UNIVERSITY OF EDUCATION, WINNEBA

ASSESSMENT OF WATER QUALITY FROM SELECTED BOREHOLES IN ASESEWA - GHANA

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MASTER OF PHILOSOPHY

2023

UNIVERSITY OF EDUCATION, WINNEBA

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A thesis in the Department of Chemistry Education Faculty of Science Education, submitted to the School of Graduate Studies in partial fulfillment of the requirements for the award of the degree of Master of Philosophy (Chemistry Education) in the University of Education, Winneba

JUNE, 2023

DECLARATION

CANDIDATE'S DECLARATION

I, **GODWIN YAO BUTTA** 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 M. Phil 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. ARKOFUL SAM

Signature: ……...……

Date: ……...……

DEDICATION

I dedicate this thesis to my parents, siblings, Ghanaian and Africa students.

ACKNOWLEDGEMENTS

My gratitude and praise go to the Lord Jesus Christ who has been my guide throughout my studies. I also wish to express my sincere gratitude and appreciation to my supervisor Prof. Arkoful Sam, whose encouragement, discussions, suggestions and prompt vetting of the script have made this Research work a reality. I am grateful to the entire lecturers and other staff of the chemistry department-UEW.

My next thank goes to Mr. Reiss Paul Okoto, the Headmaster of Asesewa Senior High School, Mr. Robert Kwasi Butta, Assistant Headmaster Academic of Asesewa Senior High School, Mr. Victor Fred Ohene, the Head of Department of Science, Mr. Thomas Abambilla and Mr. Teye-Nobi Peter both at Information Communication Technology Department for their unfeigned support, assistance and encouragement.

My appreciation also goes to Mr. Emmanuel Dziwornu Aklie and Mr. Felix Akompi, of Department of Science at Awudome Senior High School, Mr. Thomas Kwame Dorpe and Mr. Ezekiel Isaac Butta for their encouragement and support and proof reading of the script.

My thanks also go to the following people: Mr. Moses Abeiku Paintsil, the Manager of Water Quality Assurance Department of Ghana Water Company Limited Koforidua, Mr. Kobina Asieku Boni, Nafisa Mahama Issah, Delali Dornyo, Mavis Oduro Asante, Veronica Acquah, Mavis Amponi and Lydia Gbengor all staff in Water Quality Assurance Department of Ghana Water Company Limited koforidua for their dedicated work and assistance during the water sample analysis.

Last but not the least, my thank goes to Mr. Humphrey Ferdinard Darko, Dr. K. A. Asante, Head Environmental Chemistry and Sanitation Engineering Division, Rev.

Dr. Gloria Addico, Head of Environmental Biology and Health Division and all the staff of Water Research Institute, Council for Scientific and Industrial Research Premises, Airport Residential Area, Accra, Ghana for their assistance in analysing the dry season water samples.

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ABSTRACT

An assessment of borehole water quality in the Asesewa-Ghana was carried out at three sampling sites at Asesewa in the Upper Manya Krobo District of the Eastern Region of Ghana. Samples were collected in May, 2022 for wet season and January and February, 2023 for the dry season. Analysis of various physicochemical parameters including Electrical conductivity, pH, turbidity, total dissolved solids, total suspended solids, salinity, alkalinity, phosphate, nitrate, nitrite, chloride, sulphate, fluoride, silica, cyanide, ammonia, chromium, hardness, arsenic, metals microbial presence were made. Metals analysed were Zinc, calcium, copper, potassium, sodium, manganese, magnesium and iron. Concentrations of the metals were determined using DR 6000 Spectrophotometer, alkalinity, chloride and hardness were analysed using EDTA titration, electrical conductivity using conductivity meter, pH and colour using colour DR 6000 Spectrophotometer, salinity total dissolved solids, total suspended solids using conductivity meter and turbidity using turbidimeter. The result of the study revealed that, the values are: the pH value 4.60 pH unit, 4.93 pH unit and 4.95 pH unit for dry season and 6.40 pH unit, 6.40 pH unit and 6.30 pH unit for wet season and 5.50 pH unit, 5.67 pH unit and 5.63 pH unit for their means at sites G, N and O respectively making it acidic. The Silica value 10.14 mg/L and 12.71 mg/L for wet season at sites G and N respectively. Bicarbonate values 13.40 mg/L, 29.80 mg/L and 19.87 mg/L for dry season and 26.84 mg/L, 43.92 mg/L and 21.96 mg/L for wet season and 20.12 mg/L, 36.86 mg/L and 20.92 mg/L for the means at sites G, N and O. Phosphate values 0.44 mg/L at site O for dry season and 1.70 mg/L, 2.40 mg/L and 1.30 mg/L for wet season and 0.88 mg/L, 1.24 mg/L and 0.87 mg/L means at sites G, N and O respectively. Potassium content 20.90 mg/L, 13.95 mg/L and 21.65 mg/L at sites G, N and O for dry season and 15.97 mg/L, 14.29 mg/L for wet season at sites G, and O and finally Magnesium hardness value at site G was found to be 66.30 mg/L. The water quality index for dry season was found to be 25.73 and wet season 210.94 at site G, at N for dry season was found to be 15.13 and wet season 267.14 and finally, at O for dry season was found to be 59.82 and wet season 157.23. The study clearly indicates that, the selected borehole water sites at Asesewa in the Upper Manya Krobo District of the Eastern Region of Ghana should be monitored to ensure the parameters that were within permissible limit are and those above should be brought within by means of treatment so that it can therefore be used for human consumption and domestic use.

CHAPTER ONE

INTRODUCTION

1.0 Overview

This chapter gives a general introduction to the study. It encompasses the background to the study, statement of the problem, the aim of the study, objectives of the study, as well as the significance of the study, limitation of the study, delimitation of the study and the organization of the work.

According to Upper Manya Krobo District Assembly Budget Estimates Report, (2019), the four main sources of water in the district are borehole, river, stream and public tap. The percentage of households who drink water from boreholes was 37.7%.

Despite the proliferation of boreholes, not much information exists on the quality of ground- water in Ghana. It is assumed that ground water is naturally pure and free from infections (Apau et al., 2013).

Despite the reported increase to access improved water sources in many rural regions of Ghana, the use of unimproved water sources is still common and household water source choices in rural Ghana. Typically, women are responsible for 64% of the household water collection (Armah et al., 2018). Ability to choose improved water sources over unimproved water sources for household activities depends on water management decisions made at the district level, local level of civil government, and the local level of traditional government (Deal & Sabatini, 2020). Typically, District Assemblies deal with local government and resource management; however, water resource planning cannot be implemented without input from the Chief of the community (Chew et al., 2019). At each level, men have traditionally determined

water management policy, despite the dominant role of women in water collection (Chew et al., 2019).

Beyond the political and social factors that affect water source choices, it is known that water source preferences are also affected by practical considerations, such as distance to the water source and perceived water quality (Chew et al. 2019). Some residents of rural Ghana chose not to use pipe-borne water systems because it tasted salty and it did not lather with soap. Aesthetic characteristics, such as taste, color, and smell are also known to play a role in perception of risk. Other studies have noted rationing of high-quality water for consumptive purposes and matching different source types to different uses of tasks (Bakobie, Ibrahim & Duwiejuah, 2020).

Studies have found that, groundwater used by school children, mostly in rural areas of developing countries, is of poor quality and has negative health impacts (Odiyo et al., 2020).

Amevenku et al., (2012) stated that, during the implementation of the Water Resources Assessment programme in the Manya Krobo Districts, some challenges were observed to be militating against the success of the programme and these included low success rate, low yield and poor water quality. These challenges prevented the achievements of the expected targets of water delivery and coverage in the district, which according to the Millennium Development Goals, should reach at least 75 % by 2015 (Amevenku et al., 2012).

Safe drinking water is still a challenging public health issue in the midst of lots of borehole water in-use in our various communities; thus, these further justify the trend that the integrity of such a source of drinking water might not be guaranteed in the

end and access to safe drinking water is a human right and it is one of the basic requirements for good health (Azuonwu, 2020).

Amfo-Otu, (2012) reported that, most studies linked the physicochemical quality of groundwater to health and that, there seems to be a gap between groundwater quality and its effect on distribution systems and consumer complaints. Reports suggest that water quality tests are either not regularly done or not done at all for rural water supply systems, wells and boreholes as suggested by experts in the field (Amfo-Otu, 2012).

1.1 Background to the Study

Water is an essential component of life that is why the adage "water is life" and for that matter the use of quality water (Mugagga & Nabaasa, 2016). Water is very important for Biochemical processes in the body such as digestion, circulation, excretion and also for temperature control and also used for cooking, drinking, washing and bathing in our home (Mara et al., 2010). Water is a resource that has many uses, including recreation, transportation, hydroelectric power and domestic, industrial and commercial uses (Igwe et al., 2017). Igwe et al (2017), also asserted that water also supports all forms of life and affects our health, lifestyle, and economic well-being.

Appiah-Effah et al., (2021) reported that, the importance of clean and safe water cannot be overstressed. Appiah-Effah et al. (2021) asserted that access to potable water is a basic right and necessary for good health and wellbeing. The UN General Assembly has explicitly called for actions leading to the provision of "safe, clean, accessible and affordable drinking water and sanitation for all" and there are myriad uses of water and thus, water is considered an elixir of life since most activities of

humans involves the use of water (United Nation, 2010). At the domestic level, water is mostly consumed and used for general household activities such as cooking, washing, bathing, etc. (Appiah-Effah et al 2021). Water makes up 60-75% of human body weight, a loss of just 4% of total body water leads to dehydration and a loss 15% can be fatal, likewise, a person could survive a month without food but would not survive 3 days without water and this crucial dependence on water broadly governs all life forms and shows clearly that water is vital for survival (Sargen, 2019).

Chaplin, (2001) found that, life as we know it could not have evolved without water and dies without it. Droughts cause famines and diseases and water is essential to sustain life and a satisfactory (adequate, safe and accessible) supply must be available to all (W.H.O, 2011). Improving access to safe drinking-water can result in tangible benefits to health (W.H.O, 2011). Every effort should be made to achieve drinking-water that is as safe as practicable and safe drinking-water, as defined by their guidelines, does not represent any significant risk to health. Consumption, including different sensitivities that may occur between life stages and those at greatest risk of waterborne disease are infants and young children (Charles, Nowicki & Bartram, 2020).

With the increasing demand for water, irrespective of its potability; borehole has become a common source of drinking water in many countries across the globe. In Ghana the quality of drinking water contributed to an increase in morbidity, due to water borne diseases especially in children and immuno-compromised individuals thereby increasing the burden of diseases (Azuonwu, 2020).

Water is an important component of life; Water supply and accessibility is goal 6 of the Sustainable Development Goals (SDGs) that aims at ensuring environmental

sustainability, (Abok et al., 2018). Historically, efforts to ensure access to safe drinking and food processing water have been focused on the community-based water sources. Most regions of the developing nations are experiencing shortage of potable water supply as improved water sources are only limited to urban areas, (Abok et al., 2018).

Research has shown a major link between water supply infrastructure, treatment operations, water quality, waterborne diseases and health (Hrudey & Hrudey, 2004). It has been indicated that a lot of waterborne diseases epidemics have been preceded by customer complaints about aesthetic water quality problems (Hrudey & Hrudey, 2007).

Water quality complaints have been used to monitor treatment operations and quantify the extent of distribution and water quality problems (Dietrich, 2006). Research has shown that rural water wells are not tested as suggested by professionals, and are contaminated with pathogens and chemicals from various sources (Charrois, 2010). Others have shown that, 33% documented outbreaks of water-related infections could be attributed to groundwater systems (Reynolds, Mena & Gerba, 2008).

Ghana aims at achieving an efficient and effective management system for the sustainable development of water resources and to ensure full socio-economic benefits for present and future generations by 2025 (Owusu et al,. 2016). Water management is still a major developmental challenge as human activities have resulted in the dwindling of freshwater resources, increased pollution load, health and transportation problems and reduced ecosystem resilience which pose significant threat to sustainable development (Roosbroeck et al., 2006).

Lack of good quality water is the cause of 80% of diseases in developing countries (Lin, Yang & Xu, 2022). In many countries around the world, including Ghana, water has become a scarce commodity as only a small proportion of the populace has access to treated water (Nkansah, 2010). The assessment of water quality of water from boreholes, wells, springs and waterfalls has become imperative because they have a direct effect on the health of individuals (World Health Organisations, 2006).

The measurement of physicochemical and bacteriological properties of water enables scientists to predict its quality and the levels of these parameters in water must fall within an acceptable reference range prescribed by World Health Organization (World Health Organisations, 2003). In Ghana, Ghana standard Authority (GSA) provides permissible values for potable water parameters which must be complied with and these guidelines are adopted from the World Health Organisations (WHO) Guidelines for Drinking Water Quality (Danso-Boateng & Frimpong, 2013).

Hussain et al., (2013) reported in their studies that physicochemical characteristics of water quality are deteriorating day by day owing to anthropogenic activities. It is appropriate to assess drinking water safety by checking its quality at regular time interval as it was discovered that the use of unsafe drinking water has caused many human communities to suffer from a variety of water borne diseases (Yongsi, 2010). Man-kind should put in all effort to protect water bodies for healthy living (Lemo, 2002).

In assessing the quality of water for safety use, the physical, chemical and microbiological Parameters of water makes it desirable to study in the environment (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 (Ghana standard Authority (GSA) 2009; WHO, 2011). Good quality of water resources largely depends on physicochemical and biological characteristics (Medudhula, 2012).

Because of possible contamination of drinking water or poor treatment procedures, human beings suffer from different types of water related diseases like typhoid; diarrhea, cholera, dysentery, typhoid, and polio (Addisie, 2022). These are some of the diseases linked to poor drinking water quality. It is estimated that 485,000 people die worldwide from diarrhea worldwide as a result of contaminated drinking water (Addisie, 2022). Groundwater resources are formed when water infiltrated the topsoil and fills up voids within underlying soils and rocks (Pastore et al., 2020). Water shortage and contamination of existing water supplies threaten to be a critical environmental issue for agricultural production as well as for domestic and industrial uses. Many countries already have serious water contamination problems and more than one billion people lack access to clean water or adequate sanitation (Sam, 2007).

Upper Manya Krobo District is one of the thirty-two districts in the Eastern Region of the Republic of Ghana. It was carved out of the then Manya Krobo District in February, 2008 by Legislative Instrument 1842 in pursuance of the Government's Decentralization policy with its capital as Asesewa, a historic trading post, attracting a mix of cultures from all over the country. The district capital, Asesewa is about 45km drive from Koforidua, the regional capital of Eastern Region (Manya Krobo District Assembly Budget Estimates Report, 2019).

The Upper Manya Krobo District has a 2021 estimated population of 90,826 with males constituting 50.6 percent (45,958) and females 44,868 (49.4%) percent. The district is predominantly rural with 64,223 representing 77% of the population living in rural areas as compared to 19,285 (13%) people in the urban areas. This means more than three-quarters of the district's population is rural. Average household size in the district is 4.6 persons per household. Total Fertility Rate is 3.7, Literate population 66.7%, non-literate 33.3% (Upper Manya Krobo District Assembly Budget Estimates Report, 2019). The District is located in the Eastern part of the Eastern Region with coordinates 6°23'59.03"N 0°8'32.92"W (Wikipedia dictionary).

