and above being visible, affects the appearance and acceptability of drinking-water to consumers (Herschy, 2012; Mathebula, 2015).

Although turbidity can be used in multiple ways within WSPs, this versatility can cause confusion and misinterpretation. Each of the relationships between turbidity and drinking-water quality is different and needs to be considered separately (Herschy, 2012).

2.5.3 Colour

The colour of water is affected by factors like the light source, absorption and scattering of light, as well as suspended materials in the water. Water colour can strongly be influenced by the presence of certain metallic substances such as manganese and iron compounds. Quality drinking water should be colourless (WHO, 2008). Colour and turbidity determine the depth to which light penetrates the water systems. It is important to investigate the quality of water if substantial colour change is observed (WHO, 2011). Slight discolouration is measured in Hazen units (HU) (ISO 2211).

Water which is coloured can pose adverse health effect on human beings as well as aquatic organisms. Clean water does not have colour and so the presence of any colour in water may suggest contamination (Department of Fisheries and Aquatic Sciences, 2004; WHO, 2011).

2.5.4 Total dissolved solids (TDS)

Total dissolved solids (TDS) represent the total concentration of dissolved substances in water. The degree to which these dissociate into ions, the amount of electrical charge on each ion, ion mobility and the temperature of the solution all have an influence on conductivity. Total dissolved solids (in mg/L) may be obtained by multiplying the conductance by a factor which is normally between 0.55 and 0.75. This factor is determined for each water body, but remains approximately constant provided the ionic proportions of the water body remain stable. The multiplication factor is close to 0.67 for water in which sodium and chloride dominate and higher for water containing high concentrations of sulphate (WHO, 2017).

The WHO guideline value for TDS is 1000 mg/L (WHO, 2017). Water with high dissolved solids can impart laxative effect on consumers (Putz, 2003). The author is also of the view that, consumption of water with high TDS may also lead to several diseases like nausea, lung irritation, rashes, vomiting and dizziness. Drinking water with elevated amount of TDS for longer periods may expose the body to various chemicals, toxins and may cause chronic health conditions like cancer, liver and kidney problems (Putz, 2003; WHO, 2011). Higher TDS concentrations often gives undesirable taste to drinking water by making it salty or bitter and also elevate scaling in distribution pipe lines, heaters and boilers (Gray, 2008).

Drinking water with high TDS concentration above 1000 mg/L often becomes objectionable to people (WHO, 2004). This implies that drinking water with TDS concentration below 1000 mg/L may be appreciated by consumers.

2.5.5 Total suspended solids (TSS)

Total suspended solids (TSS) refer to waterborne particles that exceed two (2) microns in size. Any particle that is smaller than two (2) microns, on the other hand, is considered a total dissolved solid. The majority of total suspended solids comprise of inorganic materials; however, algae and bacteria may also be considered TSS (Hassan et al., 2020). The composition of TSS may include sand, silt, clay, mineral precipitates and biological matter. TSS could be anything that floats or “suspends” in water, including sand, sediment and plankton. TSS formation primarily depends on physical processes driven by hydrology (Putz, 2003). Processes that generate TSS in streams include erosion of adjacent surface soils and stream banks, scouring of the streambed and aggregation of dissolved organic matter or chemical precipitation of inorganic solids within the water column (Department of Fisheries and Aquatic Sciences, 2004).

When certain water sources are contaminated with decaying plants or animals, the organic particles released into the water are usually suspended solids. While some sediment will settle at the bottom of the water source, other TSS will float on water's surface or remain suspended somewhere in between (Herschy, 2012). TSS affects water's clarity, so the higher a water's TSS content, the less clear it will be.

Water with high TSS can easily be detected and rejected by consumers. High concentrations can lower the water quality in the receiving environment. The suspended solids absorb light, causing increased water temperature and decreased oxygen in water (Hassan et al., 2020). WHO (2017), however sets a guideline value of 50 mg/L for TSS.

2.5.6 Electrical conductivity (EC)

Electrical conductivity refers to the measurement of both water salinity and its ability to conduct electricity. It gives a useful indicator of the mineralization and the pollution status of any water source (Jain et al., 2005). It depends on dissolved ions present in a solution. Principal ions involved are chlorides, phosphate, bicarbonates, sulphate, sodium, iron, calcium and magnesium. The electrical conductivity of water is temperature dependent and it is measured in (µS/cm) at 25 °C.

Natural background concentrations found in many fresh waters ranges from 10.0 – 300.0 µS/cm. Health effect associated with EC in drinking water can occur at levels as low as 370 µS/cm. However, water sources with electrical conductivity levels' exceeding 1000 µS/cm generally are regarded as polluted though no health-related conditions have been stated (Fatoki & Muyima, 2003).

2.6 Chemical Parameters of Drinking Water

Most chemicals arising in drinking water are of health concern only after extended exposure of years, rather than months. The principal exception is nitrate who's effect is noticed within days (Herschy, 2012). A few chemical contaminants have however, been shown to cause adverse health effects in humans as a consequence of prolonged exposure through drinking-water (EPA, 2003; Herschy, 2012).

Typically, changes in water quality occur progressively, except for those substances that are discharged or leach intermittently to flowing surface waters or groundwater supplies from, for example, contaminated landfill sites (Herschy, 2012; Mathebula, 2015; William, 2014).

In some cases, there are groups of chemicals that arise from related sources – for example, agricultural or disinfection byproducts (DBPs) (Herschy, 2012). In this study, only chemicals which may result from agricultural activities and landfills will be considered.

2.6.1 pH

pH is the most commonly measured attribute of water. The concentration of hydrogen ion (H^+) activity in a solution defines the pH. Thus, it is a measure of the acidity or alkalinity of a solution. pH is measured on a scale of 0 to 14. Acidic water has pH values less than 7, with 0 being the most acidic. Basic water has a value likewise greater than 7, with 14 being the most basic. The pH of most natural water ranges from slightly acidic (6.0) to slightly basic (8.5). If a stream water has a pH less than 5.5, it may be too acidic for fish to survive in, while stream water with pH greater than 8.5 may be too basic (WHO, 2004). Water with high or extremely high or low pH is deadly as it has been established that pH below 4 or above 10 will kill most fish and very few animals can tolerate water with a pH of 3 or above 11 (Gensemer, 2018; Messner & Loftsson, 2010).

The acidity of groundwater is due to the presence of organic acids in the soil as well as those of atmospheric origin infiltrated to the water (Suponik et al., 2022). Acid rain contains dissolved carbon dioxide (CO_2), nitrogen dioxide (NO_2) or sulphur dioxide (SO_2) often yields an elevated hydrogen ion (H^+) concentration and carbonic acid (H_2CO_3) and may cause serious threat to groundwater pH (Li, 2022). The pH of rainwater is about 5.7 (Schmitz & Schnabel, 2022; Zhongming et al., 2021). Increase in acidity is also attributed to the oxidation of reduced sulphur compounds in the soils of the areas (Efe et al., 2005).

The ideal pH level of drinking water should be between 6.5 and 8.5 (WHO, 2017). Water with pH less than 6.5 is acidic, soft and corrosive. Acidic water could contain metal ions such as iron, manganese, copper, lead and zinc (Ibrahim, 2016). pH of water determines the solubility (amount of solute that can be dissolved in water) and biological availability of chemical constituents and heavy metals.

According to Islam et al. (2017), no health-based guide is proposed for pH, although eye irritation and exacerbation of skin disorders have been found to be associated with pH values greater than 11 (WHO, 2004). pH levels below 6.5 means the water is acidic and this could pose health risks to consumers (Boakye, 2013). Fatoki & Muyima (2003), are in agreement that, water at very low values can burn the mucous membranes of the throat and intestinal mucosa an effect similar to sore throat. The WHO (2017), guideline for pH of drinking water is 6.5 - 8.5.

2.6.2 Alkalinity

The measurement of the buffering capacity of water is known as its alkalinity. Alkalinity gives information about the ability of water to maintain its pH upon the addition of acids or bases (Boyd et al., 2016). Alkalinity acts as a buffer and prevents the water from abrupt changes in pH which can be detrimental for the desired use. This ability to neutralize acid, or H^+ ions, is particularly important in regions where acid rain is a problem. The dissolution of chemical components of certain rocks like limestone generates carbonate (CO_3^{2-}) and bicarbonate (HCO_3^-) ions in water to form the major source of alkalinity in water. Regulation of alkalinity level in drinking water improves taste and appearance. Higher levels of alkalinity can facilitate corrosion in distribution lines thereby contaminating drinking water (WHO, 2008). Alkalinity has a guideline value of 120 mg/L (WHO, 2017; GSA 2009).

2.6.3 Magnesium

Magnesium is found naturally in minerals like epsomite, magnesium limestone, and magnetite. The dissolution of these minerals liberates magnesium into water. Water usually contains more calcium than magnesium since magnesium is less both in terms of abundance and quantity. In surface waters, magnesium aluminosilicates can decompose to release magnesium into solution. Magnesium is an important nutrient required for proper functioning of the body. For instance, it serves as a cofactor for more than 350 enzyme reactions; many are used for energy metabolism as well as in the synthesis of nucleic acid and proteins (Kožíšek, 2003). Magnesium level in humans can be influenced by water consumption. When drinking water that contains high amount of magnesium and sulphate is consumed (usually above 250 ppm) possible laxative effect may be experienced by consumers (WHO, 2011).

Epidemiological studies indicated a relationship between hypertension and cardiac disease with the intake of "soft water" – less magnesium consumption (Geleijnse et al., 2005). On the other hand, "hard water" with higher concentration of magnesium, protects the body against cardiovascular disease. There is no health-based quantity for the consumption of magnesium since scientists have not recorded any hazard related to magnesium toxicity. Like calcium, magnesium contributes to water hardness. The WHO (2017) maximum guideline value for magnesium contaminant level is set at 500 mg/L.

2.6.4 Hardness

Water hardness is determined by the concentration of multivalent cations in the water. Common cations found in hard water include calcium (Ca^{2+}) and magnesium (Mg^{2+}) ions. These ions enter water supply by leaching from minerals within an aquifer. Hardness is most commonly expressed as mg/L of $CaCO_3$. The following equilibrium reaction describes the dissolving or formation of calcium carbonate scales:

$$CaCO_3 + CO_2 + H_2O \leftrightharpoons Ca^{2+} + 2HCO_3^-$$

Calcium carbonate scales formed in water-heating systems are called lime scale (Weingärtner, 2006; Yousefi et al., 2019).

Water can be classified on the basis of hardness into the following categories, soft water which has between 0-75 mg $CaCO_3$ per litre, moderately hard water (75-150 mg/L), hard water with about 150-300 mg $CaCO_3$ per litre and very hard water with over 300 mg/L of $CaCO_3$ per litre of water (Shelton, 2000). Temporary hardness of water is caused by the presence of dissolved bicarbonate minerals (calcium bicarbonate and magnesium bicarbonate). When dissolved, these minerals yield calcium and magnesium cations (Ca^{2+}, Mg^{2+}) and carbonate and bicarbonate anions (CO_3^{2-}, HCO_3^-). The presence of the metal cations makes the water hard. However, unlike the permanent hardness caused by sulphate and chloride compounds, this "temporary" hardness can be reduced either by boiling the water, or by the addition of lime (calcium hydroxide) through the process of lime softening. Boiling promotes the formation of carbonate from the bicarbonate and precipitates calcium carbonate out of solution, leaving the water soft (Yousefi et al., 2019). Permanent hardness cannot be removed by boiling. Despite the name permanent, the hardness of the water can easily be removed using an ion exchange column.

Water should have a total hardness of less than 75 to 85 mg/L as $CaCO_3$ and a magnesium hardness of less than 40 mg/L as $CaCO_3$ to minimize scaling at elevated temperatures. Calcium and magnesium are important minerals in body building. They are required for building strong bones and teeth as well as supporting newly fertilized freshwater fish eggs (Timmons *et al.,* 2002). Total hardness below 200 mg/L is accepted by consumers and do not make complains. Although there is no proposed health-based guideline value for hardness in drinking-water (WHO, 2011), the permissible value for total hardness was set at 500 mg/L (WHO, 2017).

2.6.5 Ammonia (NH_3)

The term ammonia as applied to water quality and treatment includes the non-ionized (NH_3) and ionized (NH_4^+) species (Herschy, 2012). Ammonia exists in solution as Ammonium. Ammonium is present in groundwater naturally as a result of anaerobic degradation of organic matter and artificially as a result of organic waste disposal. Anthropogenic NH_4^+ is one of the major dissolved components in some types of groundwater contaminant plumes. NH_4^+ concentrations of the order of 1–10 mmol/L have been observed in aquifers contaminated by landfill leachate and concentrated wastewater disposal practices (Brennan et al., 2017; Cozzarelli et al., 2000; Christensen et al., 2001). Septic systems and agricultural practices also may result in locally elevated recharge rates of NH_4^+. NH_4^+ in aquifers can cause degradation of groundwater quality and usability. It can have substantial effects on water-rock interactions and it can be a substantial source of nitrogen (N_2) in surface waters receiving groundwater discharge. Despite the environmental importance of NH_4^+, there are few studies documenting NH_4^+ transport and reaction processes in aquifers (Cozzarelli et al., 2000).

Ammonium movement may be retarded by physical-chemical processes such as sorption (including cation ex-change), or biological processes such as microbially induced transformations, depending on aquifer geochemistry and the nature of the groundwater flow system. Retardation of NH_4^+ transport has been observed in contaminated groundwaters (Lutz et al., 2020), and it may lead to much longer aquifer flushing times for NH_4^+ than for other more mobile aqueous species, with relative retardation factors potentially ranging over 3 orders of magnitude (100 to 103) (Silver et al., 2018).

Ammonium oxidation occurs commonly in conjunction with oxygen (O_2) reduction (nitrification) and possibly may be associated with Mn-oxide reduction (Li et al., 2021; Zhang & Furman, 2021). Nitrification results in production of NO_2^- followed by NO_3^-. Due to this, there is a high correlation between ammonia, nitrate and nitrite as a result of nitrification (Yin et al., 2022).

A health-based guideline has not been developed for ammonia levels in drinking water (Cordner et al., 2019). However, the World Health Organization suggests that at a concentration above 1.5 mg/L, ammonia can cause odour and taste problems (Herschy, 2012; WHO, 2017). Ammonia can also compromise disinfection efficiency, increase oxidant demand, cause the failure of filters for the removal of manganese, and corrode copper alloy pipes and fittings. Moreover, a major concern with ammonia in drinking water is nitrification associated with the formation of nitrites and nitrates (Water Security Agency, 2012).

2.6.6 Nitrate and Nitrite

Nitrate (NO_3^-) and nitrite (NO_2^-) are interconvertible through reduction-oxidation processes. Nitrite is not usually present in significant concentrations except in a reducing environment where the nitrite is the more stable oxidation state. Nitrite can be formed by the microbial reduction of nitrate and by reduction from ingested nitrate (Herschy, 2012). Nitrite can also be formed chemically in distribution pipes by *Nitrosomonas* bacteria during stagnation of nitrate containing and oxygen-poor drinking water in galvanized steel pipes or if chloramination is used to provide a residual disinfectant (WHO, 2011).

Nitrate contamination of groundwater results from leaching of fertilizer, septic tank leachate, unsewered sanitation, pit latrines, animal waste or human waste mineralization of decomposing or oxidation of decaying matter by soil micro-organisms (Margalef-Marti et al., 2021; Shukla & Saxena, 2020; Suthra et al.,2009). Unutilized urea leached into groundwater for micro-organisms to degrade is also another source of groundwater nitrate (Singh et al, 2012). According to the United States Geological Service (USGS) (2012), nitrate concentrations of greater than 3mg-N/L indicate a fairly direct connection of water with source of pollution (Lins, 2012).

Nitrate can readily be transported beneath the soil zone because it is relatively soluble and not prone to ion exchange (Masoud & El-Magd, 2022). Nitrate can be endogenously reduced to nitrite, which can then undergo nitrosation reaction in the stomach with amines to form a variety of N-nitroso compounds (NOC). These compounds are carcinogens, thereby causing health hazards like impairing the ability of the blood to carry oxygen (Blue-baby syndrome or infantile methemoglobinemia), gastrointestinal cancer, Alzheimer disease, vascular dementia, adsorptive secretive functional disorders of the intestinal mucosa, multiple sclerosis, non-Hodgkin's lymphoma and hypertrophy of thyroid (Sinha et al., 2021; Suthra, 2009). In Aarlborg Denmark, water had a relatively high nitrate content of about 30mg/L and there was a slightly greater frequency of stomach cancer (Manyama, 2018). Nitrate contamination can be treated by technologies such as ion exchange; denitrification and reverse osmosis or anaerobic reduction in the subsurface which can limit nitrate contamination of groundwater (Bishayee, et al., 2022).

Nitrite ions present in water constitute primary toxicity to humans. Methaemoglobinemia which occurs through the oxidation of normal haemoglobin in the presence of these ions (nitrite and nitrate) to produce methaemoglobin is of health concern, especially to children (WHO, 2017). This disrupts the blood's ability to transport oxygen to the body tissues. More serious conditions due to nitrate intoxication are cyanosis, asphyxia, gastric and colo-rectal cancer (Uba & Aghogho, 2001). The WHO safety drinking water guideline value for nitrate-nitrogen is 10 mg/L while that of nitrite-nitrogen is 1 mg/L (WHO, 2017; Health Canada, 2013).

2.6.7 Sulphate

Sulphate is found almost universally in natural waters at concentrations ranging from a few tenths to several thousand milligrams/liter (mg/L). Sources of sulphate in natural water systems can be from industrial wastes such as mining, from wood preservation and acid rain. WACAM (2008), stated that the major sources of sulphates in water comes from the dissolution of natural minerals like barite ($BaSO_4$), epsomite ($MgSO_4 \cdot 7H_2O$) and gypsum ($CaSO_4 \cdot 2H_2O$). The highest concentrations are usually found in groundwater and are considered to be a mixture of sulphates from atmospheric, geochemical and biological sources (EPA, 2003). Approximately 30% of sulphate in groundwater may be of atmospheric origin, and the remainder from geological and biological processes (Sharma & Kumar, 2020). Sulphates are discharged into surface water through industrial wastes and atmospheric deposition of Sulphur dioxide (Torres-Martínez et al., 2020).

Drinking water should have sulphate concentration below 250 mg/L since there is likelihood of causing purgative effect in humans at levels above this value (WHO, 2017). However, natural background levels of sulphates in most water sources are always very small and vary between 0.1 to 10 mg/L (Herschy, 2012). The large intake of sulphate can have some undesirable physiological effects like dehydration, gastrointestinal irritation and catharsis. In addition, excess Sulphate may also contribute to hardness of water and cause corrosion of drinking water distribution systems. Under anaerobic conditions, sulphate in water may be reduced to H_2S and this can give the water source an unpleasant or rotten egg smell (WHO, 2017).

2.6.8 Phosphate

Phosphate exists in three forms in water; orthophosphate, metaphosphate (or polyphosphate) and organically bound phosphate. Each compound contains phosphorus in a different chemical state. Organic phosphates are important in nature. Their occurrence may result from the breakdown of organic pesticides which contain phosphates. Phosphates enter water ways from human and animal wastes, phosphorus rich bedrock, industrial effluents and fertilizer runoff from agriculture (Ghazali et al., 2013; Teodorescu et al., 2009; Wimalawansa, 2016).

Phosphates are not toxic to humans or animals unless they are present in very high levels, which could cause digestive problems (www.waterresearch.net). Phosphate occurs naturally in trace amounts in waters but often in appreciable amounts during periods of low biological productivity. Traces of phosphate can result in algal blooms in water reservoirs (Putz, 2003). Phosphates are water treatment chemicals used to solve specific water quality problems resulting from inorganic contaminants (iron, manganese, calcium, etc.) in groundwater supplies and also to maintain water quality (inhibit corrosion, scale, biofilm, reduce lead and copper levels) in the distribution system. The guideline value for phosphate in drinking water is 0.30 mg/L (WHO, 2017).

2.6.9 Cyanide

Cyanides can be found in some foods, particularly in some developing countries, and they are occasionally found in drinking-water but usually only at very low concentrations (Herschy, 2012). However, there are occasions where large spills of cyanide, from industry, occur and these can give rise to very high concentrations in drinking-water source waters, particularly surface waters (Ritter et al., 2002).

Cyanide is highly acutely toxic. It is detoxified in the liver by first-pass metabolism following oral exposure. As a consequence, exposure to a dose spread over a longer period, through a day, for example, will result in lower toxicity, or higher tolerance, than the same dose given in a single bolus dose (Herschy, 2012). Exposure to high doses can give rise to thyroid toxicity as a secondary effect of exposure due to the inhibition of iodine uptake from the thiocyanate generated through the detoxifying action of rhodanese (IPCS, 2004; WHO, 2017). It is difficult to interpret human data in view of the difficulty in assessing the actual absorbed dose in humans following acute fatal intoxication and the lack of well-conducted studies on sublethal toxicity (Herschy, 2012).

There is the need for guidance regarding concentrations that would not be of concern for public health following short-term exposure to cyanide. However, because cyanide is unlikely to occur in drinking-water at concentrations of health concern, it is considered unnecessary to derive a formal guideline value for short-term exposure to cyanide (Herschy, 2012).

It should be noted that the lowest reported odour threshold for cyanide in drinking-water is 0.17 mg/L, which is below the short-term health-based value (Herschy, 2012). Cyanide is described as having a “bitter almond” (and sometimes a pungent) smell. It is therefore possible that a small number of individuals will detect cyanide by odour at concentrations below the health-based value (WHO, 2008).

The health-based value relates to total cyanide concentration at the tap, including cyanide from cyanogen chloride in drinking-water as a by-product of disinfection with chlorine. Cyanogen chloride rapidly breaks down to cyanide in the distribution system or when ingested. As the low levels of cyanide normally found in drinking-water are mostly a consequence of the presence of cyanogen chloride, it is not considered necessary to develop a guideline value for long-term exposure to cyanide (WHO, 2011). However, it is recommended that, people should not consume water with cyanide concentration above 0.50 mg/L for more than 5 days.

2.6.10 Chlorides

One of the minerals that contribute largely to the presence of chloride in the earth crust is halite ($NaCl$) formed mainly from evaporation of sea water. Other salts that contribute to chloride ions in small quantities are potassium chloride (KCl) and calcium chloride ($CaCl_2$). The dissolution of these salts in water generates chloride ions in water. Human waste, agriculture fertilizers and industrial discharges also introduce some chloride ions in varying degrees into water bodies. Chloride is not poisonous to humans but at high concentration, it can impart salty taste and cause corrosion problems in drinking water supply lines.

The corrosion rate of metals in the distribution system increases at elevated chloride levels. Chloride ions enhance electrical conductivity of water and increase its ability to corrode metals (WHO, 2008). Scientists have less knowledge about the consequences of prolonged intake of large amounts of chloride. The presence of chloride ion in underground water could however be a likely indication of faecal pollution (Ahmed et al., 2008). Chloride taste is detected in water at concentration exceeding 250 mg/L. It is therefore accepted that chloride concentration in drinking water should not be more than 250 mg/L (WHO, 2017).

2.7 Heavy Metals

Heavy metals are a class of ill-defined subset of elements that exhibit metallic properties (Singh, 2007). Certain heavy metals in small quantities are nutritionally essential for a healthy life. Some of these elements such as iron, copper, manganese, and zinc, are commonly found naturally in foodstuffs, fruits and vegetables, and in commercially available multivitamin products. Heavy metals are used for making metal alloys and pigments of paints, cement, paper and rubber. All metals are toxic at higher concentrations (Malik, 2021).

Advancement in technology had led to high level of industrialization leading to discharge of heavy metals into our environment (Abidemi, 2011). Heavy metals have high density and a specific gravity 4 times greater than water. Density of a heavy metal is the mass per unit volume of the heavy metal. Specific gravity is a measure of density of a given amount of a solid substance when it is compared to an equal amount of water. Some well-known toxic metals with a specific gravity 5 or more times that of water are cadmium (8.65), iron (7.9) and lead (11.34) (Adimalla & Qian, 2019; Sahoo & Khaoash, 2020; Seifi et al., 2017).

Heavy metals once released into the environment can remain in waterways for decades or even centuries, in concentrations that are high enough to pose a health risk. Several methods are used to clean up the environment from these kinds of contaminants, but most of them are costly and difficult to get optimum results. Currently, phytoremediation is an effective and affordable technological solution used to extract or remove inactive metals and metal pollutants from contaminated soil and water. This technology is environmentally friendly and potentially cost effective (Tangahu *et al*., 2011).

In the Eastern Region, drilling records indicate that 20–30% of rural boreholes have iron and manganese concentrations well in excess of the WHO water quality (WQ) guidelines (0.30 mg/L and 0.40 mg/L, respectively) (Siabi, 2003; Siabi, 2004;

Kulinkina et al., 2017). Analysis of River Densu also in the Eastern region indicates copper levels above WHO permissible level (Duncan et al., 2019). In line with this observation, the study will focus on only iron, copper and manganese in the borehole water in the Tafo-Akim in the Eastern region.

2.7.1 Total Iron

Iron is not toxic, but imparts objectionable taste to water and may leave brown stains on porcelain and clothing. Objectionable taste is due to reduced form (Fe^{2+}). On exposure to air, water becomes reddish brown due to ferric hydroxide and prolonged consumption of such water may lead to liver disease (Ranjana, 2010). The largest contributors of iron in groundwater are minerals contained within the underlying bedrock, soil and sand. The most common is iron (II) ion (Fe^{2+}). Limestone, shale and coal which often contain the iron rich mineral pyrite which is the major source of iron in groundwater. Acidic rain also releases iron into groundwater (Breward, 2003; Idoko, 2010). Iron content increases with depth (Nayak et al., 2002).

An aquifer in which groundwater is in a mildly oxidized state and a near neutral pH, the most likely Iron is Fe^{3+} and is tied up in the solid phases (Breward, 2003). At a given temperature changing from their oxidized form / giving up of electrons (Fe^{3+}) to the reduced (accepting electrons) form requires a decrease in redox potential (dissolved oxygen) or a decrease in pH. Reduction / treatment of iron by using a water softener, Potassium Permanganate or green sand filters and aeration (addition of oxygen to water) all aid in precipitation of Iron.

Salts may be concentrated in the groundwater as result of evaporation and transpiration. This depends on the vegetative cover, warmth, soil type, and climate (Xin et al., 2022). Ferric salts are regarded as skin irritants. Early symptoms of acute iron toxicity include diarrhoea, sometimes containing blood, fever, nausea, severe stomach pain or cramping, sharp vomiting, sometimes containing blood. Late symptoms of acute iron toxicity include bluish-coloured lips, fingernails, palms of hands; drowsiness; pale, clammy skin; seizures; unusual tiredness or weakness; weak and fast heartbeat (Mirlohi et al., 2011; Rahman et al., 2021).

Water containing iron has the ability to promote the growth of iron bacteria which obtain their energy through the oxidation of ferrous iron to ferric iron and in the process deposit a slimy coating on the piping. When the Iron concentration in water is above 0.30 mg/L, it is able to stain laundry and plumbing fixtures (WHO, 2008).

2.7.2 Manganese

Manganese is an element that occurs naturally and can be found ubiquitously in the air, soil, and water. The concentration of manganese in borehole (underground) water can fluctuate seasonally and vary with the depth and location of the borehole and the geology of an area. Manganese naturally occurs in underground water that has little or no oxygen, in areas where groundwater flow is slow and in areas where groundwater flows through soils rich in organic matter (Kousa et al., 2021; Zhang et al., 2020). It is one of the important elements needed to maintain the health of humans and animals (U.S. EPA, 2003a).

Manganese is not available in pure state, but it exists in more than 100 minerals (ATSDR, 2000). Manganese as an essential nutrient is required in low doses since continual exposure to high doses may be detrimental to health. In drinking water supplies, the presence of manganese at levels above 0.1 mg/L imparts undesirable taste in beverages and stains sanitary ware and laundry (Ali, 2021; Singh, 2021). Manganese precipitated from the oxidation of manganese (II) compounds may accumulate as deposits in distribution systems. The acceptable concentration of manganese in drinking water is set below 0.40 mg/L. In pipe distribution systems, manganese can form coatings which may slough off as black precipitate when its concentration in water is 0.20 mg/L. The health-based value of 0.30 mg/L for manganese is lower than this acceptability threshold of 0.40 mg/L (WHO, 2017; WHO, 2021).

2.7.3 Copper

Copper is both an essential element and a drinking water contaminant (Herschy, 2012). The concentration of copper in water varies widely with the primary source most often being the corrosion of interior copper plumbing. Levels in running or fully flushed water tend to be low, whereas those in standing or partially flushed water are more variable and can be substantially higher (frequently > 1 mg/L) (Harvey et al., 2016; Herschy, 2012).

General corrosion is most often associated with soft, acidic waters. Water with pH below 6.5 and hardness of less than 60 mg of calcium carbonate per litre are very aggressive to copper. Copper, like lead, can enter water by dissolution of the corrosion product in the form of basic copper carbonate (Herschy, 2012).

Decades of study indicate that oral exposures of copper are typically not a human health concern. Ingesting high levels of soluble copper salts can cause acute gastrointestinal symptoms and in uncommon cases, liver toxicity in susceptible individuals with repeated exposure (Taylor et al., 2020). Recent studies have delineated the threshold for the effects of copper in drinking water on the gastrointestinal tract, but there is still some uncertainty regarding the long-term effects of copper on sensitive populations such as carriers of the gene for Wilson disease and other metabolic disorders of copper homeostasis. (Angelova et al., 2011; Taylor et al., 2020). The guideline value for copper is 2.0 mg/L (WHO, 2017).

2.8 Microbial Parameters of Drinking Water

Infectious diseases caused by pathogenic bacteria, viruses and parasites (e.g., protozoa and helminths) are the most common and widespread health risk associated with drinking water. The public health burden is determined by the severity and incidence of the illnesses associated with pathogens, their infectivity and the population exposed (Christine et al., 2018; Herschy, 2012; Lutterodt et al., 2018).