The four main sources of water in the district are borehole, river stream, public tap and pipe borne water. About forty percent of households (37.7%) drink water from boreholes (Upper Manya Krobo District Assembly Budget Estimates Report, 2019).

1.2 Statement of the Problem

It has been observed in Asesewa that any time water from newly drilled borehole is stored for about three days, insoluble substances which are hard and difficult to remove are formed in the containers. Considering at the brown colour of the rocks and the hardpans through which the drilling is done at Asesewa, there is probability of high content of heavy metals in the land. In addition, the continuous complaint of burning sensation in the throat by the students of Asesewa Senior High School anytime they drink water from the borehole in the school calls for concern. There is therefore the need to assess the quality of borehole water in Asesewa to ascertain their suitability and safety for human consumption.

1.3 Purpose of the Study

The purpose of this study was to assess the quality of borehole water at Asesewa in the Upper Manya Krobo District in the Eastern Region of Ghana.

1.4 Objectives of the Study

The objectives of this study were to:

1. assess the physicochemical parameters of the borehole water at Asesewa in the Upper Manya Krobo District in the Eastern Region of Ghana.
2. assess the levels of some selected heavy metals and the microbial quality of borehole water at Asesewa in the Upper Manya Krobo District in the Eastern Region of Ghana.
3. calculate the weighted arithmetic water quality index of selected physicochemical parameters.

1.5 Research Questions

1. What are the physicochemical parameters values of borehole water at Asesewa-Ghana?
2. What are the heavy metals values and microbial presence of borehole water at Asesewa-Ghana?
3. Do the weighted arithmetic water quality index calculated for the physicochemical parameters of the borehole water at Asesewa-Ghana indicate they safe for use?

1.6 Significance of the Study

The outcome of the study would be made available to the relevant stakeholders such as Upper Manya Krobo District Assembly, Community water and Sanitation Agency at Asesewa and Asesewa Senior High School and would be useful for policy makers to develop proper policies towards the development of water resources in Ghana. It would also enable individuals who own and sell borehole water to improve upon the quality of their water.

1.7 Limitations of the Study

There are several components of water, but this study is limited to some selected physicochemical and microbial parameters due to cost and scarcity of materials. Another limitation of this Research work was that analysis was done at two places. The wet season analysis was done at Ghana Water Company Limited in Koforidua which later had challenges which were not resolved early which made the dry season analysis done at water Research Institute at Council for Scientific and Industrial Research, Accra. Moreover, there was total dryness of some sources of borehole water due to fall in water table during dry season.

1.8 Delimitation of the Study

Though there are several sources of borehole water in Ghana and the Eastern Region, this study focused on borehole water sources from some selected sites in Asesewa in Upper Manya Krobo District in Eastern of Ghana.

1.9 Organization of the Study

The Thesis is organised under five chapters. Chapter one dealt with, the background, the statement of the problem, purpose, research questions, significance, limitation, delimitation and organization of the study. The second chapter reviewed literature related to the study. Literature was reviewed under the following areas: Safe drinking water, Physical parameters of drinking water, Chemical parameters of drinking water, Microbial content of drinking water, Health implications of physicochemical parameters, microbial content of drinking water and Water Quality Index. The third chapter considered the materials and methods. It included sample collection and treatment, Collection of water samples for analysis, Analysis of water samples at Water Quality Assurance department of Ghana Water Company limited in Koforidua and finally the description of the processes involved in the analysis. The fourth

chapter took care of results, analysis and discussion obtained from the research. Finally, the fifth chapter was on conclusion, recommendations and suggestions of the study.

1.10 Abbreviations

DWAF: Department of Water Affairs and Forestry

EPA: Environmental Protection Agency

Feb.: February

IQ: Intelligent Quotient

Jan.: January

SDG: Sustainable Development Goals

U.S.: United States

UEW: University of Education, Winneba

UNESCO: United Nations Educational, Scientific and Cultural Organisation

UNICEF: United Nations International Children's Emergency Fund

W.H.O: World Health Organisation

WQI: Water Quality Index

CHAPTER TWO

LITERATURE REVIEW

2.0 Overview

This chapter reviews literature related to the study. The opinions, ideas, research works of other researchers and authors who have studied and written on water safety, that is physicochemical parameters were reviewed. Literature was reviewed under the following areas:

2.1 Safe drinking Water

With the ever-increasing world's population, provision of good quality drinking water is a challenge for governments especially in developing countries and nearly one billion people lack access to safe drinking water worldwide (Treacy, 2017). People therefore have resorted to the use of hand dug wells, boreholes and river water for their domestic, agriculture and industrial uses. Meanwhile no proper treatment is carried out on water from these sources before use (Apau et al., 2013). 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 (Pruss-Ustun et al., 2019). Water is necessary for the healthy development of man, animals and plants. Developing countries are witnessing deterioration in water quality as well as depletion of ground water which constitute another source of potable water. The preference for ground water to surface water may be due to the need for purification of the latter prior to distribution (Shmeis, 2018). Generally speaking, groundwater is characterized by low temperature, low redox potential, high carbon dioxide and mineral content, a smaller number of suspended solids and free from microbial contaminants (Briffa, 2020).

Amoako, (2011) stated that, groundwater is often considered as the best of these alternative sources of water, owing to natural protection from pollution when compared to surface and perceived natural filtration as water flows down during rainy period. The groundwater as one of the natural resources is of fundamental importance to human life, because of its perceived good microbiological quality in the natural state (Amoako, 2011). It is often the preferred source of drinking water supply as treatment is limited to disinfection and aesthetically, it looks clean and acceptable to various people as it is often free from odour and sometimes do have a pleasant taste, (Francis et al., 2015).

Despite the perceived safety associated with groundwater consumption, several researches have shown that groundwater can also be susceptible to contamination. Factors that influence the quality of groundwater include the geology of the aquifer, climate and anthropogenic activities (Chegbeleh, Akurugu & Yidana, 2020). To improve water quality, there should be a mechanism of keeping safe water source from chemical contaminants in an effective and protective way through the application of regular checkup and with interventions by taking exact measure periodically before it is supplied for usage (Behailu et al., 2018). Water is one of the most important and most precious natural resources which is vital to man's existence and without it, there would be no life on earth (Kilic, 2020)

Ghana is not exempted from the world water crisis which is affecting other countries in many parts of the world hence, assessment of groundwater quality status is important for socio-economic growth and development (Ishaku, 2011). Government of Ghana is currently developing groundwater resources for water supply to rural communities due to high pollution of surface water sources, lack of requisite human resource capacity and high cost of operating surface water treatment plants in the rural

areas (Kortatsi, 2007). Exploration report by the Water Research Institute in Ghana, indicated that 90% and 25% of the rural and urban communities uses groundwater sources for their domestic use respectively. Chemical composition of water may be rendered unfit for human consumption (Hassan & Aziz, 2019). The importance of groundwater quality in human health has recently attracted a great deal of interest (Vasanthavigar et al., 2010).

According to Samlafo & Ofoe (2017), water is essential as a medium for preparing food. One study noted that, the volume of cooking water available may be an important determinant for diarrhea incidence in children over 3 years of age. Water is a common chemical substance that is essential for the survival of all known forms of life. The major proportion of all water quality degradation worldwide is due to anthropogenic causes (Akhtar et al., 2021). Given the importance of safe drinking water, the availability of potable water has become a daunting problem (Gemeda, 2021). This is especially so in developing countries, where, coupled with illegal mining and sanitation conditions that leave much to be desired water resources have become threatened (Albaggar, 2021). The quality of water consumed is well recognized as an important transmission route for infectious diarrhoea and other diseases. The importance of water quality continues to be emphasised by its role in epidemics and contribution to endemic disease from pathogens (Freeman et al., 2017). Water provided for direct consumption and ingestion via food should be of a quality that does not present a significant risk to human health (Magana-Arachchi & Wanigatunge, 2020).

In urban areas, anthropogenic activities generate atmospheric emissions that mostly consist of submicron-sized particles and aerosols and therefore play a major role in contributing to the pollution of water bodies (Bouwman et al., 2001). Rapid

population growth, urbanization and large-scale development are potential factors in the pollution of road runoffs from urban roads and highways within a municipality. It becomes a serious problem, particularly in the heavily populated areas, where natural exchange of air is restricted by a compact settlement (Kuddus, Tynan & McBryde, 2020). The diffuse form of pollution which is fast becoming one of the nation's leading threats to water quality, is derived from contaminants washed off the surface of roads by rain water and carried either directly or indirectly into waterways or groundwater (Saifur & Gardner, 2021). Second-hand (home use) spare parts (tyres, brake lining, clutch plate lining, bearing and bushing, moving engine parts, etc.), which are commonly used by vehicle owners, wear out easily leaving contaminants on the surface of the roads. These are carried from the road surfaces in road runoffs during storm events, and either infiltrate into the soils within the immediate environment or may end up in various water sources (Khatri & Tyagi, 2014). The increasing number of over-aged vehicles in conjunction with heavy traffic in a municipality has also contributed to the pollution of the environment with heavy metals and has become a major concern because of their toxicity and threat to human life and the environment (Nawrot et al., 2020).

Odiyo et al., (2020) stated that, Studies have found that groundwater used by school children, mostly in rural areas of developing countries, is of poor quality. This poor quality has negative health impacts. Nearly 1.7 billion cases of childhood diarrhoeal disease which results to deaths of around 525,000 children every year are reported globally. Children are more susceptible to diseases than adults and therefore, the need for healthy school environment, including safe drinking water. It is crucial to assess and monitor the quality of groundwater used by school children and identify potential

health risks, as this will aid in identifying intervention strategies and preventive measures (Luvhimbi et al., 2022).

Azuonwu, (2020) reported that, the microbial contamination of borehole water has posed health threats and complications with some imminent waterborne disease outbreaks in some regions, especially in the developing countries like Nigeria. The issue of microbial contamination in borehole water is of public health concern because most of the water for consumption in these regions (developing countries) is from borehole, either from government facilities or private/homemade facilities (Lutterodt et al., 2018). As such, the quality of borehole water should be guaranteed since the common source of drinking water available. Microbial quality of borehole water is related to sanitary habits and environmental activities like agricultural practices (Lutterodt et al., 2018). Nonetheless, water remains the major source of transmission of enteric pathogens in developing countries Therefore, it is important to evaluate the quality of these boreholes to ascertain the presence of pathogenic microbes (Lutterodt et al., 2018).

In order to ensure a safe public health, water supply for human consumption must be free from pathogens, free from chemical toxins and must be physically clear and appealing to taste. It is also important that water for domestic, agricultural or industrial uses should not be acidic or alkaline than is required by standards for the purpose (Afiukwa & Eboatu, 2007).

Lack of safe drinking water and improved sanitation have been attributed to the occurrence of about 80% of all reported cases of diseases in developing world (Amfo-Otu et al., 2012). Water is essential to life and safe drinking water reduces the burden of infection and increases life expectancy (Amfo-Otu et al., 2012). Poor water quality

continues to pose a major threat to human health and safe drinking water is essential to the protection of public health and wellbeing of citizenry (Levallois & Villanuella, 2019).

Contaminants in water can affect the water quality and consequently the human health. Access to safe drinking water is considered a universal human right by the United Nations convention. However, this human right remains a dream for several developing countries in Asia, South America, and Africa, (Rahmanian et al., 2015). For instances, in Uganda previous studies have placed a lot of emphasis on the microbial load with a focus on infectious diseases. Little information is available regarding heavy metal concentrations in drinking water (Yasin, Ketema & Bacha 2015). Uganda lack of proper water treatment and these is increased agrochemical use and industrial growth which suggest that water contamination is ongoing and is a threat to public health (Yasin, Ketema & Bacha 2015). Several human-based practices that include pesticide application and industrialization are associated with soil and plant contamination. Subsequently, after the heavy rains, the runoff water carries the pollutants to water reservoirs from which humans and animals consume the contaminated water (Wuana & Okeiemen, 2011). Heavy metals subsequently bioaccumulate in the bodies of animals and humans predisposing them to cancer and other public health risks following oral ingestion (Syafrudin, et al., 2021). Water is the most important nutrient essential to the survival of all humanity because it is involved in every bodily function, and makes up about 75% of total body weight (Armstrong & Johnson, 2018).

The lack of this essential mineral can lead to serious implications such as hypertension, high cholesterol, and heart disease but recent studies have also linked the lack of water to headaches, arthritis, and heartburn (Adekola et al., 2015). It is

recommended that one should drink at least 8-10 glasses per day. The need to ensure sufficient water quantity, one of the biggest development challenges is ensuring sufficient water quality (Mishra, 2021). Providing safe drinking water is one of the most complex challenges facing African rural communities. The continent has the highest number of people lacking access to safe, drinkable water and more than 3.4 million people die each year from water sanitation and hygiene-related causes and majority of these are in Africa (Kamara, et al., 2017).

The impact of the consumption of unsafe drinking water in Africa has been likened to "death of children at a rate equivalent of a jumbo jet crashing every 4 h" (The United Nations Children's Fund, 2010). In a bid to stem the tide, programmes such as the Millennium Development Goals which aim at improving the quality of water are widely adopted (World Health Organisation, 2006). Emphasis has also been placed on diversifying water sources from reliance on surface water to include rain water and groundwater. Traditionally, many societies have depended on surface water; however, with increasing challenges of contaminated surface water resulting in diseases such as bilharzia, sleeping sickness, river blindness and guinea worm, many societies have adopted digging of boreholes (Chigor et al., 2012). A lot of funds have been allocated into building boreholes even though sometimes the purity of the drinking water from the boreholes is questionable (Ncube & Schutte, 2005). The quality of borehole water depends upon several factors including local geology, hydrology and geochemical characteristics of the aquifers (Ige, Ameh & Olaleye, 2021).

Apart from these factors, the activities of microorganisms, temperature and pressure are also responsible for the chemical characteristic of groundwater (Kura et al., 2013). If certain mineral constituent is present in excessive amounts, some type of treatment may be necessary before the water can be used for the intended purpose (Sharma &

Bhattacharya, 2016). Water should be free from any physical, chemical or bacteriological contaminant. Unfortunately, water is not always found pure and for this reason drinking water quality standard is set up to ensure the safety of drinking water supplies and the protection of public health (Sharma & Bhattacharya, 2016). There is the need to ensure that the water people drink and use for household activities is reliable and safe. On a global scale, World Health Organisation produces international norms on water quality and human health in the form of guidelines that are used as the basis for regulation and standard setting, in developing and developed countries world-wide (World Health Organisation, 2011). It is even more important now because the chemical quality of drinking water during recent years has deteriorated considerably due to the presence of toxic elements, which even in trace amounts can cause serious health hazards (Ikem et al., 2002).

2.2 Physical Parameters in Drinking Water

Rahmanian et al., (2015) stated that, water quality and suitability for use are determined by its taste, odour, colour, and concentration of organic and inorganic matters. Sustainable access to potable water has been achieved in different developed countries of the world. However, this is not true for many developing countries like Africa, where access to potable water has been achieved in a few cities not in the entire region (Tetteh et al. 2022). This problem is more pronounced in rural areas where some do not have water supply infrastructure and residents of such rural communities often resort to different sources of water. Most of these various alternative sources are susceptible to water pollution (Omarova et al., 2019). Some of the major sources of pollution include the discharge of domestic, industrial and agricultural wastewater into freshwater bodies (Mateo-Sagasta et al., 2017).