In some cases, low-level, potentially repeated contamination may lead to significant sporadic disease, but public health surveillance is unlikely to identify contaminated drinking water as the source (Herschy, 2012). There are many microorganisms associated with water quality but for the purpose of this study, only the common ones will be analysed. These are the total coliform, feacal coliform, *Escherichia coli* and heterotrophic bacteria (Lutterodt et al., 2018; Nkansah et at., 2010; Saana et al., 2016).

2.8.1 Total and Faecal coliforms

According to Bodoczi (2010), the sanitary quality of water is appreciated by the presence or absence of pathogenic micro-organisms indicated by presence of coliforms. There is practically no geological environment at or near the earth's surface where pH will not support some form of organic life, also at the depth that water pressures are not high enough to deter microbial activity (Du et al., 2021; Reddy et al., 2021; Summons et al., 2021). Pathogenic bacteria can survive long underground and may have a life span of about 4 years (Mazurkiewicz et al., 2022).

Coliform group of bacteria are a large group of disease-causing bacteria that inhabit intestine of man and animals (Thakur et al., 2012).

Prescence of faecal Coliform is the most reliable indicator of faecal bacterial contamination of surface and groundwater waters in different countries (WHO, 2017). Faecal coliform bacteria are bacteria found in faeces. They are a subset of a larger group of organisms known as coliform bacteria which are facultative anaerobes that can survive in the absence of oxygen. They are gram negative, non-spore forming, rod-shaped bacteria that ferment lactose, producing carbon dioxide gas and acid at temperatures of about 35°C. Human waste contaminant in water causes water borne diseases such as diarrhoea, typhoid, hepatitis and flu-like symptoms such as nausea, vomiting and fever (Abdulla, 2021; Kumar et al., 2020; Patra & Mukherjee, 2019). High coliform counts in water samples are an indication of poor sanitary conditions in the community.

According to Adekunle et al. (2007), and Kumar et al. (2020), inadequate and unhygienic handling of solid wastes in the rural and urban areas leads to high concentrations of microbial organisms. In 2006, the Environmental Protection Agency (EPA) published the groundwater rule in the United States to keep microbial pathogens out of public water sources to reduce incidence of diseases associated with disease causing micro-organisms (Gross et al., 2013).

2.8.2 Escherichia coli

Escherichia coli (*E. coli*) is a gram-negative rod-shaped bacterium that is commonly found in the lower intestines of warm-blooded organisms. *E. coli* and related bacteria constitute about 0.1% of gut flora (Osei, 2015) and faecal oral transmission is the major route through which pathogenic strains of the bacterium causes diseases. Cells are able to survive outside the body for a limited amount of time which makes them ideal organisms to test environmental samples for faecal contamination. *E. coli* can be differentiated from other thermotolerant coliforms by their ability to produce indole from tryptophan or by the production of the enzyme β-glucuronidase (Maarit Niemi et al., 2003; Pant, 2004; Zhurbenko et al., 2017).

E. coli is present in very high numbers in human and animal faeces and is rarely found in the absence of faecal pollution. It is considered the most suitable index of faecal contamination and as such it is the first organism of choice in monitoring programmes for verification, including surveillance of drinking water quality (Ashbolt et al., 2001). Water temperatures and nutrient conditions present in potable water distribution systems are highly unlikely to support the growth of these organisms (Gabrielli et al., 2021; Nowicki et al., 2021).

The table below shows the plate count of microbial level of water and their associated risk according to WHO (2011).

Table 1: Water Quality counts per 100 mL and the Associated Risk

Count Per 100 mL	**Risk Category**
0	In conformity with WHO guidelines
1 – 10	Low risk
11 – 100	High risk
> 100	Very high risk

Source: WHO (2011)

2.8.3 Heterotrophic bacteria

Heterotrophs are a group of microorganisms (yeast, moulds & bacteria) that use organic carbon as food (as opposed to autotrophs like algae that use sunlight) and are found in every type of water (Sharma et al., 2022). Detecting heterotrophs in water is done by using a method called Heterotrophic Plate Count (HPC) (Bartram et al., 2003). HPC, also known as Standard Plate Count, is used to measure bacteriological quality or drinking water in public and private water systems (Herschy, 2012).

HPC reflects the load of general aerobic bacteria in the water system. Although HPC was used in the late 1800s to assess the "purity" of source water (Bartram et al., 2003), it is no longer used as a health-related indicator. Today, significant changes in HPC serve as an alert for possible deterioration of water quality, triggering further investigation (Herschy, 2012).

Most heterotrophic bacteria present in water poses no health risks to humans but a high HPC count is an indicator for ideal conditions for the growth of bacteria (Vukić Lušić et al., 2021). This can be a breeding ground for more dangerous bacteria, such as Legionella or E. Coli, which cause foul-tasting water and lead to corrosion or slime growth in pipes (Herschy, 2012). According to the author, *Aeromonas spp.*, a heterotrophic bacterium, are generally readily found in most fresh waters, and they have been detected in many treated drinking water supplies, mainly as a result of regrowth in distribution systems. They are detected by HPC, which can be used together with other parameters such as disinfectant residuals to indicate conditions that could support growth of these organisms.

Aeromonas spp. can cause infections in humans, including septicaemia, particularly in immunocompromised patients, wound infections and respiratory tract infections.

There have been some claims that *Aeromonas spp*. can cause gastrointestinal illness, but epidemiological evidence is not consistent (Herschy, 2012).

2.9 Effects of Seasonal Variations

Seasonal variations change the aesthetic quality of the water and bring discomfort amongst consumers. Seasonal variations in water quality arise due to variations in ecological activity and geology of the area. Artesian boreholes / rock wells constructed in unconsolidated sediments tend to respond slowly to rainfall, possibly several days or weeks later because of the poor permeability of the confining layer (El Abd et al., 2020; Sammy, 2019). When boreholes penetrate fractured material in an area of thin overburden, they respond quickly to percolated water from the rain (Singh et al., 2012). The eco-system, characteristics of the surrounding area, residence time and geological characteristics affect the heavy metal concentration, physicochemical and micro-biological seasonal variations of groundwater parameters (Howarth & McGillivray, 2001; Mor et al., 2006). Due to this, samples for analysis were taken in the dry and raining seasons.

In the Eastern region of Ghana, the first rainy season starts from April to July and a second rainy season in September and October while the dry season starts from December to March with January recording the least rainfall (Gbangou et al., 2020; World Bank, 2011). Based on this, the first sampling was done in July, the first raining season and the second one in March, the dry season.

2.10 Instrumentation

Recently, there are a wide variety of water contaminant detection technique such as sample-based method and microwave sensor-based method. Sample-based water contaminant detection method has been introduced since 1917s which involved the use of international standard laboratory instruments in a laboratory that is manually handled by a group of trained and skillful technicians or laboratory assistants (Ong & Yee, 2020). The conventional laboratory techniques usually involve laboratory and potable testing kits. Microwave sensor-based method involved the use of smart sensor to monitor water quality (Banda & Kumarasamy, 2020; Ong & Yee, 2020). This model has been adopted in various water contaminants detection which include water quality sensor, microfluidic sensors and spectroscopy techniques.

Water quality sensor has been introduced since early 1900s (Ong & Yee, 2020). Ong & Yee (2020) and it is suitable when resources are limited since it requires less time, simple to use and low-cost testing method. Furthermore, a water quality sensor with simple testing methods enables the on-site water testing without sending the samples to the commercial laboratories (Illangasekare et al., 2018). Despite its popularity, however, microwave sensor has its downsides as it is less precise and less accurate compared to the lab-based method. Hence, the laboratory assistants and other professionals will need to consider the sensitivity and accuracy of the selected microwave sensor during water testing (Ong & Yee, 2020). This suggests that, there is a collection of instruments or methods which can be used to measure any single parameter.

Now a days, several types of detection techniques for metal ions in drinking water samples are available like Atomic Absorption Spectroscopy (AAS), Flame Emission, Vapour Generation Accessory (VGA), Graphite Tube Atomizer (GTA), Inductively Coupled Plasma Emission, Ion Chromatography, UV-Visible Spectrophotometer, High Performance Liquid Chromatography (HPLC), etc. all of which are capable of detecting the concentration of metal ions up to part per billion (ppb) levels (Banda &

Kumarasamy, 2020; Ong & Yee, 2020). The speciation of metal ions in drinking water samples can also be achieved by advanced instrumentation techniques including chromatography, capillary electrophoresis, spectroscopic and other techniques.

Titration remains the exact, most reliable and common method to determine alkalinity, hardness and chlorides in water analysis (Kumar et al., 2022; Omer et al., 2020). Burette titrations are performed by dispensing titrant from a burette into a flask containing the water sample containing an indicator reagent. The flask is swirled after each addition of titrant until a permanent colour change is observed. The concentration of the analyte of interest (alkalinity, hardness, etc.) can then be calculated using a formula given in the test instructions. According to Kumar et al. (2022), dispensing the titrant with a burette instead of a dropper bottle offers a twofold advantage:

- Tighter control over the amount of titrant added to the sample.
- Calibration marks on the glassware to measure the volume dispensed more precisely.

Burette titrations can achieve a precision of ±2% or better, and are commonly used when increased precision is required (Omer et al., 2020).

All instruments and methods used in this study are based on international standard recommendation (APHA, 2012; Herschy, 2012; Ong & Yee, 2020; Shamsudin et al., 2016). In addition to this, availability, proximity to the laboratory and cost involved were also considered.

CHAPTER THREE

MATERIALS AND METHODS

3.0 Overview

This chapter deals with the materials and methods used in the collecting and analyzing data. The chapter includes the description of the study area, sampling, sample preparations and determination of physicochemical parameters, heavy metals and microbial parameters.

Physical analysis includes determination of temperature, colour, total dissolved solids (TDS), electrical conductivity (EC), salinity, turbidity and total suspended solids (TSS). Chemical analysis includes determination of pH, alkalinity, total hardness, calcium hardness, magnesium hardness, chlorides, ammonia, nitrates, nitrites, sulphates, phosphates and cyanides and the determination of heavy metals include determination of total iron, manganese and copper.

3.1 Study Site

The Abuakwa North Municipal Assembly was carved out of the erstwhile East Akim Municipal Assembly and established by L.I 2305 of 2017 with Kukurantumi as its capital. The Assembly was inaugurated on 1st June, 2018. The Municipality is bounded by Fanteakwa North District to the north, New Juaben North Municipality to the south-east, Yilo Krobo Municipality to the east and Abuakwa South Municipality to the west (Abuakwa North District Assembly, 2019). The Municipality is located in the central part of the Eastern Region with coordinates 6°22′12.72″N 0°32′24″W (Wikipedia.org).

The geology of the Eastern region of Ghana comprises the late Proterozoic-Paleozoic Voltaian Group (which forms a thick sedimentary cover in the eastern part of the

West African Craton), the Togo Formation (which is part of the Precambrian Mobile Belt), the intrusive basin-type Eburnean granitoid (Cape Coast granite complex) and the Proterozoic Birmian Supergroup belonging to the West African Craton (Ganyaglo, et al., 2011). The southern (Koforidua, Abonse and Mamfe), towards the highland areas, are mainly underlain by quartzites and phyllites, which belong to the Togo Formation. The Togo Formation, which trends in the northeast direction, originally consisted of alternating arenaceous and argillaceous sediments which have now been converted to phyllites, schists and quartzites except in few places, where unaltered shales and sandstones are seen (Dampare et al., 2006, utexas.edu). The lithology of the north-western (Akoase, Abetifi and Pepease), towards the highland areas, falls within the Voltain Group, which mainly consists of sandstones followed by shales and siltstones (Dampare et al., 2006, utexas.edu). The middle belt (Anyinam, Begoro and Tafo), mainly the lowland areas, are dominated by quartzite and weakly metamorphosed sandstones (Ganyaglo, et al., 2011, utexas.edu). Figure 1 is the contour map of the study area.

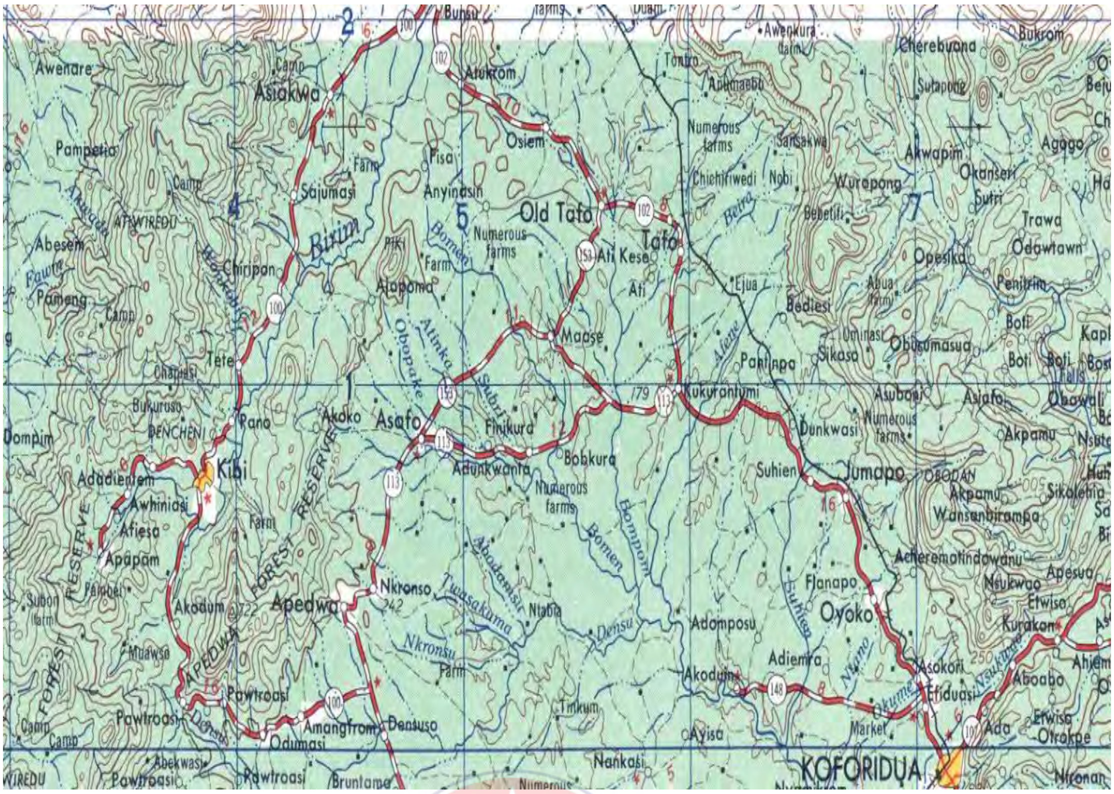

Figure 1: Contour Map of the Study Area

The 2018 census projected population for the Municipality as 98,002 comprising 48,013 (49%) males and 49,989 (51%) females indicating the dominance of females in the municipality. Projection for 2019 is 101,831 at a growth rate of 1.9%. At the local level, almost 60% of the population resides in urban localities. Landcrete, wattle and daub constitute the major housing type in the municipality making a total of about 70%. About 65% of the houses are roofed with galvanized sheets while the rest are roofed with asbestos, and thatch. As per the 2010 PHC, The Municipality is estimated to have a housing stock of about 17, 000 in 2018. About 55% of these housing units are found within the urban areas such as Kukurantumi, Tafo and Osiem (Abuakwa North District Assembly, 2019).