Groundwater with unpleasant taste or excess hardness, even when readily available, can drive consumers to continue using microbiologically contaminated unimproved sources, (DeGabriele, 2002). The aesthetic value of water in terms of flavour, odour, and appearance is viewed differently by different households (de Franca Doria, 2010). Consumer perceptions and esthetic characteristics should be addressed when examining drinking water sources, even if they do not have a negative influence on human health (Addisie, 2022).

Omer, (2019) stated that, *contaminated* (*polluted) water* is that water containing unwanted physical, chemical, biological, or radiological substances, and it is unfit for drinking or domestic use. Potable water is safe to drink, pleasant to taste, and usable for domestic purposes (Dinka, 2018). Turbidity in drinking water is aesthetically unacceptable, which makes the water look unappetizing. Suspended particles provide adsorption media for heavy metals such as mercury, chromium, lead, cadmium, and many hazardous organic pollutants such as polychlorinated biphenyls, polycyclic aromatic hydrocarbons, and many pesticides (Petrosino et al., 2018). Palatable water is esthetically pleasing; it considers the presence of chemicals that do not cause a threat to human health and palatability. Viscosity, solubility, odours, chemical reactions, sedimentation, chlorination processes and biological oxygen demand (BOD) are temperature dependent (Ma et al., 2020). Ma et al., (2020), asserted that, temperature affects the biosorption process of the dissolved heavy metals in water. Most people find water at temperatures of 10–15°C most palatable (Agudelo-Vera et al., 2020). Materials decayed from organic matter, namely, vegetation and inorganic matter such as soil, stones, and rocks impart colour to water, which is objectionable for esthetic reasons, not for health reasons (Kanamarlapudi, et al., 2018).

Meride & Ayenew, (2016) stated that, the electrical conductivity (EC) of water is a measure of the ability of a solution to carry or conduct an electrical current. Meride & Ayenew, (2016) asserted that since the electrical current is carried by ions in solution, the conductivity increases as the concentration of ions increases and therefore, it is one of the main parameters used to determine the suitability of water for irrigation and firefighting.

Cunningham et al., (2020) stated that, concerning physical health and drinking water pollution, contaminated water increases the prevalence of a number of diseases, such as hepatitis, typhoid fever, gastroenteritis, dysentery, cholera, diarrhea, malaria, giardiasis, and intestinal worms. Cunninngham et al., (2020), found that diseases and health problems resulting from water pollution include skin and respiratory illnesses, anemia, yellow fever, dengue and complications in childbirth. These health conditions increase with water pollution also result in higher levels of toxicity poisoning and cancer rates in general, as well as digestive cancer and significantly poorer physical health (Cunninngham et al., 2020).

If drinking water contains unsafe levels of contaminants, it can cause health effects, such as gastrointestinal illnesses, nervous system or reproductive effects, and chronic diseases such as cancer (United States Environmental Protection Agency (EPA), 2017). Factors that can influence whether a contaminant will lead to health effects include the type of contaminant, its concentration in the water, individual susceptibility, the amount of water consumed, and the duration of exposure, (Anderson & Meade, 2014). Chemical exposure through drinking water can lead to a variety of short-term and long-term health effects. Exposure to high doses of chemicals can lead to skin discoloration or more severe problems such as nervous system or organ damage and developmental or reproductive effects (Nedellec, rabl &

Dab, 2016). It is found that, exposure to lower doses of chemicals over long periods of time can lead to chronic, longer-term conditions such as cancer and the effects of some drinking water contaminants are not yet well understood (Amicizia et al., 2019). Health effects of consuming water with disease-causing microbes can cause most life-threatening waterborne diseases (such as typhoid fever or cholera), (Villanueva et al., 2014). The more common illnesses caused by viruses, bacteria, and parasites are stomach pain, vomiting, diarrhea, headache, fever, and kidney failure and hepatitis. It may be severe in people with weakened immune systems (e.g., infants and the elderly) and sometimes fatal in people with severely compromised immune systems (e.g., cancer patients) (Herberg et al., 2019).

2.3 Chemical Parameters in Drinking Water

Drilling records indicate that 20–30% of rural Bore Holes have iron and manganese concentrations well in excess of the WHO water quality (WQ) guidelines (0.3 mg/L and 0.1 mg/L, respectively) (Siabi 2003; WHO 2011) causing them to be abandoned or marginally used, (Siabi, 2004).

Rahmanian et al., (2015) stated that, the potential sources of water contamination are geological conditions, industrial and agricultural activities, and water treatment plants. Rahmanian et al., (2015) found that, contaminants are categorized as microorganisms, inorganics, organics, radionuclides, and disinfectants. The inorganic chemicals hold a greater portion as contaminants in drinking water in comparison to organic chemicals. Also, part of inorganics is in mineral form of heavy metals and tend to accumulate in human organs and nervous system and interfere with their normal functions (Granados-Chinchilla, Mena & Arias, 2015). The geology of Ghana is predominantly crystalline silicate rocks and weathered derivatives and these have contributed to

groundwater with low salinity, more acidic and low values of total hardness (Amfo-Otu, 2012).

2.4 Health Implications of Physicochemical Parameters of Drinking Water

Even though some of the trace elements found in water are essential to man, at elevated levels, they cause morphological abnormalities, reduce growth, increase mortality and mutagenic effects (Apau et al., 2013). Contamination of water sources leads to increased pH that affects mucous membranes, causes water to taste bitter and gives water a corrosive property. Increased dissolved oxygen, increases temperature of water and results in increased microbial activity (WHO, 2006).

2.4.1 Salinity

Castano-Sanchez, Hose & Reboboleria (2020), reported that, human activities can induce salinization of groundwater in multiple ways, such as seawater intrusion into coastal aquifers caused by rising sea levels and excessive groundwater pumping. Inland salinization caused by rising and lowering the water tables through saline sediment layers or by direct salt application, e.g., to prevent ice formation on roads (Castano-Sanchez, Hose & Reboboleria,2020). Salinization processes associated with human activities are notably intensified in arid and semi-arid regions which, at the same time, are expected to be very sensitive to climate change effects, particularly, increased temperatures due to global warming, (Bannari & Al-Ali, 2017). Australia has the world's highest proportion of salt-affected soils, and with that, the sum of salts in groundwaters reach as high as 19.32 g/L (sea salt concentrations around 30 g/L), large increases in salinity (e.g., EC ranged from 7,000 to 27,000 µS/cm or 600 to 17,000 µS/cm) have been observed over the last 50 years, especially in shallow aquifers (Kaushal et al., 2021). High salinities in some parts of Australia are due to the geological history of the continent, much of which was subject to periods of

marine inundation which have left saline layers in the geological profile (Skrzypek et al., 2013). High salinities may be also due to dryland salinity, a consequence of land clearing, over grazing and irrigation; Sodium chloride (NaCl) is a common component of natural waters. Increasing concentrations of NaCl and other salts in groundwater are a serious long-term environmental problem, that impacts (among others) surface vegetation (including agricultural crops), groundwater-dependent ecosystems and drinking water quality, as well as roads and built infrastructure (Bricheno, Wolf & Sun, 2021).

2.4.2 Nitrates

Underground water contamination is one of the main environmental issues today due to improper and indiscriminate disposal of sewage, industrial and chemical waste (Obot & Edi, 2012). Nitrates can also soak into the ground and end up in drinking-water and all these can result into health problems that contribute to methemoglobinemia or blue baby syndrome disease which causes death in infants (WHO, 2006).

2.4.3 Fluoride

Dental fluorosis is an enamel mineralization disorder caused by long period of high intake of fluoride during early stages of tooth formation (Liu, Zhu & Gegen, 2020). Liu, Zhu & Gegen (2020) asserted that, Dental fluorosis can result in tooth discoloration, pitting of tooth enamel and weakening and collapse of tooth structure. High fluoride exposure can also cause skeletal fluorosis, characterized by joint pain and/or stiffness, bone deformities and fractures. Since the 1930's, dental fluorosis has been used as a biomarker in humans to indicate systemic fluoride exposure (Everett, 2011). Water is the most important source of dietary fluoride in people, accounting for 75–90% of daily intake (Araya, 2022). At moderate water fluoride levels (0.5 to

1.0 mg/L), fluoride protects teeth against development of dental caries and is not known to cause adverse systemic effects. Prolonged exposure to water fluoride levels above this maximum permissible level can result in dental fluorosis (1.5 mg/L), skeletal fluorosis (3.0–6.0 mg/L) and crippling fluorosis (10 mg/L) in people. (DenBesten & Li, 2011). Excessive fluoride exposure during early growth influences the extent and impact of dental fluorosis and children between one and four years of age are at the highest risk for dental fluorosis in their permanent anterior teeth. After eight years of age, the permanent anterior teeth are generally fully developed and less subject to esthetic change (Kebede et al., 2016). World Health Organisation, (2021) stated that, the exposure of juvenile animals to excessive fluoride during teeth formation period is implicated in dental fluorosis of anterior teeth. In human populations, loss of tooth esthetics due to dental fluorosis is associated with poor self-esteem, shame, and stigma (Molina-Frechero et al., 2017). Ingestion of excess fluoride, most commonly in drinking-water, can cause fluorosis which affects the teeth and bones; moderate amounts lead to dental effects, but long-term ingestion of large amounts can lead to potentially severe skeletal problems so paradoxically, low levels of fluoride intake help to prevent dental caries and therefore the control of drinking-water quality is therefore critical in preventing fluorosis (Kierdorf, 2016).

The dental effects of fluorosis develop much earlier than the skeletal effects in people exposed to large amounts of fluoride. Clinical dental fluorosis is characterized by staining and pitting of the teeth and in more severe cases all the enamel may be damaged (Al Warawreh et al., 2020). Fluoride may not be the only cause of dental enamel defects. Enamel opacities similar to dental fluorosis are associated with other conditions, such as malnutrition with deficiency of vitamins D and A or a low protein-energy diet, (Habiyakare, 2021). Ingestion of fluoride after six years of age will not

cause dental fluorosis. Chronic high-level exposure to fluoride can lead to skeletal fluorosis which is progressions of fluoride accumulation in the bone over many years (Habiyakare, 2021).

World Health Organisation, (2021) stated that, the early symptoms of skeletal fluorosis include stiffness and pain in the joints and in severe cases, the bone structure may change and ligaments may calcify, with resulting impairment of muscles and pain. World Health Organisation, (2021) asserted that, acute high-level exposure to fluoride causes immediate effects of abdominal pain, excessive saliva, nausea, vomiting, seizures and muscle spasms may also occur. Acute high-level exposure to fluoride is rare and usually due to accidental contamination of drinking-water or due to fires or explosions (Kanduti, Sterbenk & Artnik, 2016). Moderate-level chronic exposure (above 1.5 mg/litre of water - the WHO guideline value for fluoride in water) is more common (Santa-Rosa, 2014). People affected by fluorosis are often exposed to multiple sources of fluoride, such as in food, water, air (due to gaseous industrial waste), and excessive use of toothpaste (Peckham & Awofeso, 2014). Drinking water is typically the most significant source and a person's diet, general state of health as well as the body's ability to dispose of fluoride all affect how the exposure to fluoride manifests itself (Demelash et al., 2019). Prolonged exposure to excess fluoride can cause fluorosis, a condition that can weaken the teeth, and calcify tendons and ligaments, (U.S. National Science Foundation, 2021).

A fluoride content of 0.7 ppm is now considered best for dental health and a concentration that is above 4.0 ppm could be hazardous (Brazier,2018*)*. Exposure to high concentrations of fluoride during childhood, when teeth are developing, can result in mild dental fluorosis. This results in tiny white streaks or specks in the enamel of the tooth and this does not affect the health of the teeth, but the

discoloration may be noticeable (Demelash et al., 2019). Exposure to high concentrations of fluoride can cause the bones to become hardened and less elastic, increasing the risk of fractures. If the bones thicken and bone tissue accumulates, this can contribute to impaired joint mobility. Excess fluoride can damage the parathyroid gland (Demelash et al., 2019). Exposure to high concentrations of fluoride can result in hyperparathyroidism which involves uncontrolled secretion of parathyroid hormones (Ross, 2011). This can result in a depletion of calcium in bone structures and higher-than-normal concentrations of calcium in the blood (Simon et al., 2014).

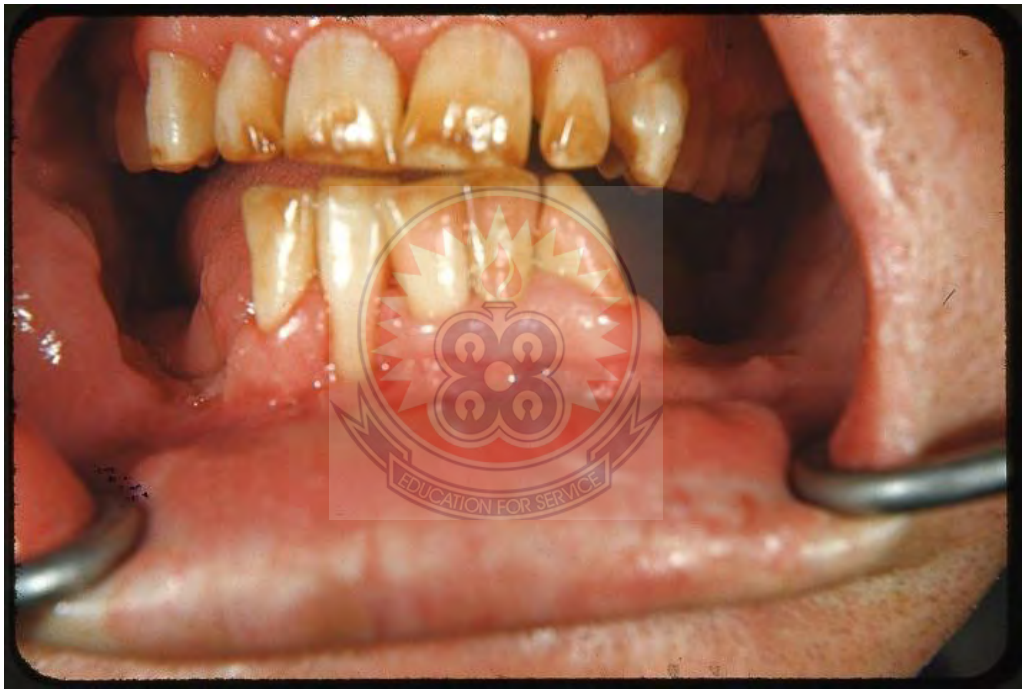

Figure 2.1: shows the discolouration of teeth by fluoride.

Community & public Health, (2019) reported that, Nitrate is converted into nitrite by bacteria in the gut and this nitrite combines with foetal haemoglobin in the foetus or infant less than 6 months old, preventing oxygen from binding and being distributed around the body. Symptoms include blueness around the mouth, hands and feet – hence the name 'blue baby' syndrome and in severe cases it can affect breathing and be life-threatening (Smith, 2009).

2.4.4 Calcium

Inadequate intakes of calcium have been associated with increased risks of osteoporosis, nephrolithiasis (kidney stones), colorectal cancer, hypertension and stroke, coronary artery disease, insulin resistance and obesity (World Health Organisation, 2011). World Health Organisation, (2011), asserted that, calcium is unique among nutrients, in that the body's reserve is also functional; increasing bone mass is linearly related to reduction in fracture risk. A large body of primary evidence from randomized controlled trials shows that increasing calcium intake, especially in those who have had habitually low calcium intakes, increases bone mass during growth and reduces bone loss and fracture risk late in life which also brings osteoporosis one of the most prevalent of age-related diseases (Kim, 2014),

2.4.5 Cyanide

Cyanide is among the most harmful substances on Earth and it is harmful to humans and most aquatic life even at low concentrations (Hosetti, 2011). Unlike toxic metals, cyanide is not an element but a compound, which tends to react rapidly with several other chemical elements and is well known to form hundreds of different compounds (Kwaansa-Ansah et al., 2021). Exposure to HCN causes bleeding, dermatitis, scarlet rash, itching, nose irritations and papules (Rajashekar & Okade, 2013).

2.4.6 Chromium

Physicochemical factors (pH, redox potential, etc.) control the speciation of chromium in the aquatic environment (Sharma et al., 2022). The uniqueness of chromium stems from the totally different chemical behavior and toxicity of its two dominant forms (Sazakli et al., 2014). As for human studies, there is one early report of abnormal deposits of chromium in three brains and decrease in the inflammation response has been reported among individuals exposed to chromium in a

contaminated area (Tumolo et al., 2020). Two ecological studies conducted in China and one in Greece, estimated cancer mortality (lung-, stomach-, etc.) associated with prolonged oral consumption of water contaminated with Cr(VI) (Wise et al., 2022). Gastrointestinal and dermatological complaints and abnormal hematological function associated with living in communities with Cr(VI) polluted groundwater were some effects of chromium, (Rauf et al., 2021).

2.4.7 Manganese

Therdkiattikul et al., (2020) stated that, the United States Environmental Protection Agency sets the manganese standard at 0.05 mg L^{-1} for drinking water, while the World Health Organisation allows a manganese concentration of 0.1 mg L^{-1} in a water supply, water treatment system. The presence of manganese (0.1 mg L^{-1} or greater) can cause aesthetic problems and pipe rusting. Therdkiattikul, (2020) asserted that a high manganese concentration (0.2 mg L^{-1} or greater) can cause neurotoxicity in humans and animals including Parkinson's symptoms, emotional instability, and hallucinations. Manganese (Mn) is an abundant, metallic element commonly present in air, soil, food, and water (Matveeva et al., 2022). It is an essential nutrient, but in excess can also interfere with the normal function of the nervous system (Avila et al., 2013). In occupational settings, manganese exposure has long been recognized as a potent neurotoxicant able to induce motor and cognitive impairments as well as neuropsychiatric symptoms (Kullar, 2019). More recently, several studies have examined the health risks arising from environmental exposures to this metal, suggesting psychological and neurological abnormalities with exposure (O'Neal & Zheng, 2015). Several regions in North America and elsewhere around the world have high concentrations of manganese in water (Frisbie et al., 2012).

According to Kullar, (2019), naturally elevated manganese levels can be found in groundwater due to the weathering and leaching of manganese-bearing minerals. A recent study from the U.S. Geological Survey on over 40,000 wells across the United States revealed that elevated concentrations of manganese in groundwater used for human consumption are associated with shallow, anoxic water tables and soils enriched in organic carbon might have associated health effect (McMahon et al., 2019). Mounting evidence indicates that manganese exposure from drinking water may pose risks for children's health, especially neurodevelopment (Bjorklund et al., 2017). In Bangladesh, where elevated concentrations of manganese are present in well-water, several epidemiological studies have reported associations with neurodevelopmental deficits, including more externalizing and internalizing problem behaviour (Khan 2011). Analysis showed that higher concentrations of manganese in nails (another biomarker of exposure) were significantly associated with worse Performance IQ scores in girls (Bouchard et al., 2018). The United States Environmental Protection Agency (2017) 'has set a secondary standard for manganese of 50 µg/L for aesthetic reasons (colour, staining and taste) and a non-regulatory health advisory for lifetime exposure of 300 µg/L in drinking water', (Kullar, 2019).

2.4.8 Heavy metals

The cardiovascular diseases, kidney-related problems, neurocognitive diseases, and cancer are related to the traces of metals such as cadmium and chromium as reported in epidemiological studies. Lead is known to delay the physical and mental growth in infants, while mercury can cause serious poisoning with skin pathology and cancer and further damage to kidney and liver, respectively (Rahmanian et al., 2015). Cobbina et al., (2015) stated that, there is increasing evidence linking toxicants such as mercury, lead, arsenic and cadmium to the incidence of cognitive impairments,

especially in children, and cancers of all sorts. Heavy metal contamination is associated with deficiencies of some essential nutrients in the human body and this can result in decreased immunological defenses, disabilities associated with malnutrition, intrauterine growth retardation, impaired psychosocial faculties (Cobbina et al., 2015). High prevalence of upper gastrointestinal cancer rates and high concentrations of lead, arsenic, and other heavy metals can affect the nervous system and kidneys, and may cause reproductive disorders, skin lesions, endocrinal damage and vascular diseases (Jaishankar et al., 2014).

Drinking groundwater and surface water contaminated by heavy metal ions is detrimental to health (Ohwoghere, 2012). Many potentially deadly diseases associated with groundwater consumption have been traced to heavy metal contaminants (Brindha et al., 2020). Brindha et al., (2020) found that, some of these metals are required by the body in trace quantities but large doses especially over the course of time are inimical to health. Water is essential for life but it does transmit diseases in countries in all continents – from the poorest to the wealthiest (Ovem, Ovem & Usese, 2015). Monitoring metals in surface or groundwater supplies provides background information needed to determine the suitability of water resources for human consumption (Edokpayi et al.,2018).

2.5 Microbial Quality in Drinking Water

In terms of microbiological water quality, a wide variety of viruses, bacteria, protozoa, and helminths can be transmitted via water. These micro-organisms have been associated with diseases such as gastroenteritis, cholera, hepatitis, typhoid fever, dysentery, salmonellosis, eye, skin and nose infections (Lugo et al., 2020). Most of these disease- causing pathogens are transmitted by the feacal-oral route (Gizaw et al., 2018).

In highly developed countries emphasis has shifted from concern over bacterial diseases to concern over water-borne diseases. Viral hepatitis for example has been found to occur more frequently in cities whose water supplies have comparatively high levels of water turbidity (Biswas & Sweetharam, 2008).

Water borne disease is a huge concern and a major public health problem, because it affects the health of an individual in most cases when it is ingested into the body via faecal-oral route, (Ramirez-Castillo, 2015). The need for the evaluation of microbial contamination of borehole water remains paramount and thoughtful towards good health, (Azuonwu, 2020).

Boadi, (2020) stated that, groundwater is generally considered safe for drinking. The quality of water varies from place to place and sometimes depends on climatic changes, the soil types and surfaces (Green, 2016). Nature of the rocks through which the water moves and human activities such as disposal of chemicals and microbiological material on landfill sites, burying them in the ground, or even directly injecting waste into the groundwater can change the water's natural composition and quality (Oyiboka, 2014). The improper construction of boreholes may also cause groundwater contamination (Masindi & Foteinis, 2021). Agricultural activities, improper solid waste disposal, and animal droppings near boreholes could also contaminate the water and in highly developed countries emphasis has shifted from concern over bacterial diseases to concern over water-borne diseases. Viral hepatitis for example has been found to occur more frequently in cities whose water supplies have comparatively high levels of water turbidity (Biswas & Sweetharam, 2008).

2.6 Water Quality Index

Water quality index (WQI) is a mathematical tool used to transform large quantities of water quality data into a single number which present water quality level (Bouslah, Djemili & Houichi, 2017). Water quality index (WQI) is valuable and unique rating to depict the overall water quality status in a single term that is helpful for the selection of appropriate treatment technique to meet the concerned issues. However, WQI depicts the composite influence of different water quality parameters and communicates water quality information to the public and legislative decision makers (Sharma, Singh & Dobhal, 2013).

Weighted Arithmetic Water Quality Index (WAWQI) is a means by which water quality data is summarized for reporting to the public in a consistent manner. It tells us in simple terms, what the quality of drinking water is from a drinking water supply. This calculation produces a score from 0 and above. The higher the score the worse the quality of water. The scores are then ranked into one of the six categories described as follows: Excellent: (Value water quality index form 0-25) –Possible Usage; drinking and industrial. Good: (water quality index Value from 26-50) –Possible Usage; domestic and industrial. Fair: (water quality index Value from 51-75) –Possible Usage; irrigation and industrial. Poor: (water quality index Value from 76-100) –Possible Usage; irrigation. Very Poor: (water quality index Value from 101-150) –Possible Usage; restricted for irrigation. Unfit for Drinking: (water quality index Value above 150) –Possible Usage; proper treatment required before use. Wikipedia dictionary.

CHAPTER THREE

METHODOLOGY

3.0 Overview

This chapter looks at the methods employed in the research work. That is sample selection, preparation, Calibration of DR 6000 Spectrophotometer, sample analysis, quality control measures and data analysis.

3.1 Study Site

Upper Manya Krobo District is one of the thirty-two districts in the Eastern Region of the Republic of Ghana. It was carved out of the then Manya Krobo District in February, 2008 by Legislative Instrument 1842 in pursuance of the Government's Decentralization policy with its capital as Asesewa, a historic trading post, attracting a mix of cultures from all over the country. The district capital, Asesewa is about 45km drive from Koforidua, the regional capital of Eastern Region (Manya Krobo District Assembly Budget Estimates Report, 2019).

The Upper Manya Krobo District has a 2021 estimated population of 90,826 with males constituting 50.6 percent (45,958) and females 44,868 (49.4%) percent. The district is predominantly rural with 64,223 representing 77% of the population living in rural areas as compared to 19,285 (13%) people in the urban areas. This means more than three-quarters of the district's population is rural. Average household size in the district is 4.6 persons per household. Total Fertility Rate is 3.7, Literate population 66.7%, non-literate 33.3% (Upper Manya Krobo District Assembly Budget Estimates Report, 2019. The District is located in the Eastern part of the Eastern Region with coordinates 6°23'59.03"N 0°8'32.92"W (Wikipedia dictionary).

The four main sources of water in the district are borehole, river stream, public tap and pipe borne water. About forty percent of households (37.7%) drink water from boreholes (Upper Manya Krobo District Assembly Budget Estimates Report, 2019).

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).

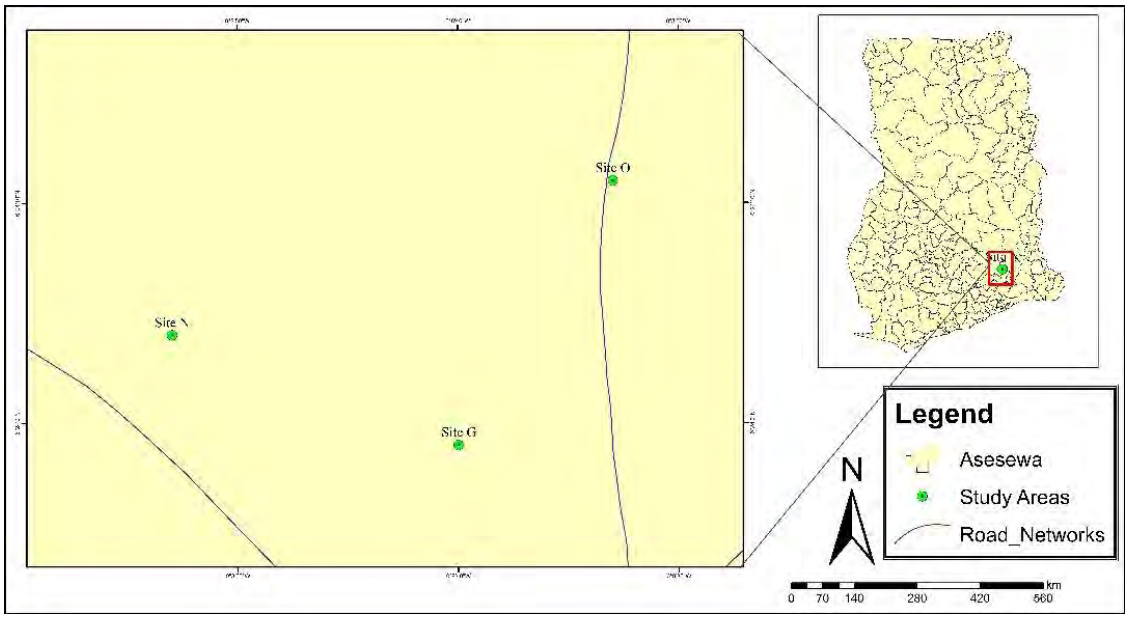

Figure 3.1: Study area map of Asesewa- Ghana

3.2 Selection of Samples

Samples were selected from three sites. Thus, site G, site N and site O. The three sites were selected out of eight sites due to the total dryness of four of the boreholes as a result of a fall in water table. Three were selected from the remaining four sites for sample collection and analysis. Site G with coordinates 6^0 23' 59''N 0^0 8' 40''W which is about 100 metres East of Assemblies of God Church on the top of the hill, site O with coordinates 6^0 24' 11''N 0^0 8' 33'' W which is about 40 metres Ebenezer Church from the middle and site N with coordinates 6^0 24' 4'' N 0^0 8' 53'' W which is about 100 metres behind Lamb of God International School from the lowest part of the town since the place is on a hill and slopy.

3.3 Preparation of the Sample

The glassware and plasticware were cleaned with laboratory phosphate-free detergent and rinsed with tap water. A 1:1 hydrochloric acid solution or a 1:1 nitric acid solution was used to rinse them. The glassware and plasticware were rinsed with deionized water and air dried. The pump was allowed to run long enough to draw groundwater into the system.

The water samples were collected from three sites namely; G, O and N into three different 1.50-liter and three 75-millilter plastic bottles which were also stored in cold box below the temperature of 6 ^{0}C and transported to the Water Quality Assurance Department of Ghana Water Company Limited in Koforidua for wet season determination, Water Research Institute in Accra for dry season for the Physicochemical analysis and microbial analysis but before the start of the analysis the temperature was change to room temperature which was 25 ^{0}C. why is the analysis done in 2 different locations. The Water Quality Assurance Department of Ghana Water Company Limited in Koforidua had a challenge that was why the analysis were done at two different places.

The micro-biological analysis was done using plate count pour plate method while the Physicochemical analysis was done using various instruments like: pH and Electrical Conductivity (conductivity meter), Colour (Spectrophotometer),Total Dissolve Solids (Evaporation method), Total suspended solids (conductive meter), Turbidity (Turbidimeter), Alkalinity (titration), Total Hardness, calcium ion, Calcium and Magnesium Hardness, Magnesium ion (Ethylenediamine tetraacetic acid (EDTA) Titration), Total Iron and Manganese (Atomic Absorption Spectrophotometer), Sulphates, Phosphates, Nitrate and Nitrite (spectrophotometer) and Chlorides (Argentometric method) that is titration. The Water Quality Index for some selected parameters for sites G, N and O were calculated and the results for the Water Quality Index are presented in Tables; 4.1 to 4.9.