The municipality is drained by rivers such as the Birim, Densu, and Bompong most of which have their catchment areas within the Apedwa Forest Ranges. Several other seasonal streams are found in the municipality. The pattern is largely dendritic, flowing in the north-south direction.

The municipality lies in the west semi-equatorial zone characterized by double rainfall maxima occurring in June and October; the first rainy season from May to July and the second from September to October. The mean annual rainfall is between 125mm and 175mm. The dry seasons are really distinct with the main season commencing in November and ending in March with January recording the least rainfall (Abuakwa North District Assembly, 2019; Gbangou et al., 2020).

Temperature is found to be fairly uniform ranging between 26ºC in August and 30ºC in March. Relative humidity is generally high throughout the year, ranging between 70% - 80% in the dry season and 75% - 80% in the wet season which promotes agriculture, the mainstay of the Municipality (Abuakwa North District Assembly, 2019). Figure 1 is a map showing the study area and sampling points.

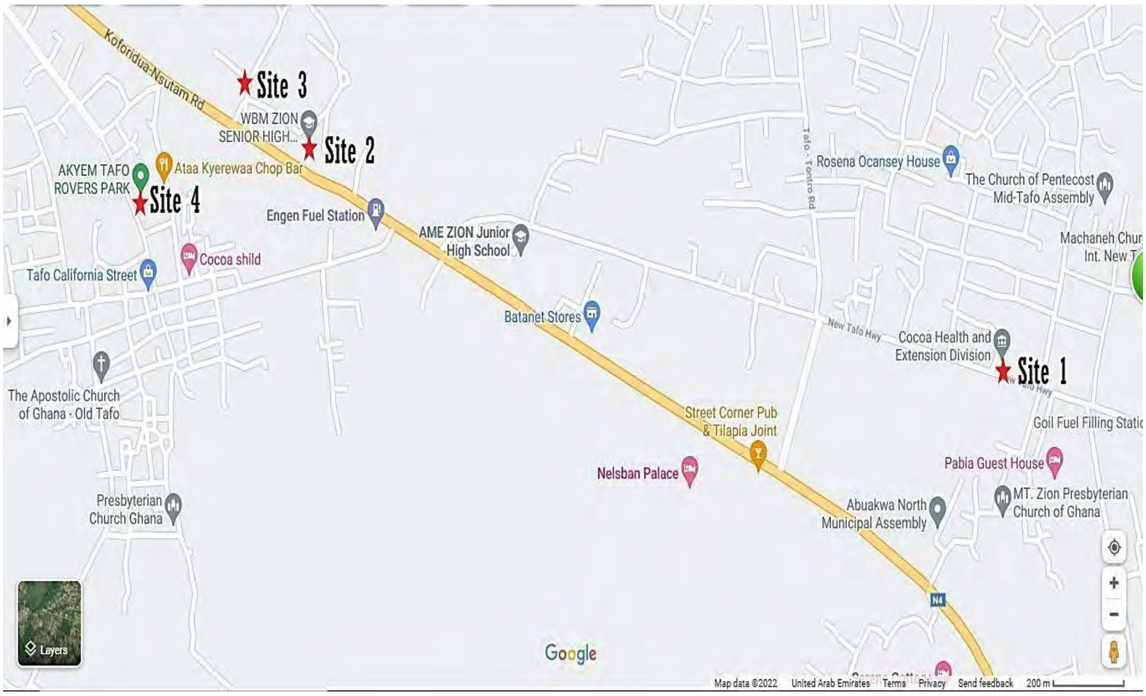

Figure 2: A Map Showing the Study Area

3.2 Sampling

Sampling was done at four (4) boreholes out of the six (6) public boreholes from Mid Tafo and old Tafo. These were opposite Cocoa Health and Extension Division popularly called Mid-Tafo cocoa nursery, W. B. M. Zion SHS new site, behind Maame Cici and Akyem Tafo rovers park (commonly called football park). These boreholes were selected because they are in the densely populated areas of the town. Google location service was used to take the coordinates of each sampling point. The Table below gives details of the sampling location and sample identities (IDs).

Table 2: Details of Sampling Location

Sample Name	Sample ID	Coordinate	Location
Mid Tafo Cocoa Nursery HH BH	Site 1	6.232083, -0.375306	Mid Tafo-Akim
WBM Zion SHS New Site BH	Site 2	6.236282, -0.393057	Old Tafo-Akim
Old Tafo Maame Cici HH BH	Site 3	6.236264, -0.393213	Old Tafo-Akim
Akyem Tafo Rovers Park HH BH	Site 4	6.735731, -1.610247	Old Tafo-Akim

HH: Hand held **BH: Borehole**

3.3 Water Sample Collection

Three water samples were collected from each of four different bore holes in the project area, namely Site 1, Site 2, Site 3 and Site 4 from Mid-Tafo through to Old-Tafo in a year. Sampling was done twice, the first in the dry season (A) and the second in the wet season (B). Water samples for physicochemical analysis were collected into 1 litre (two 0.5 L) pre-washed and screw-capped plastic bottles. Micro-biological samples were put in sterilized 0.5 L screw-neck glass bottles. All the bottles for sampling were rinsed with some of the water sample before final collection. Prior to water collection for microbial analysis, the tips of the exit nozzles were disinfected with methylated spirit soaked in cotton wool before collection. Figure 2 is a diagram showing algae growth which was cleaned from the tips of the exit nozzle prior to water collection for microbial analysis.

Figure 3: Algae Growth around the Exit Nozzle

Each sample bottle was labeled and relevant details recorded. pH and temperature of the water samples were measured on-site with a pH comparator and LCD portable digital multi-stem thermometer with external sensing probe (EUROLAB ST9269B) respectively. Figure 3 below is a diagram showing the determination of temperature on-site.

All the water samples collected were stored in ice and transported to the laboratory for analysis. The determinations of the other physicochemical and microbial properties of the water samples were performed on the same day of sampling.

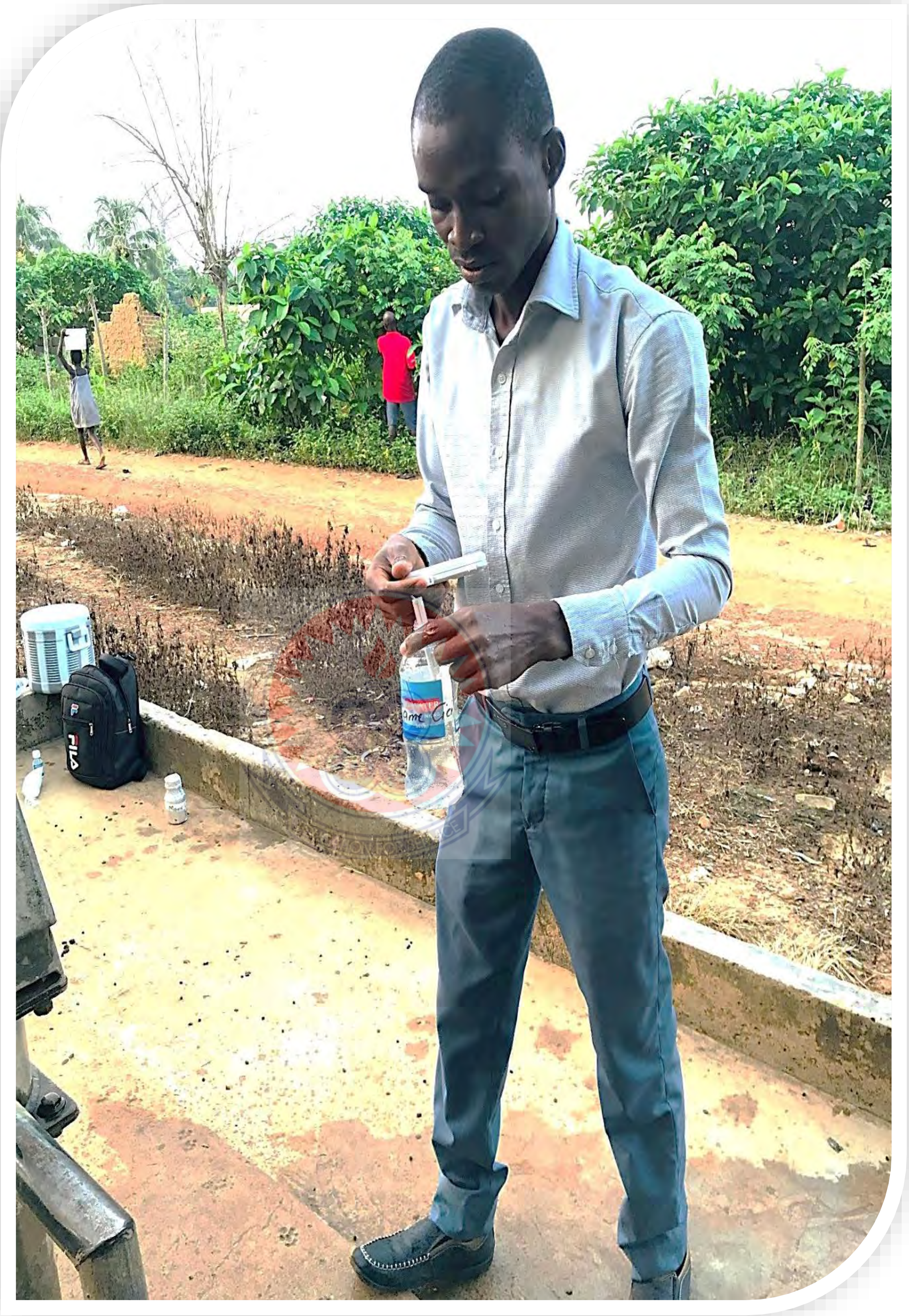

Figure 4: Determination of Water Temperature on Site

3.4 Analysis of Physical Parameters

3.4.1 Determination of temperature

Temperature was measured on site with LCD portable digital multi-stem thermometer with external sensing probe (EUROLAB ST9269B). It has a least count of ±1 °C and can measure temperature from -50 °C to 300 °C with an accuracy of 0.1 °C.

The thermometer was turned on and the measurement unit set to degree Celsius. The water was pumped out for about 5 min prior to sample collection and temperature determination. One of the 0.5 L plastic bottles was half filed with water. The thermometer probe was inserted into the water to at least 25 mm and allowed to stand until the thermometer displays a steady reading as shown in Figure 3. The temperature reading was recorded and the process repeated to get consistent values.

3.4.2 Determination of colour

Lovibond® Nessleriser 2150 Comparator with a stand was used for colour determination. It has two 50 mL tubes of a pathlength of 113 mm with a colour disc of detection limit of 0 HU.

The water sample was shaken to ensure thorough mixing. One of the tubes was filled with distilled water while the other was filled with the water sample to the 50 mL mark. The tube was inserted in the comparator, the light turned on and the colour of the water sample was compared with a series of coloured glass discs until the nearest possible match is found. The colour of the disk corresponds to the colour of the water sample and the colour value of the read.

3.4.3 Determination of electrical conductivity

The multifunctional HACH HQ 14d conductivity was used to measure Electrical Conductivity (EC) of water samples after calibration. A standard potassium chloride solution having conductivity of 1000 uS/cm (at 25°C) was used for the calibration. The solution was poured into a 50 mL beaker and allowed for a steady temperature of about 25 °C. The options button on the instrument was pressed and EC selected from programs menu. The electrode of the instrument was rinsed with distilled water and immersed into the standard solution for about 2 minutes. The analyzer reading was adjusted to read 1000 uS/cm. It was ensured that, the sensor did not touch the sides and particularly, the bottom of the beaker while adjusting the reading. This is to ensure that, the probe takes the temperature of the solution.

About 50 mL portion of water sample was poured into a clean glass beaker. The electrode of the instrument was rinsed with distilled water and immersed into the water sample for measurement. The value displayed was read and recorded.

3.4.4 Determination of total dissolved solids

The multifunctional HACH HQ 14d conductivity was used to measure Total Dissolved Solids (TDS) of water samples. The options button on the instrument was pressed and TDS selected from programs menu.

About 50 mL portion of water sample was poured into a clean glass beaker. The electrode of the instrument was rinsed with distilled water and immersed into the water sample for measurement. The value displayed was read and recorded.

3.4.5 Determination of salinity

The multifunctional HACH HQ 14d conductivity was used to measure salinity of water samples. The options button on the instrument was pressed and salinity selected from programs menu.

About 50 mL portion of water sample was poured into a clean glass beaker. The electrode of the instrument was rinsed with distilled water and immersed into the water sample for measurement. The value displayed was read and recorded.

3.4.6 Determination of turbidity

Hach DR 900 Multiparameter Portable Handheld Colorimeter was used to measure turbidity. From the home screen display, the options button on the instrument was pressed and turbidity selected from programs menu. Distilled water was used as blank to zero the instrument before measuring turbidity of water samples. This is to take care of any background colour correction.

Some of the water sample was used to rinse the cuvette after it was rinsed with distilled water before filling it with the water sample. The water samples were shaken vigorously to ensure thorough mixing before filling the cuvette. The cuvette was put into the cuvette chamber and covered with the light shield. The turbidity value displayed was read and recorded. The process was repeated for the rest of the water samples.

3.4.7 Determination of total suspended solids

Hach DR 900 Multiparameter Portable Handheld Colorimeter was used to measure Total Suspended Solids (TSS). From the home screen display, the options button on the instrument was pressed and TSS selected from programs menu. Distilled water was used as blank to zero the instrument before measuring TSS of water samples.

Some of the water sample was used to rinse the cuvette after it was rinsed with distilled water before filling it with the water sample. The water samples were shaken vigorously to ensure thorough mixing before filling the cuvette. The cuvette was put into the cuvette chamber and covered with the light shield. The TSS value displayed was read and recorded. The process was repeated for the rest of the water samples.

3.5 Analysis of Chemical Parameters

3.5.1 Determination of pH

Lovibond® Nessleriser 2000+ Comparator was used for pH determination. It has two 10 mL tubes with a pH disc of detection limit from 5.6 to 8.4.

The two tubes were filled with water sample up to the 10 mL mark. The black plate was adjusted as per direction in the manual. Three drops of bromo thymol blue was added to one tube and put in the right hand side compartment. The blank (tube without indicator) in left hand side compartment. The disc was rotated till the colour developed in the right-hand side sample coincides with the disc colour. The corresponding pH was then read and recorded.

3.5.2 Determination of alkalinity

Titrimetric method was used to determine Total alkalinity in the water. The titration was done by using 0.02 M H_2SO_4 as titrant (because H_2SO_4 will give precipitate with $CaCO_3$), phenolphthalein and methyl orange as indicators.

Fifty milliliters (50 mL) of the water sample was pipetted into a clean conical flask and two drops of phenolphthalein indicator were added. The sample turned pink and was titrated against 0.02 M H_2SO_4, swirled gently until the pink colour just disappears. The titre value (T) was read and recorded. If the sample remained colourless after the addition of the phenolphthalein indicator, three drops of methyl orange indicator were added. The yellow sample was then titrated against 0.02 M H_2SO_4 swirling gently until the colour changed from yellow to orange and the titre value (A) was read and recorded.

Calculation:

$$Total\ Alkalinity\ as\ CaCO_3\ (mg/L) = \frac{A\ x\ T\ x\ 1000}{Sample\ Volume\ (mL)}$$

Where T = Titre of standard acid at phenolphthalein end point

A = Titre of standard acid at methyl orange end point

(American Public Health Association, 2012).

3.5.3 Determination of total hardness

Fifty milliliters (50 mL) of the water sample was pipetted into a clean conical flask and 1.0 mL of 0.5 M Ammonium buffer solution (pH = 10.0) and 2 mL of Eriochrome Black-T indicator was added. The content in the conical flask was titrated with 0.011 M EDTA solution (Ethylene Diamine Tetra Acetic acid), mixed gently until the colour changed from red to blue. The titration process was repeated to obtain consistent values. The average titre value was recorded and total hardness was calculated as: $Total\ Hardness\ (mg/L) = \frac{Average\ titre\ x\ 1000}{Sample\ Volume\ (mL)}$

(American Public Health Association, 2012).

3.5.4 Determination of Calcium hardness

Fifty milliliters (50 mL) of the water sample was pipetted into a clean conical flask. About 1 mL of aqueous solution of 1.0 M NaOH was added to the contents of the flask, followed by the addition of about 0.2 g powdered Ammonium murexide indicator. The content in the conical flask was titrated with 0.011 M Ethylene Diamine Tetra Acetic acid (EDTA) solutions, mixing gently until the colour changed from pink to purple indicating the endpoint. Titration was repeated until a consistent titre was obtained. The average titre value was read and recorded.

Calculation:

$$Hardness\ hardness\ as\ CaCO_3\ (mg/L) = \frac{Average\ titre\ x\ 1000}{Sample\ Volume\ (mL)}$$

(American Public Health Association, 2012).

3.5.5 Magnesium hardness

Magnesium hardness determination was done by subtracting the value representing calcium hardness from that of total hardness when they were expressed in the same unit.

3.5.6 Determination of chloride

The amount of chloride in water samples were determined by the Argentometric method. Potassium chromate indicator solution was prepared by dissolving 50 g of K_2CrO_4 in a little distilled water and 1.0 M $AgNO_3$ solution was added until a definite precipitate occurred. The solution was made to stand for twelve hours, after which it was filtered and diluted to 1000 mL. The silver nitrate titrant solution (0.0141 M) was prepared by dissolving 2.395 g $AgNO_3$ in distilled water and diluted to 1000 mL.

Fifty milliliters (50 mL) of the water sample was pipetted into a clean conical flask. One milliliter (1 mL) of 5% Potassium chromate (K_2CrO_4) indicator was then added. This was titrated against 0.014 M $AgNO_3$ solution, with gentle swirling until the colour changed from yellow to brick red. The titre was read and recorded in milliliters (mL). The concentration of chloride was calculated as:

$$Cl^- \ (mg/L) = \frac{(A - 0.2)\ x\ 0.5\ x\ 1000}{Sample\ Volume\ (mL)}$$

Where A = Titre value (American Public Health Association, 2012).

3.5.7 Determination of ammonia

HACH DR 6000 UV VIS Spectrophotometer was used to determine Ammonia-Nitrogen in the sample using Nessler method USEPA Low Range Powder Pillow (LR PP) at a wavelength of 425 nm. The detection limit was 0.00 mg/L.

A pipette was used to measure 25 mL of the sample into a 50 mL beaker. Three drops of mineral stabilizer was added to the sample and swirled to mix. Three drops of Polyvinyl Alcohol Dispensing Agent was added to the sample. 1.0 mL of Nessler Reagent was added to the sample by a pipette. A 1-minute reaction timer was started on the instrument. A yellow colour develops if Ammonia is present. Ten milliliters (10 mL) of the solution was poured into a sample cell.

Distilled water was measured and treated in the way as the sample and used as a blank to zero the instrument. The sample cells were then cleaned, inserted into the cell holder and read after the 1-minute reaction timer expired. The value displayed was recorded as ammonia-nitrogen concentration in mg/L.

3.5.8 Determination of nitrate

HACH DR 6000 UV VIS Spectrophotometer was used to determine Nitrate-Nitrogen using Cadmium reduction method MR Low Range Powder Pillow (LR PP) at a wavelength of 500 nm. The detection limit was 0.0 mg/L.

The sample was prepared by filling a sample cell with 10 mL of sample. The contents of one Powder Pillow (PP) for N-Nitrate MR was added to the sample cell. A 1-minute reaction timer was started on the instrument. The sample was shaken vigorously until the timer expires. A 5-minute reaction timer was started on the instrument.

Distilled water was used as a blank and used to zero the instrument. The sample cells were then cleaned, inserted into the cell holder and read after the 5-minute reaction timer expired. The value displayed was recorded as nitrate-nitrogen concentration in mg/L.

3.5.9 Determination of nitrite

HACH DR 6000 UV VIS Spectrophotometer was used to determine Nitrite-Nitrogen in the sample using Diazotization method Low Range Powder Pillow (LR PP) at a wavelength of 507 nm. The detection limit was 0.000 mg/L.

The sample was prepared by filling a sample cell with 10 mL of sample. The contents of one NitriVer 3 reagent Powder Pillow (PP) was added to the sample cell with constant swirling for the content to mix. A 20-minute reaction timer was started on the instrument.

Distilled water was used as a blank and used to zero the instrument. The sample cells were then cleaned, inserted into the cell holder and read after the 20-minutes reaction timer expired. The value displayed was recorded as nitrite-nitrogen concentration in mg/L.

3.5.10 Determination of sulphate

HACH DR 6000 UV VIS Spectrophotometer was used to determine sulphate in the sample using SulfaVer 4 method USEPA Low Range Powder Pillow (LR PP) at a wavelength of 450 nm. The detection limit was 0 mg/L.

The sample was prepared by filling a sample cell with 10 mL of sample. The contents of one SulfaVer 4 Powder Pillow (PP) was added to the sample cell with constant swirling for the contents to mix. A white turbid solution soon forms if sulphate is present. A 5-minute reaction timer was started on the instrument. The sample was not disturbed during this time period.

Distilled water was used as a blank and used to zero the instrument. The sample cells were then cleaned, inserted into the cell holder and read after the 5-minute reaction timer elapsed. The value displayed was recorded as sulphate ion concentration in mg/L.

3.5.11 Determination of phosphate

HACH DR 6000 UV VIS Spectrophotometer was used to determine phosphorus, reactive (orthophosphate) in the sample using PhosVer 3 (Ascorbic Acid) method USEPA Low Range Powder Pillow (LR PP) at a wavelength of 430 nm. The detection limit was 0.0 mg/L.

The sample was prepared by filling a sample cell with 10 mL of sample. The contents of one PhosVer 3 phosphate reagent Powder Pillow (PP) was added to the sample cell and shaken vigorously. A 2-minute reaction timer was started on the instrument. A blue colour developed indicating phosphorus is present.

Distilled water was used as a blank and used to zero the instrument. The sample cells were then cleaned, inserted into the cell holder and read after the 2-minute reaction timer elapsed. The value displayed was recorded as phosphorus concentration in mg/L.

3.5.12 Determination of cyanide

HACH DR 6000 UV VIS Spectrophotometer was used to determine cyanide in the sample using Pyridine-Pyrazalone method Low Range Powder Pillow (LR PP) at a wavelength of 612 nm. The detection limit was 0.000 mg/L.

The sample was prepared by filling a sample cell with 10 mL of the water sample. The contents of one CyaniVer 3 cyanide reagent Powder Pillow (PP) was added to the sample cell and shaken for 30 seconds. The sample was left undisturbed for another 30 seconds. The content of one CyaniVer 4 cyanide reagent Powder Pillow was added to the sample cell and shaken for 10 seconds followed by adding the content of one CyaniVer 5 Cyanide Reagent Powder Pillow immediately. The cell was shaken vigorously. A 30-minute reaction timer was started on the instrument.

Distilled water was used as a blank and used to zero the instrument. The sample cells were then cleaned, inserted into the cell holder and read after the 30-minutes reaction timer elapsed. The value displayed was recorded as cyanide ion concentration in mg/L.

3.6 Heavy Metal Analysis

3.6.1 Determination of total iron

HACH DR 6000 UV VIS Spectrophotometer was used to determine the total iron using the FerroVer method USEPA Low Range Powder Pillow (LR PP) at a wavelength of 510nm. The detection limit was 0.00 mg/L.

The sample was prepared by filling a sample cell with 10 mL of sample. The contents of one FerroVer Iron reagent Powder Pillow (PP) was added to the sample cell with constant swirling for the content to mix. A 3-minute reaction timer was started on the instrument. An orange colour shows if iron is present. Figure 4 is a diagram showing cuvettes containing water samples for total iron determination after adding the reagents. The samples were arranged from Site 1 (from the left) to Site 4 (on the right).

Distilled water was used as a blank and used to zero the instrument. The sample cells were then cleaned, inserted into the cell holder and read after the 3-minutes reaction time elapsed. The value displayed was recorded as iron concentration in mg/L.

Figure 5: Cuvettes containing Samples for Iron Determination

3.6.2 Determination of manganese

HACH DR 6000 UV VIS Spectrophotometer was used to determine the manganese using Periodate Oxidation method USEPA Low Range Powder Pillow (LR PP) at a wavelength of 525 nm. The detection limit was 0.000 mg/L.

The sample was prepared by filling a sample cell with 10 mL of sample. The contents of one buffer Powder Pillow (PP), Citrate type for manganese was added to the sample cell with constant swirling for the content to mix. The content of one Sodium periodate Powder Pillow was added and swirled. A 2-minute reaction timer was started on the instrument. A violet colour shows if manganese is present. Figure 5 is a diagram showing cuvettes containing water samples for manganese determination after adding the reagents. The samples were arranged from Site 1 (from the left) to Site 4 (on the right).

Distilled water was used as blank and used to zero the instrument. The sample cells were then cleaned, inserted into the cell holder and read after the timer expires. The value displayed was recorded.

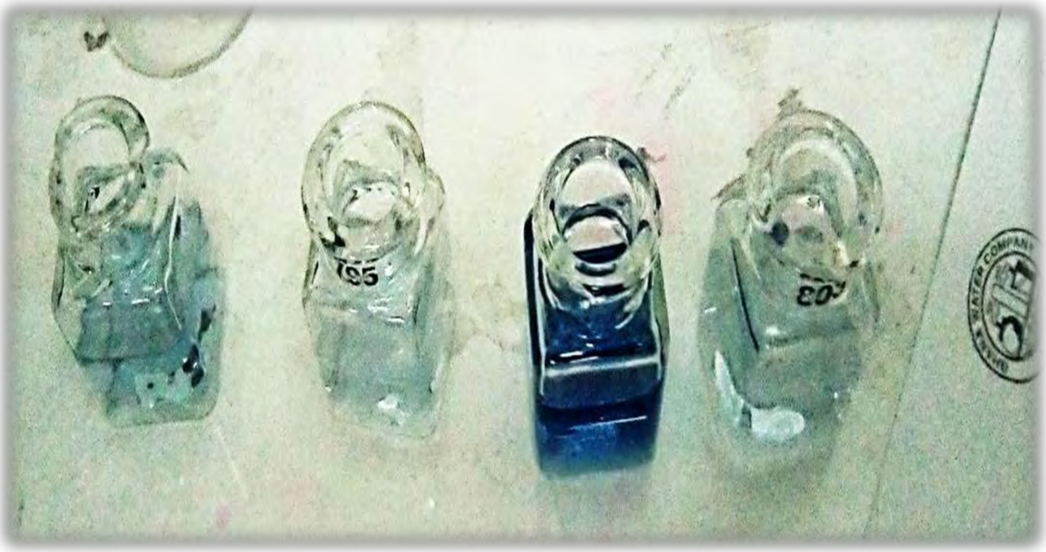

Figure 6: Cuvettes containing Samples for Manganese Determination

3.6.3 Determination of copper

HACH DR 6000 UV VIS Spectrophotometer was used to determine the copper in the sample using Bicinchoninate method USEPA Low Range Powder Pillow (LR PP) at a wavelength of 560 nm. The detection limit was 0.00 mg/L.

The sample was prepared by filling a sample cell with 10 mL of sample. The contents of one CuVer 1 Copper reagent Powder Pillow (PP) was added to the sample cell with constant swirling for the content to mix. A 2-minute reaction timer was started on the instrument. A purple colour developed indicating that copper was present.

Distilled water was used as a blank and used to zero the instrument. The sample cells were then cleaned inserted into the cell holder and read after the 2-minuite timer expires. The value displayed was recorded as copper concentration in mg/L.

3.7 Microbial Analysis

Plate count (pour plate) method was used for the determination of total coliform, fecal coliform and heterotrophic bacteria (APHA, 2012; Pontius, 2000). The laboratory bench was sterilized using methylated spirit while the glass wares (pipettes and Petri dishes) were autoclaved at 121 ºC for 30 minutes (APHA, 2012).

3.7.1 Preparation of culture media

Brilliance *E. coli* culture medium was prepared by suspending 28.1 g of Brilliance *E. coli* in 1 L of distilled water. The mixture was gently heated on a heating plate to boil with agitation to dissolve completely. It was cooled to about 50 ºC, mixed well and poured into a prewashed 10 mL McCartney bottles. The media was then sterilized by autoclaving at a pressure of 1 atm and a temperature of 121 ºC for 15 minutes.

Similarly, the plate count agar was prepared by suspending 17.5 g of the agar in 1 L of distilled water. The agar was dissolved by heating the mixture on a heating plate to boil with frequent stirring. The media was cooled to about 50 ºC, mixed well and distributed into 15 mL prewashed McCartney bottles. The media was then sterilized by autoclaving at a pressure of 1 atm and a temperature of 121 ºC for 15 minutes.

3.7.2 Total coliform and E. coli

Ten milliliters (10 mL) of Brilliance *E. coli* culture medium was used to innoculate total coliform and *E. coli*. Sterile but empty Petri dish was labeled with the name, the type of growth and the type of organism to be added to the melted agar medium. The agar was melted in a water bath at about 55 ºC and allowed to cool to about 48 ºC. Ten milliliters (1.0 mL) of the water sample was plated using a pre-sterile pipette which was flamed with a Bunsen burner. The cap was removed from the bottle of the melted agar and the rim of the open bottle was passed through the flame of the Bunsen burner. The cover of the petri dish was adjusted to about 45 ºC and the agar transferred onto the water sample and then mixed gently by swirling the plate. The agar was allowed to thoroughly solidify before inverting the plate for incubation at a temperature of 37±0.5 ºC for 24 hours.