3.4 Calibration of DR 6000 Spectrophotometer and Preparation of water samples for physicochemical analysis

The instrument cap was installed on cell holder before ZERO or READ was pressed. The calibrations were done automatically any time the DR 6000 Spectrophotometer is

put on operation. The reagent blank value was measured for each new lot of reagents for the best results. The reagent blank value was subtracted from the sample results automatically with the reagent blank adjust option. This method is technique-sensitive. Shaking time and technique influence the colour development. For most accurate results, a standard solution that is within the test range was used and ran the test several times. The shaking time was increased or decreased to get the expected result. The shaking time was adjusted for sample measurements. The sample cell was rinsed immediately after use to remove all particles. A deposit of unoxidized metal remained at the bottom of the sample cell after the reagent dissolved. The deposit will not affect results.

Figure 3.2: DR 6000 Spectrophotometer used to analyse the water samples

Figure 3.3 shows Sampled Water and Sample Cells

3.4.1 Zinc

The program 780 Zinc from DR 6000 Spectrophotometer was used to analyse Zinc. A 25-mL graduated mixing cylinder was filled with 20 mL of the sample. The contents of one zinco ver 5 Reagent Powder pillow was added to the mixing cylinder and the cylinder shook vigorously to dissolve the powder completely. The blank was prepared by pouring 10 ml of the solution into a sample cell. The sample was prepared by adding 0.5 ml of cyclohexanone to the solution in the mixing cylinder.by the use of plastic dropper. The instrument was started for a 30-second reaction time. During the reaction period, the mixing cylinder was closed and the prepared sample was shaken vigorously. The instrument timer was started and a 3-minute reaction period was allowed to complete the next step. The prepared sample solution was poured from the mixing cylinder into a second sample cell. The zero button was pushed to display 0.00 mg/L Zn. The prepared sample cell was cleaned and inserted into the cell holder. The READ button was then pressed to show results in mg/L Zn. The readings or results are presented in Table 4.1 to 4.9

The researcher adopted Ghana Water Company Limited Department of Water Quality Assurance's DR 6000 Spectrophotometer manual (Unpublished).

Figure 3.4: shows Samples for analysis.

Figure 3.5: shows Researcher rinsing sample cell

3.4.2 Nitrogen/Ammonia

The program 380 from DR 6000 Spectrophotometer was used to analyse Ammonia. The mixing cylinder was filled to 25 mL line with the sample. The blank was prepared by filling mixing cylinder to 25 mL line with deionized water. 3 drops of mineral stabilizer were added to each mixing cylinder. The mixing cylinders were

stoppered and inverted several times to mix. Three drops of polyvinyl Alcohol Dispersing Agent were added to each mixing cylinder. The mixing cylinder was stoppered and inserted several times to mix. 1.0 mL of Nessler Reagent was added to each mix cylinder by the use of pipette. The mixing cylinders were stoppered and inserted several times to mix. 10 mL of blank was poured from the blank cylinder into a sample cell. The blank sample cell was cleaned after the timer expired. The blank was inserted into the cell holder. The zero button was pressed to display 0.00 mg/L

NH_3-N. 10 mL of sample was poured from the sample into a second sample cell. The prepared sample cell was cleaned and inserted into the cell holder. The READ button was pressed to show results in mg/L NH_3-N. The readings or results are presented in Table 4.1 to 4.9

The researcher adopted Ghana Water Company Limited Department of Water Quality Assurance's DR 6000 Spectrophotometer manual (Unpublished). This manual was used for analysing all the selected heavy metals.

3.4.3 Copper

The program 135 copper from DR 6000 Spectrophotometer was used to analyse Copper. The mixing cylinder was filled to 25 mL line with the sample. A sample cell was filled with 10 mL of sample. The contents of one Copper Reagent powder pillow and was swirl to mix. The instrument timer was started for a 2-minute reaction time to starts. The sample showed a purple colour when copper in the sample mixed with the reagent powder.

The blank was prepared by filling a second sample cell with 10 mL of sample. The blank sample cell was cleaned and the blank was inserted into the cell holder. The ZERO button was pressed to display 0.00 mg/L Cu. The prepared sample cell cleaned and inserted into the cell holder within 30 minutes of reaction time. The READ button was pressed to show results mg/L Cu. The readings or results are presented in Table 4.1 to 4.9

3.4.4 Cyanide

Program 160 Cyanide from DR 6000 Spectrophotometer was used to analyse Cyanide. The mixing cylinder was filled to 25 mL line with the sample. The sample was prepared by filling a sample cell with 10 mL of sample. The content of one

cyaniVer 3 cyanide Reagent powder pillow was added. It was stoppered and shook for 30 seconds and allowed to sit for another 30 seconds. The content of one cyaniVer 4 cyanide Reagent powder pillow was added. The sample cell was closed and shook for 10 seconds. The sample cell was closed and shook vigorously. Pink colour indicated the presences of cyanide. The instrument timer was started for a 30-minutes reaction time. The solution showed pink and then blue. The blank was prepared by filling a second sample cell with 10 mL of sample when the timer expired. The blank sample cell was cleaned and was inserted into the cell holder. The ZERO button was pressed to display 0.00 mg/L CN^-. The prepared sample cell was cleaned and inserted into the cell holder. The READ button was pressed to show the result in mg/L CN^-. The readings or results are presented in Table 4.1 to 4.9.

3.4.5 Fluoride

Program 190 Fluoride from DR 6000 Spectrophotometer was used to analyse Fluoride. The mixing cylinder was filled to 25 mL line with the sample. The sample was prepared by 10.0 mL of a sample to a sample cell. A pipette was used to add 2.0 mL of SPADNS Reagent solution into each sample cell and was swirled to mix. The instrument timer was started for 1-minute reaction time. The blank sample cell was cleaned when the timer expired and was inserted into the cell holder. The ZERO button was pressed to display 0.00 mg/L F^-. The prepared sample cell was cleaned and inserted into the cell holder. The READ button was pressed to show the results. The readings or results are presented in Table 4.1 to 4.9.

The researcher has adopted Ghana Water Company Limited Department of Water Quality Assurance's DR 6000 Spectrophotometer manual (Unpublished).

Figure 3.6: show DR 6000 Spectrophotometer

Figure 3.7: Samples ready for analysis respectively.

3.4.6 Total iron

Program 265 from DR 6000 Spectrophotometer was used to analyse Iron. The blank was prepared by using a pipette to measure 10.0 mL of deionized water to a sample cell. The sample was prepared by filling a sample cell with 10 mL of sample. The content of one ferro Ver Iron Reagent powder pillow was added to the sample cell and was swirled to mix. The instrument timer was started for 3-minutes reaction time. Orange colour indicated the presence of iron. The sample that contains rust was allowed to react for 5-minutes or more. The sample cell was clean and inserted into the cell when the timer expired. The ZERO button was pressed to display mg/L Fe. The prepared sample cell was cleaned inserted into the cell holder. The READ button pressed to show results. The readings or results are presented in Table 4.1 to 4.9.

The researcher has adopted Ghana Water Company Limited Department of Water Quality Assurance's DR 6000 Spectrophotometer manual (Unpublished).

Figure 3.8: Samples for analysis

Figure 3.9: Researcher preparing some blanks

3.4.7 Manganese

Program 295 Manganese for DR 6000 Spectrophotometer was used to analyse Manganese. The Sample was prepared by filling a sample cell with 10 mL of sample. The contents of one Buffer powder pillow, citrate Type for Manganese was added. The sample cell stoppered and inverted to mix. The content of one sodium Periodate powder pillow was added to the sample in the cell. It was stoppered and inverted to mix. A violet colour show the presence of manganese. The instrument timer was started for 2-minutes reaction. The blank was prepared by filling a second sample cell with 10 mL of sample. The blank sample cell was cleaned and inserted into the cell holder when the timer expired. The READ button was pressed to display 0.00 mg/L Mn. The prepared sample cell was cleaned and was inserted into cell holder within 8 minutes after the timer expired. The READ button was pressed show results in mg/L Mn. The readings or results are presented in Table 4.1 to 4.9.

3.4.8 Arsenic

The instrument program for DR 6000 Spectrophotometer was used to analyse Arsenic. The distillation apparatus was prepared. A cotton ball was soak with 10% lead Acetate solution. The cotton was putin gas scrubber. It was to Make sure that the cotton seals were against the glass. A graduated cylinder was used to pour 25-mL of prepared arsenic absorber solution into the cylinder/gas bubbler assembly. The cylinder/gas bubbler attached to the distillation apparatus. The graduated cylinder was used to pour 250 mL of sample into the flask. Heater power was set to on. The stir control was set to 5. The heat control was set to 0. 5. The graduated cylinder was used to pour 25-mL of prepared arsenic absorber solution into the cylinder/gas bubbler assembly. The cylinder/gas bubbler assembly was attached to the distillation apparatus. The graduated cylinder was used to pour 250 mL of sample into the distillation flask. The heater power was set to on. The stir control was set to 5. The heat control was set to 0. 9. The graduated cylinder was used to add 25 mL of Hydrochloric Acid to the distillation flask. A serological pipette was used to add 1 mL of Stannous Chloride Solution to the distillation flask. The serological pipet was used to add 3 mL of Potassium Iodide Solution to the distillation flask. The flask was copped. The instrument time was started for a 15-minute reaction time. When the timer expired, 6.0 g of 20-mesh zinc was weighed and added to the distillation flask. The flask was capped immediately. The heat control was set to 3. The instrument timer was started for a 15-minute reaction time. When the timer expired, the heat control was set to 1. The instrument timer was timed for a 15-minute reaction time. When the timer expired, the heater power was set to off. The cylinder/gas bubbler assembly was removed as a unit. The gas bubbler was moved up and down in the arsenic absorber solution to rinse the bubbler. The blank was prepared by Filling a dry 10-mL sample cell with unreacted arsenic absorber solution. The sample cell was

stoppered. The blank sample cell was cleaned and inserted into the into the cell holder. the ZERO button was pressed to display the (non-zero) intercept that is calculated from the user- entered calibration curve. The sample was prepared by Pouring the reacted arsenic absorber sample into a sample cell. The sample cell was stoppered. The prepared sample cell cleaned and inserted into the cell holder. The READ button was pressed to show the results in mg/L As. The readings or results are presented in Table 4.1 to 4.9.

3.4.9 Potassium

The program 905 Potassium for DR 6000 Spectrophotometer was used to analyse Potassium. The sample was prepared by Filling a mixing cylinder to the 25-mL line with a sample. A 25-mL sample cell was used as an alternative to the mixing cylinder. The contents of one Potassium 1 Reagent Pillow was added. The contents of one of Potassium 2 Reagent Pillow were added. The mixing cylinder was stoppered. The mixing cylinder was inverted several times to mix. The solution was left to become clear. The contents of one Potassium 3 Reagent Pillow was added. The mixing cylinder was stoppered. The cylinder was shaken for 30 seconds. A white turbidity formed to show the presence of potassium is in the sample. The instrument timer was timed for a 3-minute reaction time. A 10 mL of the solution from the mixing cylinder was poured into the sample cell. The blank was prepared by Filling a sample cell with 10 mL of fresh sample into a sample cell. When the timer expired, the blank sample cell was cleaned and insert into the cell holder. The ZERO button was pressed to display 0.0 mg/L K. The prepared sample cell was cleaned. Within 7 minutes after the timer expired, the prepared sample was inserted into the cell holder. The READ button was pressed to show results in mg/L K. Immediately the graduated cylinder

and the sample cells were cleaned with soapy water and a brush and rinsed with deionized water. The readings or results are presented in Table 4.1 to 4.9.

3.4.10 Bicarbonate

A sample volume and titration cartridge were used to analyse Bicarbonate. A clean delivery tube was inserted into the digital titration cartridge. The cartridge was attached to the Digital Titrator. The Digital Titrator held with the cartridge tip up. The delivery knob was turn to eject air and a few drops of titrant. The counter was reset to zero and the tip was cleaned. A graduated cylinder was to measure the sample volume. The sample was poured into a cleaned 250-mL Erlenmeyer flask. The sample volume can be diluted if it is less than 100 mL to approximately 100 mL with deionized water. The contents of one Phenolphthalein Indicator Powder Pillow were added and swirled to mix. The indicator is not necessary if a pH meter is used. If the solution is colorless or the pH is less than 8.3, the Phenolphthalein alkalinity is zero. The end of the delivery tube was fully put into the solution and the flask swirled. The knob on the Digital Titrator was turn to add titrant to the solution. The flask was swirled continuous and the titrant was added until the color changes from pink to colorless, or until the pH is 8.3, the Phenolphthalein alkalinity is zero. The number on the counter was recorded. The multiplier was used to calculate the concentration. Digits used × digit multiplier =mg/L as $CaCO_3$ Phenolphthalein alkalinity. The contents of one Bromocresol Green-Methyl Red Indicator Powder Pillow were added. The indicator is not necessary if a pH meter is used. It was swirled to mix. The end of the delivery tube was fully put into the solution. The flask was swirled. The knob was turn on, the Digital Titrator added titrant to the solution. The flask swirled continuously. The titrant was added until the color changes to a light pink color, or the pH is 4.5. The reading on the counter was recorded. The multiplier was used to

calculate the concentration. Total digits used x digit multiplier = mg/L as $CaCO_3$ Total alkalinity. The bicarbonate, carbonate and hydroxide alkalinities were calculated to determine the alkalinity relationships. The readings or results are presented in Table 4.1 to 4.9.

3.4.11 Nitrate using the spectrophotometer

The program 353 Nitrate for DR 6000 Spectrophotometer was used to analyse Nitrate. The sample was prepared by filling a sample cell with 10 mL of sample and the contents of one powder pillow was added to the sample cell. The instrument timer was started for 1-minute reaction time. The sample cell was stoppered and shook vigorously until the timer expired. Some solid materials did not dissolve but did not affect results. The instrument timer was started for 5-minutes reaction. An amber colour showed indicating the presence of nitrate. The blank was prepared by filling a second sample cell with 10 mL of blank. The blank sample cell was cleaned and inserted into the cell holder when the timer expired. The ZERO button was pressed to display 0.00 mg/L NO_3^--N. The prepared sample was cleaned and inserted into the cell holder after the timer expired. The READ button was pressed to show results in mg/LNO_3^-N. The readings or results are presented in Table 4.1 to 4.9.

3.4.12 Nitrite

Program 371 Nitrite for DR 6000 Spectrophotometer was used to analyse nitrite. The sample was prepared by filling a sample cell with 10 mL of sample. The contents of one NitriVer 3 Reagent powder pillow were added. It was swirled until a pink colour appeared indicating the presence of nitrite. The instrument timer was started for 20-minutes reaction time. The blank was prepared by filling a second sample cell with 10 mL of sample. The blank sample cell was cleaned and inserted into the cell holder.

The ZERO button was displayed to show 0.00 mg/L. NO_3^--N. The already prepared sample cell with sample was cleaned and inserted into the cell holder. The READ button was pressed to show results in mg/L NO_3^--N. The readings or results are presented in Table 4.1 to 4.9.