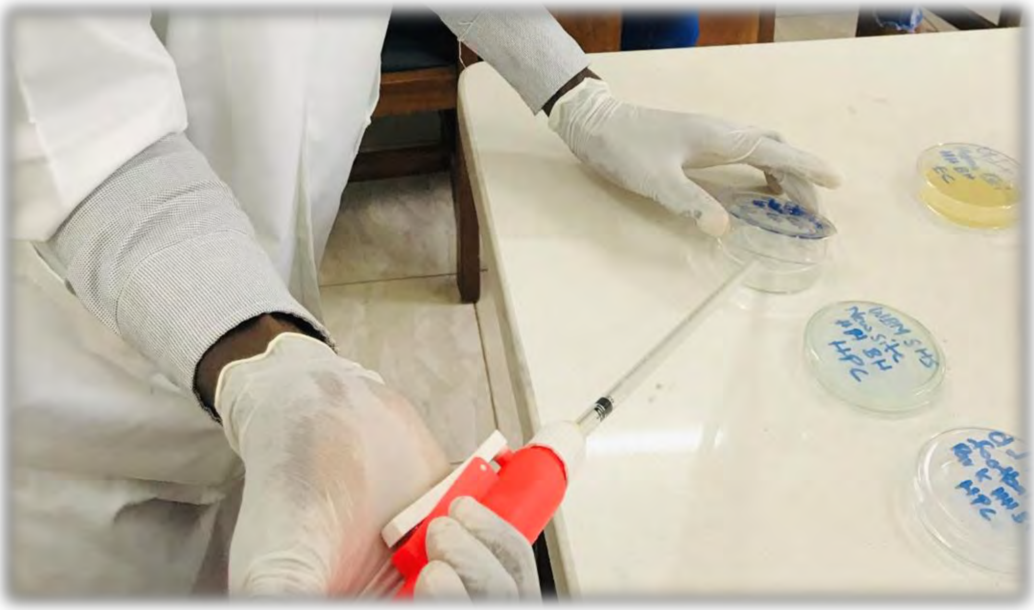

Figure 7: Transferring sample into the petri dish

Blue and rose-pink spots developed in the growth media indicating *E. coli* and total coliform colonies respectively. The number of blue spots (*E. coli* colonies) were counted and recorded as count per mL of water sample. The number of both blue and rose-pink spots (total coliform) were counted and recorded as count per mL of water sample. The values were then converted to count per 100 mL by multiplying with a factor of 100. Figure 6 is a diagram showing suspected colony growth. In addition to coliform colonies, there was a growth shown by a purplish-red colour (fuchsia) as shown in Figure 6.

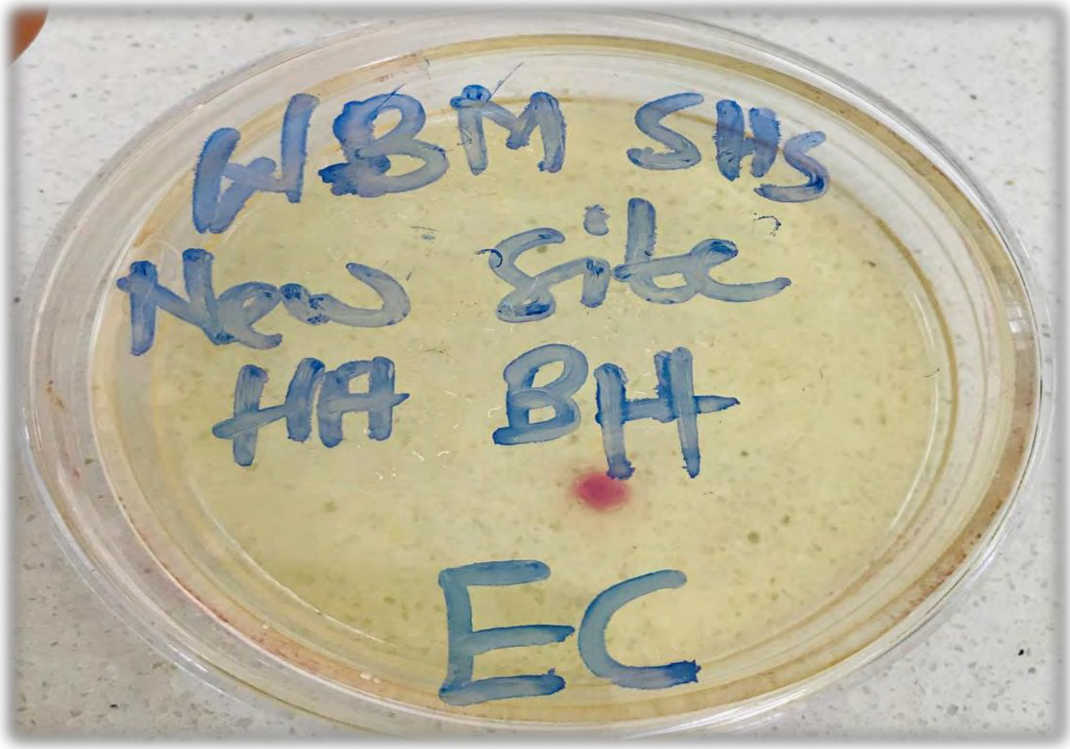

Figure 8: A Petri Dish showing Suspected Coliform Colonies

3.7.3 Heterotrophic bacterial count

Similarly, fifteen milliliters (15 mL) of plate count agar was used as the culture medium to innoculate heterotrophic bacteria and incubated at a temperature of 35±0.5 ºC for 24 hours. Appendix A and B gives the details of the analysis. Yellow spots developed in the culture medium indicating the presence of heterotrophic bacteria.

The number of colonies were counted and recorded as count per mL of water sample. The value was then converted to count per 100 mL by multiplying with a factor of 100.

3.8 Statistical Analysis

The mean values of the results were obtained from all the two-analysis made, dry season and wet season for each parameter was determined and used for comparison.

The mean value of each parameter was compared to WHO (2017), standard for drinking water which was adopted by Ghana Standard Authority (GSS).

One way ANOVA was used to compare results of dry season and raining season using the statistical package of Microsoft Excel, 2019 edition. The level of probability at which significant difference existed between the groups was set at $p<0.05$ at 95% confidence level.

CHAPTER FOUR

RESULTS AND DISCUSSION

4.0 Introduction

The mean values of all the various parameters were computed from the raw data obtained from the field. For the purpose of discussion, the mean values of measurements for the dry and rainy seasons were compared with WHO guideline values where applicable. The mean values for the dry season were also compared with that of the rainy season for any differences. Some descriptive and inferential statistics were made and added to the table for discussion.

4.1 Physical Parameters

Table 3 shows the mean values of major physical parameters of borehole water analysed in Tafo-Akim with their corresponding WHO (2017) standard values for drinking water.

Table 3: Mean Levels of Major Physical Parameters in Borehole Water in Tafo-Akim

Parameter	**Site 1**	**Site 2**	**Site 3**	**Site 4**	**SD**	**WHO, 2017**
Temp (°C)	27.55	26.85	26.00	27.45	0.71	-
pH (units)	**6.05**	6.65	**6.40**	**6.05**	0.29	6.5-8.5
Conductivity (µS/cm)	**2187**	1311	**3150**	1908	767	2000
Salinity (mg/L)	0.10975	0.06555	0.15750	0.09540	0.03834	600
TDS (mg/L)	109.5	65.6	157.8	95.4	38.4	1000
Colour (HU)	1.0	1.0	**21.5**	1.0	10.3	15
Turbidity (NTU)	0.0	0.0	**14.5**	0.0	7.3	5
TSS (mg/L)	0.0	0.0	13.5	0.0	6.8	50

Figures highlighted bold are outside the standard. **SD: Standard Deviation**

4.1.1 Temperature

From Table 3, the mean values obtained for temperature in the borehole water samples analysed ranged from 26.0 ºC to 27.55 ºC. The minimum temperature was recorded at Site 3 (26.0 ºC) while Site 1 recorded the highest value (27.55 ºC) with a standard deviation of 0.71, which implies that, the temperature values observed deviated slightly from each other.

A similar study in Aburi in the Eastern region of Ghana also recorded a similar temperature value of 26.21 ± 1.57ºC (Apau et al., 2014) since temperature is climate dependent (Badino, 2010). Temperature influences the rate of chemical and biological reactions. It affects the dissolved oxygen level in water, and the sensitivity of parasites and disease (Qin et al., 2017).

4.1.2 pH

The mean values obtained for pH in the borehole water samples analysed ranged from 6.05 to 6.65 (Table 3). The minimum pH was recorded at Site 1 and 4 (6.05) while Site 2 recorded the highest value (6.65) with a standard deviation of 0.29. Which implies that, the pH values observed deviated slightly from each other. The observed pH values of Site 1, 3 and 4 was unacceptable considering WHO standard of 6.5-8.5.

The pH values show that, the water is slightly acidic similar to what was observed in Dodowa and Aburi (6.38 to 7.28) (Apau et al., 2014). pH levels below 6.5 means the water is acidic and this could pose health risks to consumers (Boakye, 2013). Fatoki & Muyima, 2003 are in agreement that, water with low pH values can burn mucous membranes of the throat and intestinal mucosa an effect similar to sore throat. Other analogous researches in the middle belt and the northern sector of Ghana however reported values that are within the WHO standard (Obiri-Danso et al., 2009; Saana et al., 2016). The low pH may be due to the presence of organic acids in the soil as well as those of atmospheric origin infiltrated to the water (Du et al., 2021; Reddy et al., 2021; Obiri-Danso et al., 2009).

4.1.3 Electrical Conductivity

From Table 3, the mean values obtained in the borehole water samples analysed ranged from 1311 µS/cm to 3150 µS/cm with a standard deviation of 767. The high standard deviation indicates that the observed conductivity values deviated more from each other. The minimum value was recorded at Site 2 while the maximum value was recorded at Site 3. Observed values at Site 1 and 3 are above WHO standard of 2000 µS/cm.

The high electrical conductivity may be mainly caused by dissolved inorganic salts such as sodium and sulphate salts. Higher levels of TDS concentration can impart salty or bitter taste to water thereby making it undesirable for consumption. Water with high salty concentration causes excessive scaling in distribution pipes, heaters, and boilers (Gray, 2008).

Health based guideline value for conductivity is absent. However, drinking water usually has to meet a standard of 1,000 mg/L TDS. It is well known that the conductance of water increases with increasing salt dissolution. Total dissolved solids and conductivity can be used to delineate each other; conductivity is proportional to the total dissolved solids (Corwin & Yemoto, 2020). Health effect associated with EC in drinking water can occur at levels as low as 370 µS/cm. However, water sources with electrical conductivity levels' exceeding 1000 µS/cm generally are regarded as polluted though no health-related conditions have been stated (Fatoki & Muyima, 2003). Water at all the 4 Sites is, thus, polluted though only that at Sites 1 and 3 were above WHO's guideline value.

4.1.4 Salinity

The mean values obtained for salinity in the borehole water samples analysed ranged from 0.06555 mg/L at Site 2 to 0.15750 mg/L at Site 3 with a standard deviation of 0.03834 (Table 3). All values observed for salinity are below the WHO maximum value of 600 mg/L.

Salinity of drinking water is not measured by most researchers as it is directly related to total dissolved solids (TDS) and electrical conductivity (Corwin & Yemoto, 2020; Subba, 2008). A similar study at the Aburi, Dodowa and Keta basin of Ghana however recorded values slightly higher (2.47 mg/L) than those observed in this study (Apau et al., 2014; Yidana et al., 2010).

4.1.5 Total Dissolved Solids (TDS)

Total dissolved solids (TDS) in the borehole water ranged from 65.6 mg/L to 157.8 mg/L with a standard deviation of 38.4 (Table 3). This shows that, the observed values of total dissolved solids deviated widely from each other. The minimum value was observed at Site 2 while the maximum value was observed at Site 3. All observed values are below WHO maximum acceptable value of 1000 mg/L.

The observed values are similar but more narrow than values observed in underground water from Aburi and Dodowa (13mg/L to 526mg/L with a standard deviation of 53.5) (Apau et al., 2014).

The lower values suggest that the filtration efficiency of installed filters underground is high. Water with high dissolved solids can impart laxative effect on consumers

(Putz, 2003). Higher TDS concentrations often gives undesirable taste to drinking water by making it salty or bitter and also elevate scaling in distribution pipes, heaters, and boilers (Gray, 2008). This suggests that stabilizing TDS value of drinking water below 1000 mg/L improves water quality and acceptability.

4.1.6 Colour

From Table 3, the colour of borehole water ranged widely from 1.0 HU at Site 1, 2 and 4 to 21.5 HU at Site 3 with a standard deviation of 10.3. The observed value at Site 3 (21.5 HU) was higher than WHO standard of 15.0 HU for colour. The higher colour value observed at Site 3 could be due to the presence of iron (III) in the water (Leszczyński, 2019).

Other researches in the Eastern region recorded colour values between 1.0 HU to 5.0 HU (Apau et al., 2014) in contrast, a maximum value of 130.0 HU was observed in the northern sector (Saana et al., 2016). Water which is coloured can pose adverse health effect on human beings. Clean water does not have colour and so the presence of any colour in water may suggest contamination (Department of Fisheries and Aquatic Sciences, 2004; WHO, 2011). Water at Site 3 may be contaminated and hence unacceptable for drinking considering WHO's standard for drinking water.

4.1.7 Turbidity

Turbidity of borehole water varied from 0.0 NTU to 14.5 NTU with a standard deviation of 7.3 as seen in Table 3. The higher standard deviation implies that the observed values deviated widely from each other. The maximum value was observed at Site 3 which is higher than WHO standard of 5.0 NTU.

An analogous study at Aburi and Dodowa recorded 0.00 NTU for turbidity (Apau et al., 2014), Abinah, 2013, recorded a maximum of 3.57 NTU in the Brong Ahafo region whiles a maximum of 105.00 NTU was recorded in the northern sector of Ghana (Saana et al., 2016). In turbid water, particulate matters have the potential to protect microbiological organisms from effective disinfection (WHO, 2017). Highly turbid water consumption can pose health risk as extreme turbidity can protect pathogenic microbes from the effect of disinfectants and enhance bacteria growth at storage (Pichel et al., 2019; Karim et al., 2020).

4.1.8 Total Suspended Solids (TSS)

From Table 3, the mean values for total suspended solids (TSS) ranged widely from 0.0 mg/L at Site 1, 2 and 4 to 13.5 mg/L at Site 3 with a standard deviation of 6.8. All observed values for total suspended solids are below WHO maximum standard of 50 mg/L.

In the Kassena-Nankana district in the Upper East region, a similar study recorded 1.10 mg/L to 3.02 mg/L with a standard deviation of 1.32 (Oyelude et al., 2013). Most researches on groundwater quality however do not measure TSS since it is related to other parameters like TDS and phosphates.

Water with high TSS can easily be detected and rejected by consumers. High concentrations can lower the water quality in the receiving environment. The suspended solids absorb light, causing increased water temperature and decreased oxygen in water (Hassan et al., 2020).

4.2 Heavy Metals

Table 4 below shows the mean values of major heavy metals of borehole water analysed in Tafo-Akim with their corresponding WHO (2017) standard values for drinking water.

Table 4: Mean Levels of Major Heavy Metals in Borehole Water in Tafo-Akim

Parameter	Site 1	Site 2	Site 3	Site 4	SD	WHO, 2017
Copper (mg/L)	0.005	0.005	0.160	0.005	0.078	2.0
Manganese (mg/L)	0.018	0.004	0.374	0.010	0.182	0.40
Iron (mg/L)	0.015	0.010	**1.585**	0.040	0.782	0.30

Figures highlighted bold are outside the standard. **SD: Standard Deviation**

4.2.1 Copper (Cu)

From Table 4, the mean concentration of copper in the borehole water samples analysed ranges from 0.005 mg/L to 0.160 mg/L with a standard deviation of 0.078. The minimum value for copper concentration was recoded at Site 1, 2 and 4 while the maximum value was recorded at Site 3. The high concentration of copper at Site 3 may be as a result of corrosion from the underground plumbing system aside geological factors. All observed values are however below WHO maximum value of 2.0 mg/L.

A similar study at Wamfie in the Bono region recorded a slightly higher value for copper concentration, 0.05mg/L to 0.19mg/L with a standard deviation of 0.06 (Abinah, 2013). Decades of study indicate that oral exposures of copper are typically not a human health concern. Ingesting high levels of soluble copper salts can cause acute gastrointestinal symptoms and in uncommon cases, liver toxicity in susceptible individuals with repeated exposure (Taylor et al., 2020). Recent studies have delineated the threshold for the effects of copper in drinking water on the gastrointestinal tract, but there is still some uncertainty regarding the long-term effects of copper on sensitive populations such as carriers of the gene for Wilson disease and other metabolic disorders of copper homeostasis. (Angelova et al., 2011; Taylor et al., 2020).

4.2.2 Manganese (Mn)

Manganese concentration in the water samples analysed fluctuated between 0.004 mg/L and 0.374 mg/L with a standard deviation of 0.182 (Table 4). The minimum value was observed at Site 2 while the maximum value was observed at Site 3. The high manganese concentration at Site 3 may be an indication that the water; has little or no oxygen, flow is slow and/or flows through soils rich in organic matter (Kousa et al., 2021; Zhang et al., 2020).

All the values for manganese concentration in this study, fall below WHO's (2017) guideline level of 0.40 mg/L. The value (0.374 mg/L) observed at Site 3 is however undesirable considering health base value of 0.30 mg/L (WHO, 2021).

Other studies on underground water in the Ashanti region recorded 0.001 mg/L to 0.028 mg/L (Boakye, 2013; Nkansah et al., 2010). When the concentration of manganese is lower than 0.1 mg/L, then both guidelines for organoleptic properties and health guidelines can be met (Ong *et al.,* 2007). Humans and animals require manganese for the proper functioning of their bodies, as it is needed to enhance many cellular enzymatic activities (e.g., manganese superoxide dismutase, pyruvate carboxylase) and also help to activate many others (e.g., kinases, decarboxylases, transferases, hydrolases) (IPCS, 2002).

4.2.3 Iron (Fe)

Iron concentration in the analysed water samples ranged from 0.010 mg/L to 1.585 mg/L with a standard deviation of 0.782 (Table 4). The minimum value was observed at Site 2 while the maximum value was observed at Site 3. The high concentration of iron at Site 3 may be as a result of the depth of the borehole and/or minerals contained within the underlying bedrock, soil and sand (Breward, 2003; Idoko, 2010; Nayak et al., 2002). The mean observed value at Site 3 is unacceptable, considering WHO's (2017) guideline level of 0.30 mg/L.

Similarly, Nkansah (2010), recorded iron concentration in underground water as 0.00 mg/L to 1.20 mg/L in the Ashanti region. Iron concentration as reported by Apau et al. (2014), in Aburi and Dodowa in the Eastern region is below (0.25 mg/L) WHO limit.

The taste of iron is usually unnoticed by consumers at concentrations lower than 0.30 mg/L (WHO, 2011), although turbidity and colour may build up in pipe distribution systems at levels more than 0.05 mg/L. Laundry and sanitary ware will stain at iron concentrations greater than 0.30 mg/L (WHO, 2011). Prolonged consumption of such water may also lead to liver disease (Ranjana, 2010).

4.3 Chemical Parameters

For the purpose of this discussion, the chemical parameters would be grouped into two (2). These are nutrients and other chemical parameters. Nutrients include phosphates, nitrates, nitrites, ammonia and sulphates. Alkalinity, hardness, chloride and cyanide were considered as other chemical parameters.

4.4 Nutrients

Table 5 below shows the mean values of major nutrients of borehole water analysed in Tafo-Akim with their corresponding WHO (2017) standard values for drinking water.

Table 5: Mean Levels of Major Nutrients in Borehole Water in Tafo-Akim

Parameter	Site 1	Site 2	Site 3	Site 4	SD	WHO, 2017
Phosphate (mg/L)	**4.50**	**2.60**	**7.70**	**2.50**	2.43	0.30
Nitrate (mg/L)	2.25	0.60	1.80	2.25	0.78	10
Nitrite (mg/L)	0.021	0.004	0.007	0.005	0.008	1
Ammonia (mg/L)	0.015	0.000	0.055	0.000	0.026	1.5
Sulphate (mg/L)	1.0	0.0	3.0	2.0	1.3	250

Figures highlighted bold are outside the standard. **SD: Standard Deviation**

4.4.1 Phosphate (PO_4^{2-})

From Table 5, phosphates concentration varied widely from 2.50 mg/L to 7.70 mg/L with a standard deviation of 2.43. The minimum value was recorded at Site 4 while the maximum value was recorded at Site 3. All observed values for phosphate in this study were unacceptable, considering WHO’s (2017) guideline level of 0.30 mg/L.

A similar research at Aburi and Dodowa recorded a slightly lower phosphate concentration of 0.5 mg/L to 5.8 mg/L with a standard deviation of 1.42 (Apau et al., 2014). The high concentration of phosphate can be attributed to agricultural activities in the community. The major component of most agro-chemicals (that is fertilizers such as NPK, pesticides such as malathion, parathion, diazinon and herbicides such as sunphosphate and glyphosphate) is phosphate (Ghazali et al., 2013; Teodorescu et al., 2009; Wimalawansa, 2016).

Phosphate is an important nutrient for plant growth but its presence in water bodies even in small quantities lead to algal bloom (Ohio EPA, 2011). Most dissolved phosphates combine with suspended particles in water to contribute to water turbidity just as the algae produced as a result of high phosphate levels in water (Putz, 2003). This is in line with the observed high turbidity and algae growth at Site 3 (Table 5; Figure 4).

4.4.2 Nitrate (NO_3^-)

Nitrate levels for the water analysed fluctuated between 0.60 mg/L at Site 2 and 2.25 mg/L at Site 1 and 2 with a standard deviation of 0.78 (Table 5). All values observed fall below WHO (2017) maximum guidelines level of 10 mg/L.

Similar studies in Aburi, Kumasi and the northern sector recorded maximum values for nitrate as 0.73 mg/L, 0.60 mg/L and 6.00 mg/L respectively (Apau et al., 2014; Nkansah et al., 2010; Saana et al., 2016). The observed values are in line with Jafari and Mostafavi (2019), who says that, the level of nitrate in underground water is normally low, except in pollution situation, due to denitrification.

Nitrate in blood can be absorbed by hemoglobin to form methemoglobin, which interferes with oxygen carrying capacity of blood in the body. Severe methemoglobinemia can cause brain damage and lead to death (WHO, 2011).

4.4.3 Nitrite (NO_2^-)

From Table 5, the observed values for nitrite ranges from 0.004 mg/L to 0.021 mg/L. The values deviate narrowly from each other as observed in the standard deviation of 0.008. All the mean values observed are desirable considering WHO (2017) guideline level of 1.00 mg/L.

Similar studies in Kumasi recorded maximum values for nitrite as 0.038 mg/L (Nkansah et al., 2010). The observed values for nitrate and nitrite agree that, there is a high correlation between nitrate and nitrite as a result of nitrification (Yin et al., 2022).

Nitrite can get to human stomach through consumption of contaminated drinking water and reacts with nitrosatable substances in the stomach to form N-nitroso compounds. Many N-nitroso compounds are carcinogenic to many animals and humans (Ward *et al.,* 2005). Nitrite is a mutagenic substance and has the ability to change the genetic makeup of an individual (WHO, 2011). The deleterious effects of nitrite in people especially children make it important to maintain its concentration in drinking water below 1mg/L (WHO, 2017).

4.4.4 Ammonia (NH_3)

Ammonia concentration ranges from 0.000 mg/L to 0.055 mg/L with a standard deviation of 0.026 (Table 5). The minimum value was observed at Site 2 and 4 while the maximum value was observed at Site 3. The high value observed at Site 3 may be as a result of anaerobic degradation of organic matter and organic waste disposal close to the borehole (Brennan et al., 2017; Figure 4). All observed values are however lower than WHO (2017) guideline level of 1.5 mg/L.

A similar study in the northern sector of Ghana also recorded low values for ammonia from 0.00 mg/L to 0.08 mg/L with a standard deviation of 0.02 (Saana et al., 2016). The observed values for ammonia, nitrate and nitrite agree that, there is a high correlation between ammonia, nitrate and nitrite as a result of nitrification (Yin et al., 2022).

Ammonia can cause odour and taste problems in drinking water (Herschy, 2012; WHO, 2017). Ammonia can also compromise disinfection efficiency, increase oxidant demand, cause the failure of filters for the removal of manganese and corrode copper alloy pipes and fittings. Moreover, a major concern with ammonia in drinking water is nitrification associated with the formation of nitrites and nitrates (Potgieter et al., 2020; Water Security Agency, 2012).

4.4.5 Sulphate (SO_4^{2-})

From Table 5, the observed sulphate concentration values for the water samples analysed increases linearly from 0.0 mg/L to 3.0 mg/L with a standard deviation of 1.3. The minimum value was observed at Site 2 while the maximum value was observed at Site 3. Sulphate concentration of water samples analysed are acceptable, considering WHO's (2017) guideline level of 250.0 mg/L.

Kyerematen g (2014), in a similar study at Ahenema Kokoben in the Ashanti region also recorded sulphate values of 1.18 mg/L to 1.60 mg/L with a standard deviation of 0.20. These studies are in line with WHO (2011), that, natural background levels of sulphates in most water sources are always very small and vary between 0.1 to 10 mg/L. Another study in the Eastern region however recorded a higher value of 93.75 ± 49.98 mg/L (Apau et al., 2014).

The large intake of sulphate can have some undesirable physiological effects like dehydration, gastrointestinal irritation and catharsis. In addition, excess Sulphate may also contribute to hardness of water and cause corrosion of drinking water distribution systems. Under anaerobic conditions, sulphate in water may be reduced to H_2S and this can give the water source an unpleasant or rotten egg smell (WHO, 2017).

4.5 Other Chemical Parameters

Table 6 below shows the mean values of other chemical parameters of borehole water analysed in Tafo-Akim with their corresponding WHO (2017) standard values for drinking water.

Table 6: Mean Levels of other Chemical Parameters in Borehole Water in Tafo-Akim

Parameter	**Site 1**	**Site 2**	**Site 3**	**Site 4**	**SD**	**WHO, 2017**
Alkalinity (mg/L)	28.0	23.5	52.5	21.0	14.5	120
Total Hardness (mg/L)	72.0	51.0	125.0	42.0	37.2	500
Calcium Hardness (mg/L)	49.0	30.0	110.0	37.0	36.5	500
Magnesium Hardness (mg/L)	23.0	21.0	15.0	5.0	8.1	500
Chloride (mg/L)	19.5	16.5	11.0	22.0	4.7	250
Cyanide (mg/L)	0.0005	0.0025	0.0075	0.0020	0.0030	0.07

SD: Standard Deviation

4.5.1 Alkalinity

From Table 6, the observed alkalinity of water samples analysed ranged from 21.0 mg/L to 52.5 mg/L with a standard deviation of 14.5. The high standard deviation indicates that, the observed values of alkalinity deviated widely from each other. Alkalinity level of the water samples analysed is desirable, considering WHO's (2017) guideline of 120 mg/L.

A similar study in the Eastern region recorded alkalinity values ranging from 10.00 mg/L to 260.34 mg/L with a standard deviation of 62.09. The low alkalinity of the water samples in the study area may be connected to the geology of the area which is dominated by quartzite and weakly metamorphosed sandstones. These rocks have been identified to impart acidity to underground water (Ganyaglo, et al., 2011).

4.5.2 Total hardness

From Table 6, the total hardness of water samples analysed fluctuated between 42.0 mg/L and 125 mg/L with a standard deviation of 37.2. Total hardness observed in the water samples analysed fall within WHO's (2017) guideline level of 500 mg/L.

The total hardness values observed in this study are in agreement with similar studies in the Eastern region, Ashanti region and the northern sector of Ghana (Apau et al., 2014; Nkansah et al., 2010; Saana et al., 2016). Hardness in drinking water does not pose negative health effect on people (WHO, 2008). It however, increases soap consumption and later causes scum formation. WHO (2011) guideline value for water hardness is 500 mg/L as $CaCO_3$ and is often tolerated by a lot of consumers (Basavanthappa, 2008).

4.5.3 Calcium and magnesium hardness

Calcium hardness ranged from 30.0 mg/L to 110.0 mg/L with a standard deviation of 36.5 (Table 6). Magnesium hardness ranged from 5.0 mg/L to 23.0 mg/L with a standard deviation of 8.1 (Table 6). Calcium and magnesium hardness observed in the water samples analysed fall below WHO (2017) guideline level of 500 mg/L.

Calcium and magnesium hardness values observed in this study are in agreement with similar studies in the Eastern region, Ashanti region and the northern sector of Ghana (Apau et al., 2014; Nkansah et al., 2010; Saana et al., 2016). The low concentrations of Ca^{2+} observed in this study could be attributed to the absence of sulphate and phosphate containing rocks in the study area (Saana et al., 2016).

No evidence of adverse health effects specifically attributed to calcium and magnesium in drinking water has been established (WHO, 2011). However, undesirable effects due to the presence of calcium and magnesium in drinking water may result from their ability to render water hard (Tay, 2004). Drinking hard water may assist in strengthening bones and teeth. However, high concentration of calcium may adversely affect the absorption of other essential minerals such as iron and zinc in the body.

4.5.4 Chlorides (Cl^-)

Chloride ion concentration in the water samples analysed ranged from 11.0 mg/L to 19.5 mg/L with a standard deviation of 4.7 (Table 6). Total hardness observed in the water samples analysed fall within WHO (2017) guideline level of 250 mg/L.

Chloride ion values observed in this study agreed with Nkansah et al., (2010) in a similar study 0.2 mg/L to 29.4 mg/L. Chloride is needed for proper functioning of the body as it ensures balance in body fluids. There are no health effects associated with chloride. However, at elevated levels, the presence of sodium and chloride ions in water becomes health concern to people on sodium-restricted diet and those with heart diseases (WHO, 2011).