3.4.13 Phosphorus

Program 490 for DR 6000 Spectrophotometer was used to analyse Phosphorus. The sample was prepared by filling a sample cell with 10 mL of sample. The contents of one phosVer Phosphate Reagent powder pillow was added to the cell. A cell colour develops showing the presence of phosphorus. The sample was closed immediately and shaking vigorously for 20- 30 seconds. The instrument timer was started for 2-minutes reaction time. The blank was prepared by filling a second sample cell with 10 mL of blank, the blank sample cell was cleaned and inserted into the cell when the when the timer expired. The ZERO button was pressed to show 0.00 mg/L PO_4^{3-}. The prepared sample was cleaned and inserted into the cell holder. The READ button was pressed to show results in mg/L PO_4^{3-}. The readings or results are presented in Table 4.1 to 4.9.

3.4.14 Sulphate

Program 680 Sulphate was selected for DR 6000 Spectrophotometer and was used to analyse Sulphate. The sample was prepared by filling a sample cell with 10 mL of sample. The contents of one sulfaVer 4 powder pillow was added to the sample cell and was swirled to mix. The instrument timer was started for 5-minute reaction time. The cell was not disturbed during the reaction. The blank was prepared by filling a second sample cell with 10 mL of sample, cleaned and inserted into the cell holder when the timer expired. The ZERO button was pressed to display 0. 00 mg/L SO_4^{2-}. The prepared sample cell inserted into the cell holder within 5 minutes after the timer

expired. The READ button pressed to show results in mg/L SO_4^{2-}. The readings or results are presented in Table 4.1 to 4.9.

3.4.15 Chromium

Program 90 for DR 6000 Spectrophotometer was used to analyse Chromium. The sample was prepared by filling a sample cell with 10 mL of sample. The content of one ChromaVer 3 Reagent powder pillow to the sample cell and swirled. A purple colour showed indicating the presence of hexavalent chromium. The instrument was started for 5-minute reaction time. The blank was prepared by filling a second sample cell with 10 mL of sample. The blank sample cell was cleaned and inserted into the cell holder when the timer expired. The ZERO button pressed to show 0.00 mg/L Cr^{6+1}. The prepared sample cell was inserted into the cell holder. The READ button was pressed to show results in mg/L Cr^{6+}. The readings or results are presented in Table 4.1 to 4.9.

3.4.16 Total Suspended Solids

Program 630 Suspended Solids for DR 6000 Spectrophotometer was used to analyse Total Suspended solids. A 500 mL of sample was blended in a blender at a high speed for exactly two minutes. The blended sample was poured into a 600-mL beaker. The sample was prepared by stirring the sample and immediately poured into 10 mL of the blended sample into a sample cell. The blank was prepared by filling a second sample cell with10 mL of tap water or deionized water. The blank sample cell was cleaned and inserted into the cell holder. The ZERO button was pressed to display 0.00 mg/L TSS. The prepared sample was swirled to remove any gas bubbles and uniformly suspend any residue. The prepared sample cell cleaned and inserted into the cell holder. The READ button was press to show results in mg/L TSS. The readings or results are presented in Table 4.1 to 4.9.

3.4.17 The Total Dissolved Solids

Evaporation method was used to measure the Total Dissolved Solids. Samples were first filtered to remove suspended solids. A precise amount of water was added to carefully clean, dried and weighed beaker. The difference in mass between the two weighing was the mass of the total dissolved solids. The readings or results are presented in Table 4.1 to 4.9.

3.4.18 Colour comparator

The determination of the water colour was done using a Forel-Ule scale. The disc was slowly lowered into the water until it disappeared from sight and the depth noted. It was done in a shaded area. The disc was slowly raised until half the Secchi depth. The colour of the water was determined with the Forel Ule scale (in the shade). The colour observed on top of the Secchi disc was compared with the colours of the scale (over the white bars. The readings or results are presented in Table 4.1 to 4.9.

The researcher has adopted the procedure from: Wikipedia dictionary; https://en.wikipedia.org › wiki › Forel-Ule_scale

Figure 3.10: Researcher using colour comparator

3.4.19 Electrical Conductivity

The sample was collected in a plastic bottle that has been washed in phosphate-free detergent and rinsed thoroughly with both tap and distilled water.

Conductivity was measured with a probe and a meter. Voltage is applied between two electrodes in a probe immersed in the sample water. The drop in voltage caused by the resistance of the water was used to calculate the conductivity per centimeter. The meter converts the probe measurement to micromhos per centimeter and display the results. The readings or results are presented in Table 4.1 to 4.9.

The researcher adopted/adapted the procedure from https://accendoreliability.com/ conductivity-meter-operation-use/

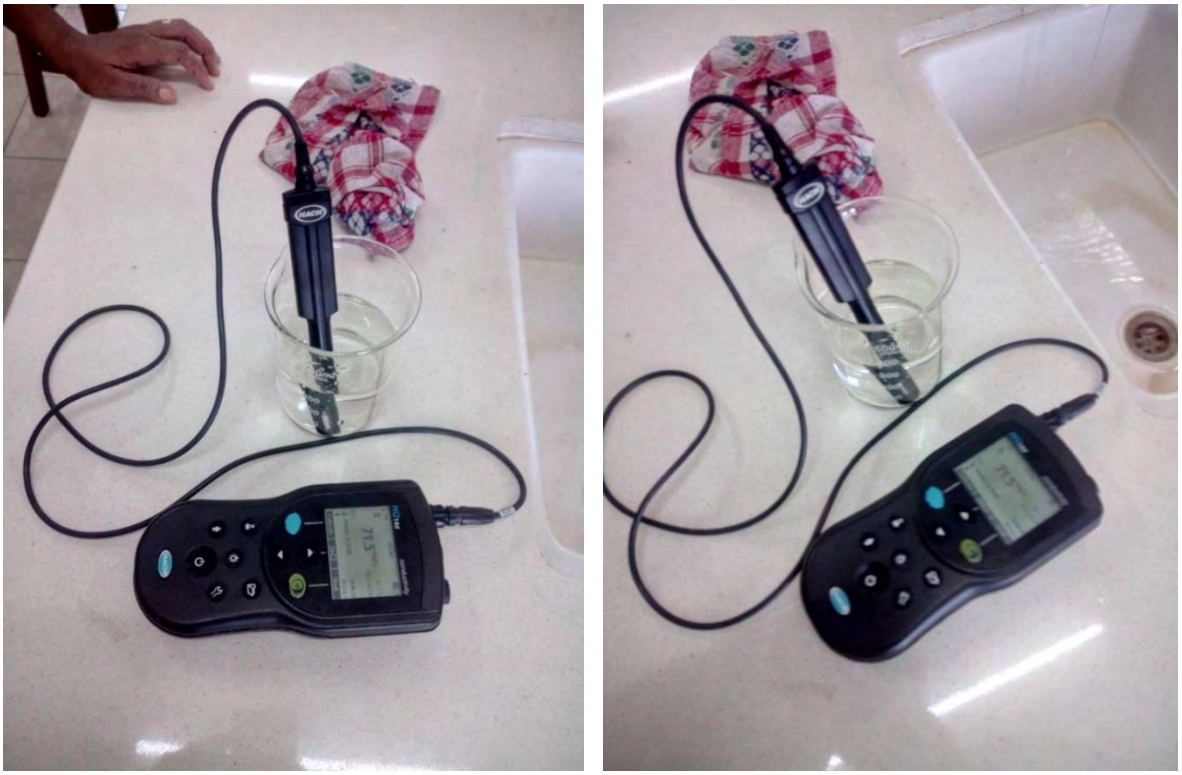

Figure 3.11: Electrical conductivity taken from sample water

3.4.20 Measurement of pH using colourimeter

Colourimetric Method for pH of Water

The water sample was put in a cleaned plastic container and the colourimeter was dipped in it. The obtained colour was computed from the standard table and the respective pH value recorded. The readings or results are presented in Table 4.1 to 4.9.

The researcher adopted the procedure from Colorimetric Method for pH of Water; Wikipedia dictionary: https://askinglot.com/

Figure 3.12: Colourimeter being used to take pH of sample water

Figure 3.13: Researcher preparing sample to be used in colourimeter

3.4.21 Measurement of turbidity using spectrophotometer

The visible spectral acquisition system consisted of a light source, a sample cell, and a spectrometer. The pulsed xenon light source (PX-2, Ocean Optics) produced visible light, which was collimated by a lens and then passed through the sample cell; the emergent light was collected into the spectrometer by the converging lens. The spectral data were shown in the computer. The readings or results are presented in Table 4.1 to 4.9.

Figure 3.14: Spectrophotometer being used to take turbidity of sample water

3.4.22 Chloride

Argentometric method is a type of titration involving silver (I) ion. The sample solution was titrated against a 12.22 mL solution of 0.9457 M silver nitrate. Chloride ions react with silver (I) ions to give insoluble silver Chloride; $Ag^{+}(aq) + Cl^{-}(aq) \rightarrow AgCl$.

Water 'hardness' is a measure of the amount of hard water cations in water. These hard water cations include calcium, magnesium, iron, zinc and the other polyvalent metal ions in most water samples.

About 4.25 g of solid $AgNO_3$ accurately weighed and dissolved in 250 mL of distilled water in a conical flask. The solution was stored in a brown bottle. About 50 mL distilled water was added to conical flask and 1 mL of chromate indicator was added. The sample was titrated with 0.1 mol L^{-1} silver nitrate solution. Although the silver chloride that forms is a white precipitate, the chromate indicator initially gives the cloudy solution a faint lemon-yellow colour. The endpoint of the titration was identified as the first appearance of a red-brown colour of silver chromate. The titration was repeated with further aliquots of diluted sample water until concordant results (titres agreeing within 0.1 mL) were obtained. Before the addition of any silver nitrate the chromate indicator gave the clear solution of a lemon-yellow colour: before the titration endpoint. Addition of Ag^+ ions lead to formation of silver chloride precipitate, making the solution cloudy. The chromate indicator gave a faint lemon-yellow colour. At the endpoint, all the Cl^- ions precipitated. The slightest excess of Ag^+ precipitates with the chromate indicator giving a slight red-brown colouration. The titration was stopped when the first of red brown colour is observed.

The average volume of silver nitrate used was determined from the concordant titres. The moles of silver nitrate reacting were calculated. The following reaction equation was used to determine the moles of chloride ions reacting. Ag^+ (aq) + Cl^- (aq) → AgCl(s). The concentration of chloride ions in the diluted sample water was calculated. The concentration of sodium chloride in the sample water in $molL^{-1}$, gL^{-1} and g/100 mL (%). The readings or results are presented in Table 4.1 to 4.9.

The Researcher adopted the procedure for Determination of Chloride Ion Concentration by Titration (Mohr's Method);

https://www.canterbury.ac.nz/media/documents/science-outreach/chloride_mohr.pdf0975-5861

3.4.23 Hardness of water by EDTA titration

Apparatus used for hardness of water experiment are: Burette, Pipettes and Erlenmeyer Flask

Reagents used for hardness of water experiment were:

Ammonia buffer solution, Erichrome Black T indicator and Standard EDTA titrant = 0.01M.

3.4.24 Procedure for determination of hardness of water by EDTA titration

A sample volume of 20 m (V mL) was taken. 20 mL of the sample was diluted in Erlenmeyer flask to 40ml by adding 20 mL of distilled water. A 1 mL of ammonia buffer was added to bring the pH to 10±0.1. 1 or 2 drops of the indicator was added to solution. EDTA titrant was added to the sample with vigorous shaking till the wine-red colour just turned blue.

Procedure for calculation of hardness of water by EDTA titration

Total hardness, mg/L

$$CaCO_3 = \frac{V1 \times N \times 100 \times 1000}{V}$$

V=Volume of the sample taken, mL.

V1=volume of titrant used for sample, mL.

N=Normality of EDTA

The readings or results are presented in Table 4.1 to 4.9.

The Researcher has adopted the method of determination of hardness of water from Environmental Engineering Lab's Determination of Hardness of Water by EDTA Titration method; https://readcivil.com/determination-hardness-water/

Figure 3.15: Researcher using titration to determine hardness of sample water

For most potable waters, the pH after this addition will be 2.5 0.1. For highly alkaline or acid waters, adjust pH to about 8 before adding indicator-acidifier reagent.

Titrate with 0.0141N $Hg(NO_3)_2$ titrant to a definite purple endpoint. The solution turns from green-blue to blue a few drops before the endpoint. Determine blank by titrating 100 mL distilled water containing 10 mg $NaHCO_3$.

b. Titration of chloride concentrations greater than 100 mg/L: Use a sample portion (5 to 50 mL) requiring less than 5 mL titrant to reach the endpoint. Measure into a 150-mL beaker. Add approximately 0.5 mL mixed indicator reagent and mix well. The color should be purple. Add 0.1N HNO_3 dropwise until the colour just turns yellow. Titrate with strong $Hg(NO_3)_2$ titrant to first permanent dark purple. Titrate a distilled

water blank using the same procedure. The readings or results are presented in Table 4.1 to 4.9.

Figure 3.16: Setup for EDTA titration

Figure 3.17: Researcher using titrating for chloride

3.5 Microbial Analysis

3.5.1 Heterotrophic plate count

3.5.1.1 Pour Plate Method

Plate count (pour plate) method was used for the determination of total coliform, fecal coliform and heterotrophic bacteria (American Public Health Association, 2012). The laboratory bench was sterilized using methylated spirit while the glass wares (pipettes and Petridishes) were autoclaved at 121 ^{o}C for 30 minutes (American Public Health Association, 2012).

3.5.1.2 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 ^{o}C, 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 ^{o}C 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 ^{o}C, 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 ^{o}C for 15 minutes.

3.5.1.3 Total coliform and E. coli

Ten milliliters (10 mL) of Brilliance E. coli culture medium was used to inoculate 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 ^{o}C and allowed to cool to about 48 ^{o}C. Ten milliliters (10 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 ^{o}C 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 ^{o}C for 24 hours. 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. The results are presented in Table 4.10 to 4.12.

3.5.1.4 Heterotrophic bacterial count

Similarly, fifteen milliliters (15 mL) of plate count agar was used as the culture medium to inoculate heterotrophic bacteria and incubated at a temperature of 35±0.5 ^{o}C for 24 hours. 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. The results are presented in Table 4.10 to 4.12.

The researcher adopted the procedure from Standard Methods for the Examination of Water and Wastewater, 23rd Edition Ebook, received 05/06/2022 https://www.yumpu.com/en/document/view/63219806/pdf-file-standard-methods-for-the-examination-of-water-and-wastewater-23rd-edition-rar;https://doi.org/10.2105/SMWW. 2882.002.