4.5.5 Cyanide (CN^-)

Cyanide concentration in the water samples analysed ranged from 0.0005 mg/L to 0.0075 mg/L with a standard deviation of 0.0030 (Table 6). The small value of standard deviation signifies that, the observed values of cyanide concentration differ only slightly from each other. Cyanide concentration observed in the water samples analysed fall within WHO (2017) guideline level of 0.07 mg/L.

Similar studies at Bogoso and Dumasi, in the Western region of Ghana recorded values (0.741±0.001 and 0.848±0.001 respectively) which were higher than WHO’s

(2017) standard (Obiri et al., 2007). Another study in the Brong Ahafo region also recorded values which are above the WHO standard. These observed values were attributed to mining activities in those areas.

Cyanide is highly acutely toxic. It is detoxified in the liver by first-pass metabolism following oral exposure. As a consequence, exposure to a dose spread over a longer period, through a day, for example, will result in lower toxicity, or higher tolerance, than the same dose given in a single bolus dose (Herschy, 2012). Exposure to high doses can give rise to thyroid toxicity as a secondary effect of exposure due to the inhibition of iodine uptake from the thiocyanate generated through the detoxifying action of rhodanese (IPCS, 2004; WHO, 2017).

4.6 Microbial Parameters

Table 7 below shows the mean values of major microbial parameters of borehole water analysed in Tafo-Akim with their corresponding WHO (2017) standard values for drinking water.

Table 7: Mean Levels of Microbial Parameters in Borehole Water in Tafo-Akim

Parameter	Site 1	Site 2	Site 3	Site 4	SD	WHO, 2017
T. Coliform (cfu/100 mL)	0	**100**	0	0	50	0
E. Coli (cfu/100 mL)	0	0	0	0	0	0
HPC (cfu/100 mL)	0	**850**	0	**50**	417	0

Figures highlighted bold are outside the standard. **SD: Standard Deviation**

4.6.1 Total coliform

From Table 7, total coliform in the water samples analysed ranges from 0 cfu/100 mL to 100 cfu/100 mL with a standard deviation of 50. The maximum count was recorded at Site 2. This water is undesirable considering WHO (2017) guideline level of 0 cfu/100 mL. It has a high risk of infection (Table 1).

This agrees with a study by Boakye (2013), who recorded a slightly higher count of 4 $\times 10^5$ cfu/100 mL to 43 x 10^6 cfu/100 mL in a similar study at Kumasi. The presence of total coliform in drinking water is of concern since it indicates possible contamination of microbiological agent that may pose adverse health problem to consumers (Brian, 2012). This agrees with the students at Site 2 assertion and the researchers' suspicion that, the drinking water is the cause of periodic 'sore throat' among the students. The presence of coliforms in these groundwater samples studied can be attributed to the absence of residual chlorine, an indication that the borehole water had not been chlorinated prior to sampling (Saana et al., 2016).

4.6.2 Escherichia coli

From Table 7, there was no detection of *E. coli* in the water samples analysed and hence agrees with WHO (2017) guideline level of 0 cfu/100 mL. This is in line with a study by Nkansah et al. (2010), where E. *coli* for all water samples analysed at Kumasi metropolis are below detection at minium detection limit of 20 MPN per 100 mL.

E. coli is considered the most suitable index of faecal contamination and as such it is the first organism of choice in monitoring programmes for verification, including surveillance of drinking water quality (Ashbolt et al., 2001). This suggests that, there is no feacal contamination in the study sites.

4.6.3 Heterotrophic plate count (HPC)

From Table 7, heterotrophic plate count (HPC) of water samples analysed ranged from 0 cfu/100 mL to 850 cfu/100 mL. There was no detection of HPC at Site 1 and 3 while Site 2 recorded the maximum mean count of 850 cfu/100 mL and a maximum count of 1,200 cfu/100 mL during the dry season (Appendix A). Water samples analysed at Site 2 and 4 are unacceptable for drinking, considering WHO's (2017) guideline level of 0 cfu/100 mL. Site 4 has a high risk (50 cfu/100 mL) while Site 2 has a higher risk (850 cfu/100 mL) of infection (Table 1).

This observation is in line with the student's (at Site 2) assumption and the researchers' suspicion that, the borehole water may be a contributing factor to the purported sore throat among the students. *Aeromonas spp.* can cause infections in humans, including septicaemia, particularly in immunocompromised patients, wound infections and respiratory tract infections. There have been some claims that Aeromonas spp. can cause gastrointestinal illness, but epidemiological evidence is not consistent (Herschy, 2012). According to Brian (2012), action is needed to be taken on water which has been compromised by microbiological contaminants.

4.7 Seasonal Variations

The mean values of the results obtained from all the four sites for each parameter was determined and used for comparison. The results of the dry season were then compared to that of the raining season.

Null hypothesis: H_0: There is no statistically significant difference between the means of parameters measured for the dry season and the raining season (using zero concentration for metals not detected and the limit of detection of the instrument for metals not detected).

Alternate Hypothesis: H_a: There is a statistically significant difference between the means of parameters measured for the dry season and the raining season (using zero concentration for metals not detected and the limit of detection of the instrument for metals not detected).

4.7.1 Physical parameters

Table 8 below is the ANOVA Table of physical parameters of water samples measured during the dry season and raining season.

Table 8: ANOVA Table of Physical Parameters

Source of Variation	SS	Df	MS	F	P-value	F crit
Between Groups	23382.59	1	23382.59	0.040859	0.842718	4.60011
Within Groups	8011812	14	572272.3			
Total	**8035194**	**15**				

From Table 8, the calculated P-value is 0.842718. Since the calculated P-value is greater than 0.05, we fail to reject the null hypothesis. This means that, there is no significant difference between the means of physical parameters measured for the rainy season and that of the dry season.

4.7.2 Heavy metals

Table 9 below is the ANOVA Table of heavy metal concentration in the water samples measured.

Table 9: ANOVA Table of Heavy Metals

Source of Variation	SS	Df	MS	F	P-value	F crit
Between Groups	0.003889	1	0.003889	0.09474	0.77361	7.70864
Within Groups	0.164195	4	0.041049			
Total	**0.168084**	**5**				

From Table 9, the calculated P-value is 0.77361. The calculated P-value is greater than 0.05 and therefore we fail to reject the null hypothesis. This means that, there is no significant difference between the means of heavy metal concentrations measured for the rainy season and that of the dry season.

4.7.3 Chemical parameters

Table 10 below is the ANOVA Table of chemical parameters of water samples measured during the dry season and raining season.

Table 10: ANOVA Table of Chemical Parameters

Source of Variation	**SS**	**Df**	**MS**	**F**	**P-value**	***F crit***
Between Groups	0.522614	1	0.52261	0.00077	0.97823	4.41387
Within Groups	12290.33	18	682.796			
Total	**12290.86**	**19**				

From Table 10, the calculated P-value is 0.97823. Since the calculated P-value is greater than 0.05, we fail to reject the null hypothesis. This means that, there is no significant difference between the means of chemical parameters measured for the rainy season and that of the dry season.

4.7.4 Microbial parameters

Table 11 below is the ANOVA Table of microbial parameters of water samples measured during the dry season and raining season.

Table 11: ANOVA Table of Microbial Parameters

Source of Variation	SS	df	MS	F	P-value	F crit
Between Groups	1666.667	1	1666.667	0.093023	0.77558	7.708647
Within Groups	71666.67	4	17916.67			
Total	**73333.33**	**5**				

From Table 8, the calculated P-value is 0.77558. Since the calculated P-value is greater than 0.05, we fail to reject the null hypothesis. This means that, there is no significant difference between the means of microbial parameters measured for the rainy season and that of the dry season.

This study agreed with Sharma and Chhipa (2016), that, there is no significant difference between water characteristics for the rainy season and that of the dry season. According to the authors, significant differences observed may be due to other factors like the topography of the soil.

CHAPTER FIVE

SUMMARY, CONCLUSION AND RECOMMENDATIONS

5.0 Overview

This chapter presents a summary of the findings and conclusion of the study. It also includes recommendations for stakeholders and suggestions for further research.

5.1 Summary of Findings

Water samples collected from the boreholes in Tafo-Akim were analysed for borehole water quality and its suitability for drinking. The purpose of the study is to determine the quality and hence the health implications of borehole water in Tafo-Akim in the Eastern Region of Ghana. Two sets of samples were taken from each of the four boreholes analysed. One set of samples was taken in the dry season while the other was taken in the raining (wet) season. Major heavy metals, physicochemical and microbial parameter of drinking water were used as a quality indicator. All instruments and methods used in this study were based on international standard recommendation, availability, proximity to the laboratory and cost involved.

Results obtained from the water samples analysed shows that, all physical parameters analysed except pH, conductivity, colour and turbidity are within the WHO's standard for drinking water. Heavy metal concentrations observed are also within the WHO's standard for drinking water except for iron at Site 3. All values obtained for phosphate are outside the WHO's standard while all other chemical parameters are within the standard for drinking water. Values observed for microbial analysis are unacceptable considering the WHO's guidelines for drinking water.

Statistical comparison of results obtained in the dry and raining season using one way ANOVA shows no significant difference for all parameters measured. The level of probability at which significant difference existed between the groups was set at $p<0.05$ at 95% confidence level.

5.2 Conclusions

Water samples collected from the boreholes in Tafo-Akim were analysed for groundwater quality and its suitability for drinking. Major heavy metals, physicochemical and microbial parameter of drinking water were used as a quality indicator. From the results obtained and analysis made, the following conclusions have been arrived at from a water quality point of view.

At Site 1, all of the data for the physicochemical parameters indicated tolerable quality except pH, electrical conductivity and phosphate which are not consistent with WHO Standard guidelines. Bacteriological quality of the water samples analysed in this study met the standard requirements set for drinking water by the WHO. Water at this site is hence potable.

At Site 2, all of the data for the physicochemical parameters indicated tolerable quality except phosphate which is above WHO guideline value. Bacteriological quality of the water samples analysed in this study indicates very high risk of infection based on standard requirements set for drinking water by the WHO. The water at this site therefore needs treatment.

At Site 3, all of the data for the physicochemical parameters indicated tolerable quality except pH, colour, turbidity, iron and phosphate which are not consistent with WHO Standard guidelines. Bacteriological quality of the water samples analysed in this study met the standard requirements set for drinking water by the WHO. Water at this site is not potable considering the health effects of high iron consumption.

At Site 4, all of the data for the physicochemical parameters indicated tolerable quality except pH and phosphate which are not consistent with WHO Standard guidelines. Bacteriological quality of the water samples analysed in this study indicates high risk of infection based on standard requirements set for drinking water by the WHO. The water at this site, therefore, needs treatment.

5.3 Recommendations

Based on the results obtained and conclusions drawn from the study, the following have been recommended.

- There should be regular clean-up of the storage facilities and chlorination of the water to kill any micro-organism that may be in the water.
- Reduction / treatment of iron should be done by installing water softener, Potassium Permanganate or green sand filters at Site 3 to aid the removal of iron.
- Since the groundwater is used for water supply, there should be constant monitoring of the groundwater levels as well as good practices towards groundwater recharge to ensure sustainable abstraction.

5.4 Suggestions for Future Research

Based on the conclusion drawn from the study, I suggest that, there should be follow-up studies to establish;

- whether the microbial contamination at Site 2 is from the groundwater source or from the storage and distribution systems.
- The kind/type of bacteria growth shown by the purplish-red (fuchsia) colour (Figure 6) in brilliance *E. coli* medium should be investigated further.

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APPENDIX A

ANALYSIS RESULTS DURING THE DRY SEASON

Sampling Date:	16/03/2021	Temperature In:	35.0ºC HPC/36.5ºC EC
Date of Analysis:	17/03/2021	Temperature Out:	35.1ºC HPC/36.6ºC EC
Time of Inoculation:	11:50 am	Date of Inspection:	18/03/2021
Time of Incubation:	12:10 pm		

Parameter	Unit	Site 1	Site 2	Site 3	Site 4
Temp	ºC	27.4	26.8	26.7	26.4
pH	pH Units	<6.0	6.8	6.3	<6.0
Conductivity	µS/cm	23.6	13.94	34.32	25.48
Salinity	mg/L	0.1188	0.0697	0.1716	0.1274
TDS	mg/L	118.3	69.8	172.1	127.4
Colour	HU	1	1	20	1
Turbidity	NTU	0	0	7	0
Alkalinity	mg/L	31	20	61	28
Hardness	mg/L	64	40	120	54
Calcium H	mg/L	48	28	106	44
Chloride	mg/L	19	17	12	24
TSS	mg/L	0	0	9	0
Copper	mg/L	0.01	0.00	0.13	0.01
Manganese	mg/L	0.023	0.001	0.386	0.004
Phosphate	mg/L	4.5	2.6	7.7	2.5
Iron	mg/L	0.03	0.01	1.24	0.08
Cyanide	mg/L	0.000	0.004	0.007	0.003
Nitrate	mg/L	1.7	0.1	1.1	2.6
Nitrite	mg/L	0.005	0.002	0.007	0.004
Ammonia	mg/L	0.01	0.00	0.01	0.00
Sulphate	mg/L	1	0	3	3
T. Coliform	cfu/100mL	0	0	0	0
E. Coli	cfu/100mL	0	0	0	0
HPC	cfu/100mL	0	1200	0	0

APPENDIX B

ANALYSIS RESULTS DURING THE RAINING SEASON

Sampling Date:	21/07/2021	Temperature In:	35.0ºC HPC/37.0ºC EC
Date of Analysis:	21/07/2021	Temperature Out:	35.0ºC HPC/36.3ºC EC
Time of Inoculation:	10:50 am	Date of Inspection:	22/07/2021
Time of Incubation:	10:46 am		

Parameter	**Unit**	**Site 1**	**Site 2**	**Site 3**	**Site 4**
Temp	ºC	27.7	26.9	25.3	28.5
pH	pH Units	6.1	6.5	6.5	6.1
Conductivity	µS/cm	20.14	12.28	28.68	12.68
Salinity	mg/L	0.1007	0.0614	0.1434	0.0634
TDS	mg/L	100.7	61.4	143.4	63.4
Colour	HU	1	1	23	1
Turbidity	NTU	0	0	22	0
Alkalinity	mg/L	25	27	44	14
Hardness	mg/L	80	62	130	30
Calcium H	mg/L	50	32	114	30
Chloride	mg/L	20	16	10	20
TSS	mg/L	0	0	18	0
Copper	mg/L	0.00	0.01	0.19	0.00
Manganese	mg/L	0.012	0.006	0.361	0.016
Iron	mg/L	0.00	0.01	1.93	0.00
Cyanide	mg/L	0.001	0.001	0.008	0.001
Nitrate	mg/L	2.8	1.1	2.5	1.9
Nitrite	mg/L	0.036	0.005	0.007	0.005
Ammonia	mg/L	0.02	0.00	0.10	0.00
Sulphate	mg/L	1	0	3	1
T. Coliform	cfu/100mL	0	200	0	0
E. Coli	cfu/100mL	0	0	0	0
HPC	cfu/100mL	0	500	0	100