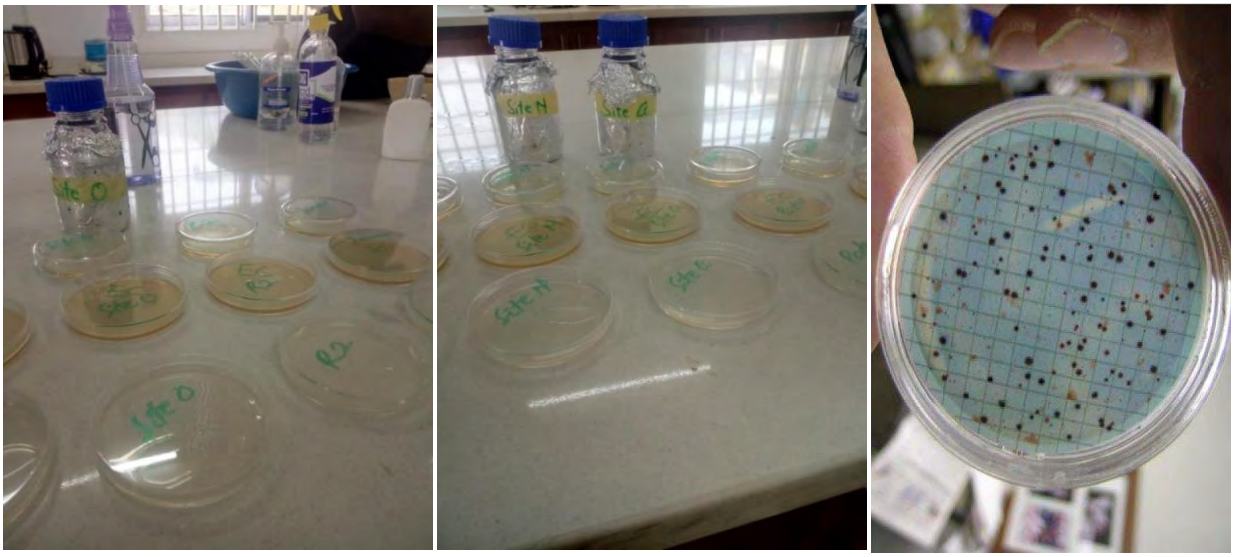

Figure 3.18: Samples for Microbial Analysis

3.6 Quality Control Measures

Blanks were prepared for individual parameters that were analysed using DR 6000 Spectrophotometer. The lid of the DR 6000 was closed after the Sample cell was inserted into cell hole to prevent light from entering the instrument. Waiting period was allowed for reaction to take place after reagent was added.

The laboratory bench was sterilized using methylated spirit while the glass wares (pipettes and Petri dishes) were autoclaved at 121 ^{o}C for 30 minutes (American Public Health Association, 2012).

3.7 Data Analysis

DR 6000 spectrophotometer gave direct results but the data or results were analysed, using statistical method; the mean of the results were calculated and presented in Table 4.1 to Table 4.9

CHAPTER FOUR

RESULTS AND DISCUSSION

4.0 Overview

This chapter deals with the dry season, wet season and their mean values of all the various parameters which were computed from the raw data obtained from the field. Weighted Arithmetic Water Quality Index were calculated and added to the Tables for discussion.

Table 4.1: Results for Physicochemical Water analysis at Site G

Analysis	Unit	Dry Season Results Jan. / Feb.	Wet Season Results
pH	pH unit	4.48 / 4.71	6.40
Conductivity	mS/m	627/655	50.18
Salinity	mg/L		0.25
Total Dissolved Solids	mg/L	376 / 393	250.90
Colour	HU	2.50 / 2.50	2.00
Silica	mg/L		10.14
Turbidity	mg/L	1.00 / 1.00	0.34
Alkalinity (as $CaCO_3$)	mg/L	12.8 / 8.20	22.00
Total Hardness	mg/L	111 / 113	120.00
Calcium Hardness	mg/L	61.3 / 30.1	106.00
Magnesium Hardness	mg/L	50.1 / 82.5	14.00
Chloride	mg/L	127 / 147	102.00
Total Iron	mg/L	0.01 / 0.01	0.02
Calcium	mg/L	24.5 / 12.0	42.40
Sodium	mg/L	38 / 42.0	66.20
Magnesium	mg/L	12.2 / 20.1	3.40
Bicarbonate	mg/L	16.8 / 10.0	26.84
Total Suspended Solids	mg/L	1.00 / 1.00	ND
Copper	mg/L		0.02
Manganese	mg/L	0.170 / 0.461	0.43
Fluoride	mg/L	0.20 / 0.150	ND
Phosphate	mg/L	0.05 / 0.063	1.70
Zinc	mg/L		ND
Cyanide	mg/L		ND
Chromium	mg/L		0.01
Potassium	mg/L	21.0 / 20.8	11.03
Arsenic	mg/L		ND
Nitrate	mg/L	2.12 / 0.735	1.00
Nitrite	mg/L	0.001 / 0.003	0.01
Ammonia	mg/L	0.001 / 0.001	0.03
Sulphate	mg/L	12.9 / 12.3	10.00

Not detected (ND)

Weighted Arithmetic Water Quality Index (WAWQI) is a means by which water quality data is summarized for reporting to the public in a consistent manner. It tells us in simple terms, what the quality of drinking water is from a drinking water supply. This calculation produces a score from 0 and above. The higher the score the worse the quality of water. The scores are then ranked into one of the six categories described as follows: Excellent: (Value water quality index form 0-25) –Possible Usage; drinking and industrial. Good: (water quality index Value from 26-50) –Possible Usage; domestic and industrial. Fair: (water quality index Value from 51-75) –Possible Usage; irrigation and industrial. Poor: (water quality index Value from 76-100) –Possible Usage; irrigation. Very Poor: (water quality index Value from 101-150) –Possible Usage; restricted for irrigation. Unfit for Drinking: (water quality index Value above 150) –Possible Usage; proper treatment required before use. Wikipedia dictionary.

Table 4.2: Results for Weighted Arithmetic Water Quality Index for Dry Season at Site G

Parameter	Standard	1/Si	Site G Observed Value (Vn)	Wn	qn= 100*[(Vn-Vio)/Sn-Vio)]	(qn*Wn)
pH (units)	8.5	0.11765	4.60	0.01138504	-160	-1.8216
Conductivity (µS/cm)	2000	0.0005	641	4.8386E-05	32.05	0.00155
TDS (mg/L)	1000	0.001	384.5	9.6773E-05	38.45	0.00372
Colour (HU)	15	0.06667	2.5	0.00645152	16.6667	0.10753
Turbidity (NTU)	5	0.2	1.0	0.01935456	20	0.38709
Alkalinity (mg/L)	120	0.00833	10.5	0.00080644	8.75	0.00706
Total Hardness (mg/L)	500	0.002	112.0	0.00019355	22.4	0.00434
Chloride (mg/L)	250	0.004	137.0	0.00038709	54.8	0.02121
Manganese (mg/L)	0.40	2.5	0.320	0.24193204	80	19.3546
Iron (mg/L)	0.30	3.33333	0.010	0.32257605	3.33333	1.07525
Phosphate (mg/L)	0.3	3.33333	0.06	0.32257605	20	6.45152
Nitrate (mg/L)	10	0.1	1.42	0.00967728	14.2	0.13742
Ammonia (mg/L)	1.5	0.66667	0.001	0.06451521	0.06667	0.0043
	∑ 1/si	10.3335	∑Wn	1	∑qn*Wn	25.7339
	K =1/ ∑ (1/si)	0.09677		∑qn	150.717	25.7339
			WQI =	**∑(qn*Wn) /∑Wn**		
			WQI =	25.73		

From Table 4.2; at Site G Weighted Arithmetic Water Quality Index value 25.73 for dry season is good for domestic and industrial use per Weighted Arithmetic Water Quality Index results calculated and this might pose serious health issues since it can be used for drinking.

Table 4.3: Results for Weighted Arithmetic Water Quality Index for Wet Season at Site G

Parameter	Standard	1/Si	Site G Observed Value (Vn)	Wn	qn= 100*[(Vn-Vio)/Sn-Vio)]	
pH (units)	8.5	0.11765	6.40	0.0113832		-40
Conductivity (µS/cm)	2000	0.0005	50	4.8379E-05		2.509
Salinity (mg/L)	600	0.00167	0.25000	0.00016126		0.04167
TDS (mg/L)	1000	0.001	250.9	9.6757E-05		25.09
Colour (HU)	15	0.06667	2.0	0.00645048		13.3333
Turbidity (NTU)	5	0.2	0.3	0.01935144		6.8
Alkalinity (mg/L)	120	0.00833	22.0	0.00080631		18.3333
Total Hardness (mg/L)	500	0.002	120.0	0.00019351		24
Chloride (mg/L)	250	0.004	102.0	0.00038703		40.8
Manganese (mg/L)	0.40	2.5	0.430	0.24189303		107.5
Iron (mg/L)	0.30	3.33333	0.020	0.32252404		6.66667
Phosphate (mg/L)	0.3	3.33333	1.70	0.32252404		566.667
Nitrate (mg/L)	10	0.1	1.00	0.00967572		10
Ammonia (mg/L)	1.5	0.66667	0.030	0.06450481		2
	∑ 1/si	10.3351	∑Wn	1	∑qn*Wn	
	K =1/ ∑ (1/si)	0.09676		∑qn		783.741
			WQI =	**∑(qn*Wn) /∑Wn**		
			WQI =	210.94		

From Table 4.3; at Site G, Weighted Arithmetic Water Quality Index value 210.94 for wet season is unfit for drinking and proper treatment is required before use per weighted arithmetic water quality Index results calculated and this might pose serious health issues.

Table 4.4: Results for Physicochemical Water analysis at Site N

Analysis	Unit	Dry Season Results Jan. / Feb.	Wet Season Results
pH	pH unit	4.50 / 5.35	6.40
Conductivity	mS/m	381 / 268	39.22
Salinity	mg/L		0.20
Total Dissolved Solids	mg/L	229 / 161	196.10
Colour	HU	2.50 / 2.50	1.00
Silica	mg/L		12.71
Turbidity	mg/L	1.00 / 1.00	ND
Alkalinity (as $CaCO_3$)	mg/L	24.0 / 24.8	36.00
Total Hardness	mg/L	63.4 / 53.2	88.00
Calcium Hardness	mg/L	31.9 / 34.7	60.00
Magnesium Hardness	mg/L	31.5 / 18.5	28.00
Chloride	mg/L	67.5 / 576	71.00
Total Iron	mg/L	0.01 / 0.01	0.02
Calcium	mg/L	12.7 / 13.9	24.00
Sodium	mg/L	17.8 / 18.2	46.08
Magnesium	mg/L	7.66 / 4.50	6.80
Bicarbonate	mg/L	29.3 / 30.3	43.92
Total Suspended Solids	mg/L	1.00 / 1.00	ND
Copper	mg/L		0.22
Manganese	mg/L	0.121 / 0.116	0.12
Fluoride	mg/L	0.180 / 0.108	0.10
Phosphate	mg/L	0.001 / 0.141	2.40
Zinc	mg/L		0.64
Cyanide	mg/L		ND
Chromium	mg/L		0.02
Potassium	mg/L	14.5 / 13.4	7.68
Arsenic	mg/L		ND
Nitrate	mg/L	4.88 / 1.51	0.40
Nitrite	mg/L	0.01 / 0.002	ND
Ammonia	mg/L	0.001 / 0.001	0.01
Sulphate	mg/L	3.88 / 6.88	2.00

Not detected

Table 4.5: Results for Weighted Arithmetic Water Quality Index for Dry Season at Site N

Parameter	Standard	1/Si	Site N Observed Value (Vn)	Wn	qn= 100*[(Vn-Vio)/Sn-Vio)]	(qn*Wn)
pH (units)	8.5	0.11765	4.93	0.01	-138.00	-1.57
Conductivity (µS/cm)	2000	0.0005	325	0.00	16.23	0.00
TDS (mg/L)	1000	0.001	195.0	0.00	19.50	0.00
Colour (HU)	15	0.06667	2.5	0.01	16.67	0.11
Turbidity (NTU)	5	0.2	1.0	0.02	20.00	0.39
Alkalinity (mg/L)	120	0.00833	24.4	0.00	20.33	0.02
Total Hardness (mg/L)	500	0.002	58.3	0.00	11.66	0.00
Chloride (mg/L)	250	0.004	62.6	0.00	25.02	0.01
Manganese (mg/L)	0.40	2.5	0.120	0.24	30.00	7.26
Iron (mg/L)	0.30	3.33333	0.010	0.32	3.33	1.08
Phosphate (mg/L)	0.3	3.33333	0.07	0.32	23.33	7.53
Nitrate (mg/L)	10	0.1	3.20	0.01	32.00	0.31
Ammonia (mg/L)	1.5	0.66667	0.001	0.06	0.07	0.00
	∑ 1/si	10.3335	∑Wn	1	∑qn*Wn	15.1285
	K =1/ ∑ (1/si)	0.09677		∑qn	80.1383	15.1285
			WQI =	**∑(qn*Wn) /∑Wn**		
			WQI =	15.13		

From Table 4.5; at Site N, Weighted Arithmetic Water Quality Index value 15.13 for dry season is excellent for drinking and industrial use per weighted arithmetic water quality Index results calculated and this might not cause serious health issues.

Table 4.6: Results for Weighted Arithmetic Water Quality Index for Wet Season at Site N

Parameter	Standard	1/Si	Site N Observed Value (Vn)	Wn	qn= 100*[(Vn-Vio)/Sn-Vio)]
pH (units)	8.5	0.11765	6.40	0.01	-40.00
Conductivity (µS/cm)	2000	0.0005	39	0.00	1.96
Salinity (mg/L)	600	0.00167	0.20000	0.00	0.03
TDS (mg/L)	1000	0.001	196.1	0.00	19.61
Colour (HU)	15	0.06667	1.0	0.01	6.67
Turbidity (NTU)	5	0.2	0.0	0.02	0.00
Alkalinity (mg/L)	120	0.00833	36.0	0.00	30.00
Total Hardness (mg/L)	500	0.002	88.0	0.00	17.60
Chloride (mg/L)	250	0.004	71.0	0.00	28.40
Manganese (mg/L)	0.40	2.5	0.120	0.24	30.00
Iron (mg/L)	0.30	3.33333	0.020	0.32	6.67
Phosphate (mg/L)	0.3	3.33333	2.40	0.32	800.00
Nitrate (mg/L)	10	0.1	0.40	0.01	4.00
Ammonia (mg/L)	1.5	0.66667	0.010	0.06	0.67
	∑ 1/si	10.3351	∑Wn	1	∑qn*Wn
	K =1/ ∑ (1/si)	0.09676		∑qn	905.604
			WQI =	**∑(qn*Wn) /∑Wn**	
			WQI =	267.14	

Table 4.6; at Site N Weighted Arithmetic Water Quality Index value 267.14 for wet season is unfit for drinking and needs proper treatment before use per Weighted Arithmetic water quality Index results obtained and this might lead to serious health issues when drank without treatment.

Table 4.7: Results for Physicochemical Water analysis at Site O

Analysis	Unit	Dry Season Results Jan. / Feb.	Wet Season Results
pH	pH unit	5.30 / 4.59	6.30
Conductivity	mS/m	289 / 386	43.16
Salinity	mg/L		0.22
Total Dissolved Solids	mg/L	173 / 232	215.80
Colour	HU	2.50 / 2.50	2.00
Silica	mg/L		8.91
Turbidity	mg/L	1.00 / 1.00	0.40
Alkalinity (as $CaCO_3$)	mg/L	25.2 / 7.40	18.00
Total Hardness	mg/L	62.2 / 63.2	106.00
Calcium Hardness	mg/L	36.3 / 8.81	62.00
Magnesium Hardness	mg/L	25.9 / 57.4	44.00
Chloride	mg/L	67.5 / 87.3	64.00
Total Iron	mg/L	0.01 / 0.01	0.04
Calcium	mg/L	14.5 / 2.33	24.80
Sodium	mg/L	29.0 / 31.0	41.54
Magnesium	mg/L	6.30 / 13.9	10.69
Bicarbonate	mg/L	30.7 / 9.03	21.96
Total Suspended Solids	mg/L	1.00 / 1.00	ND
Copper	mg/L		0.03
Manganese	mg/L	0.194 / 0.193	0.21
Fluoride	mg/L	0.23 / 0.105	ND
Phosphate	mg/L	0.068 / 0.82	1.30
Zinc	mg/L		0.06
Cyanide	mg/L		ND
Chromium	mg/L		0.02
Potassium	mg/L	11.7 / 13.3	6.92
Arsenic	mg/L		ND
Nitrate	mg/L	5.96 / 1.78	3.60
Nitrite	mg/L	0.001 / 0.011	0.02
Ammonia	mg/L	0.001 / 0.001	0.09
Sulphate	mg/L	1.67 / 5.38	2.00

Not detected (ND)

Table 4.8: Results for Weighted Arithmetic Water Quality Index for Dry Season at Site O

Parameter	Standard	1/Si	Site O Observed Value (Vn)	Wn	qn= 100*[(Vn-Vio)/Sn-Vio)]	(qn*Wn)
pH (units)	8.5	0.11765	4.95	0.01138504	-136.67	-1.556
Conductivity (µS/cm)	2000	0.0005	338	4.8386E-05	16.875	0.00082
TDS (mg/L)	1000	0.001	202.5	9.6773E-05	20.25	0.00196
Colour (HU)	15	0.06667	2.5	0.00645152	16.6667	0.10753
Turbidity (NTU)	5	0.2	1.0	0.01935456	20	0.38709
Alkalinity (mg/L)	120	0.00833	16.3	0.00080644	13.5833	0.01095
Total Hardness (mg/L)	500	0.002	62.8	0.00019355	12.552	0.00243
Chloride (mg/L)	250	0.004	77.4	0.00038709	30.96	0.01198
Manganese (mg/L)	0.40	2.5	0.200	0.24193204	50	12.0966
Iron (mg/L)	0.30	3.33333	0.010	0.32257605	3.33333	1.07525
Phosphate (mg/L)	0.3	3.33333	0.44	0.32257605	146.667	47.3112
Nitrate (mg/L)	10	0.1	3.87	0.00967728	38.7	0.37451
Ammonia (mg/L)	1.5	0.66667	0.000	0.06451521	0	0
	∑ 1/si	10.3335	∑Wn	1	∑qn*Wn	59.8243
	K =1/ ∑ (1/si)	0.09677		∑qn	232.92	59.8243
			WQI =	**∑(qn*Wn) /∑Wn**		
			WQI =	59.82		

From Table 4.8; at Site O Weighted Arithmetic Water Quality Index value 59.82 for dry season is fair for domestic and industrial use per Weighted Arithmetic water quality Index results obtained and this might cause health issues when drank without treatment.

Table 4.9: Results for Weighted Arithmetic Water Quality Index for Wet Season at Site O

Parameter	Standard	1/Si	Site O Observed Value (Vn)	Wn	qn= 100*[(Vn-Vio)/Sn-Vio)]	(qn*Wn)
pH (units)	8.5	0.11765	6.30	0.0113832	-46.667	-0.5312
Conductivity (µS/cm)	2000	0.0005	43	4.8379E-05	2.158	0.0001
Salinity (mg/L)	600	0.00167	0.22000	0.00016126	0.03667	5.9E-06
TDS (mg/L)	1000	0.001	215.8	9.6757E-05	21.58	0.00209
Colour (HU)	15	0.06667	2.0	0.00645048	13.3333	0.08601
Turbidity (NTU)	5	0.2	0.4	0.01935144	8	0.15481
Alkalinity (mg/L)	120	0.00833	18.0	0.00080631	15	0.01209
Total Hardness (mg/L)	500	0.002	106.0	0.00019351	21.2	0.0041
Chloride (mg/L)	250	0.004	64.0	0.00038703	25.6	0.00991
Manganese (mg/L)	0.40	2.5	0.210	0.24189303	52.5	12.6994
Iron (mg/L)	0.30	3.33333	0.040	0.32252404	13.3333	4.30032
Phosphate (mg/L)	0.3	3.33333	1.30	0.32252404	433.333	139.76
Nitrate (mg/L)	10	0.1	3.60	0.00967572	36	0.34833
Ammonia (mg/L)	1.5	0.66667	0.090	0.06450481	6	0.38703
	∑ 1/si	10.3351	∑Wn	1	∑qn*Wn	157.233
	K =1/ ∑ (1/si)	0.09676		∑qn	601.408	157.233
			WQI =	**∑(qn*Wn) /∑Wn**		
			WQI =	157.23		

From Table 4.9; at Site O, Weighted Arithmetic Water Quality Index value 157. 23 for wet season is unfit for drinking and needs proper treatment before use per Weighted Arithmetic water quality Index results calculated and this might pose serious health issues when taken without treatment.

The pH values 4.60 pH unit, 4.93 pH unit and 4.95 pH unit for water samples at sites G, N and O for dry season were obtained from the analysis values. The pH values 6.40 pH unit, 6.40 pH unit and 6.30 pH unit for water samples at sites G, N and O for wet season were obtained from the analysis values. The mean pH values 5.50 pH unit, 5.67 pH unit and 5.63 pH unit for water samples at sites G were obtained from the analysis values. The pH values were presented in Table 4.1, 4.4 and 4.7.

The pH of water provides information about the solubility, biological availability and chemical processes within water bodies, and indicates the relative acidic or basic nature of water. At high pH, water taste can be sour while high pH may result in soapy taste. Directly, very low or high pH values can burn mucous membranes of the intestinal mucosa (Fatoki & Muyima, 2003).

Low pH water is regarded as acidic, soft and corrosive which could leach metals such as copper, iron, lead, manganese and zinc from pipes and fixtures and this also causes damage to metal pipes and brings about aesthetic problems such as a metallic sour taste (Akpoveta, 2011). Akpoveta, 2011 asserted that, the waters might contain elevated levels of toxic metals, which could be detrimental to human health.

Acidic water can make the acid in your mouth work even harder and corrode your teeth faster. And if it can corrode your teeth, it can easily damage your soft gums as well. Elevated levels of metal contaminants found in acidic water can cause plenty of health issues that could prove fatal or debilitating for children. Vomiting, diarrhea, kidney disease, liver disease, stomach cramps, and nausea are among the leading health issues caused by the consumption of acidic water. Wikipedia dictionary.

A pH value that is too high can be hazardous to health. If the water has a high pH value (pH value above 10.5), there is a risk of damage to the mucous membranes and eyes (Buker et al, 2021).

The Conductivity values 641 mS/m, 324.50 mS/m and 337.50 mS/m for water samples at site G for dry season were obtained from the analysis values. The Conductivity values 50.18 mS/m, 39.22 mS/m and 43.16 mS/m for water samples at sites G, N and O for wet season were obtained from the analysis values. The mean Electric Conductivity values 345.59 mS/m, 181.86 mS/m and 190.33 mS/m for water samples at sites G, N and O were obtained from the analysis values. The Conductivity values were presented in Table 4.1, 4.4 and 4.7.

Electrical Conductivity is related to the mass of total dissolved solids and other ions in a water body and gives information about the level of mineralization of the water under study (Gyamfi, et al., 2012).

The Salinity values 0.25 mg/L, 0.20 mg/L and 0.22 mg/L for water samples at sites G, N and O for wet season was obtained from the analysis values. The Salinity values were presented in Table 4.1, 4.4 and 4.7.

Recent research shows that mild salinity was associated with low blood pressure and hypertension (Rosinger, 2021).

The Total Dissolved Solids values 384.50 mg/L, 195 mg/L and 202.50 mg/L for water samples at sites G, N and O for dry season were obtained from the analysis values. Total Dissolved Solids values 250.90 mg/L, 196.10 mg/L and 215.80 mg/L for water samples at sites G, N and O for wet season were obtained from the analysis values. The mean Total Dissolved Solids values 317.70 mg/L, 195.55 mg/L and 209.15 mg/L

for water samples at sites G was obtained from the analysis values. The Total Dissolved Solids values were presented showed in Table 4.1, 4.4 and 4.7.

Total Dissolved Solids is the term used to describe the inorganic salts and small amounts of organic matter present in water solution and the principal constituents are usually calcium. magnesium, sodium, and potassium cations and carbonate, bicarbonate, chloride, sulphate and nitrate anions (Aremu et al., 2011). The hardness of drinking water is determined largely by its content of calcium and magnesium and it is expressed as the equivalent amount of calcium carbonate that could be formed from the calcium and magnesium in solution (Itah & Akpan, 2005).

The Colour values 2.50 HU, 2.50 HU and 2.50 HU for water samples at sites G, N and O for dry season were obtained from the analysis values. The Colour values 2.00 HU, 1.00 HU and 2.00 HU for water samples at sites G, N and O for wet season were obtained from the analysis values. The mean Colour values 2.25 HU, 2.25 HU and 2.25 HU for water samples at sites G, N and O were obtained from the analysis values. The Colour values were presented in Table 4.1, 4.4 and 4.7.

Suspended and dissolved particles in water influence color. Water colour determines the level of accumulation of dissolved materials. Colourless water is considered pure though it may be unsafe for human health. Generally, coloured water has adverse effect on human health and aquatic environment. As pure water doesn't possess any kind of colour, water colour may provide evidence that there is some form of contamination. All kind of particles, organic matter, algae, sediments, dissolved minerals or other artificial chemicals are harmful to human and aquatic health. Coloured water may stain textile and fixtures that can cause permanent damage. Impacts of coloured water on industrial boilers, equipment and tools could lead to

high consumption of energy because of the insulation caused by minerals present in water hence reduces efficiency and life of the equipment. Wikipediadictionary;https://www.waterboards.ca.gov/water_issues/programs/swamp/docs/cwt/guidance/3159.pdf.

The Silica values 10.14 mg/L, 12.71 mg/L and 8.91 mg/L for water samples at sites G and N for wet season were obtained from the analysis values. The Silica values were presented in Table 4.1, 4.4 and 4.7.

Silica present in drinking water may be protective with respect to the decrease of cognitive function as it was suggested by several epidemiologic studies, data from French cohort have demonstrated that aluminium in drinking water seems to have a deleterious effect and increased the risk of cognitive impairment when the silica concentrations were low (Guyonnet, Andrieu & Vellas, 2007). Moreover, it has been shown that the performances to a cognitive test were positively correlated to the consumption of silica and that the risk of Alzheimer's disease was reduced in subjects who had the higher daily silica intake compared to the others (Guyonnet, Andrieu & Vellas, 2007). The silica is probably the natural antidote of the aluminium and could play a benefit role by decreasing the biodisponibility of aluminium, whose neurotoxicity is now clearly established (Guyonnet, Andrieu & Vellas, 2007).

The Turbidity values 1.00 mg/L, 1.00 mg/L and 1.00 mg/L for water sample at site G for dry season were obtained from the analysis values. The values 0.34 mg/L and 0.40 mg/L for water samples at sites G and O for wet season were obtained from the analysis values but N was not detected. The means Turbidity value 0.67 mg/L, 0.50 mg/L and 0.70 mg/L for water samples at sites G, N and O were obtained from the analysis values. The Turbidity values were presented in Table 4.1, 4.4 and 4.7.

Outbreaks of gastrointestinal (GI) illness have been linked to incidents in which turbidity exceeded acceptable limits (Mann et al., 2007).

Turbidity is caused by suspended matter or impurities that interfere with the clarity of water bodies. These impurities may include clay, silt, finely divided inorganic and organic matter, soluble coloured organic compounds, and plankton and other microscopic organisms (Bodoczi, 2010). Bodoczi, (2010) asserted that, excessive turbidity in drinking water, apart from being aesthetically unappealing, may also present a health threat by providing food and shelter to pathogens.

The Alkalinity (as $CaCO_3$) values 10.50 mg/L, 24.40 mg/L and 16.30 mg/L for water samples at sites G, N and O for dry season were obtained from the analysis values. The values 22.00 mg/L, 36.00 mg/L and 18.00 mg/L for water samples at sites G, N and O for wet season were obtained from the analysis values. The mean Alkalinity (as $CaCO_3$) values 16.25 mg/L, 30.20 mg/L and 17.15 mg/L for water samples at sites G, N and O were obtained from the analysis values. The Alkalinity (as $CaCO_3$) values were presented in Table 4.1, 4.4 and 4.7.

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).

Alkalinity is water's capacity to resist acidic changes in pH, essentially alkalinity is water's ability to neutralize acid. This ability is referred to as a buffering capacity. A water body with a high level of alkalinity (which is different than an alkaline water body) has higher levels of calcium carbonate, ($CaCO_3$), which can decrease the water's

acidity. Therefore, alkalinity measures how much acid can be added to a water body before a large pH change occurs.

Wikpediadictionary;https://extension.usu.edu/waterquality/learnaboutsurfacewater/propertiesofwater/alkalinity.

Temperature value primarily indicates good water quality, as it influences pH, alkalinity, acidity and dissolved oxygen (DO) and this might unfavorably retard dissolution of oxygen and therefore, could intensify odour due to anaerobic reaction (Wilson, 2012).

Total hardness values 112.00 mg/L, 58.30 mg/L and 62.70 mg/L for water samples at sites G, N and O for dry season were obtained from the analysis values. The values 120.00 mg/L, 88.00 mg/L and 106.00 mg/L for water samples at sites G, N and O for wet season were obtained from the analysis values. The means total hardness values 116.00 mg/L, 73.15 mg/L and 84.35 mg/L for water samples at sites G, N and O were obtained from the analysis values. The Total hardness values were presented in Table 4.1, 4.4 and 4.7.

Inadequate calcium intake is associated with an increased risk of osteoporosis, nephrolithiasis (kidney stones), colorectal cancer, hypertension and stroke, coronary heart disease, insulin resistance and obesity (Buker et al., 2021). Inadequate magnesium intake is associated with hypertension, coronary heart disease, type 2 diabetes mellitus and metabolic syndrome. Magnesium deficiency is associated with the development of hypertension (Buker et al., 2021). Calcium and magnesium intake is positively associated with bone mass density (Buker et al., 2021). Calcium or magnesium deficiency in drinking water appears to cause lower bone mass density

(osteoporosis) and thus leads to a higher incidence of bone fractures (Buker et al., 2021).

In general, an excess intake of calcium is not a problem. If more calcium is taken in than is necessary, the excess is simply excreted by the kidneys in healthy people (Buker et al., 2021). Increased intake of magnesium may cause a temporary change in bowel habits (diarrhoea), but rarely leads to hypermagnesemia for people with normal kidney function (Buker et al., 2021). As hard water is full of minerals, and minerals improve the taste of water, hard water tastes better to most people than soft water (Buker et al., 2021).

Calcium hardness values 45.70 mg/L, 33.30 mg/L and 22.55 mg/L for water samples at sites G, N and O for dry season were obtained from the analysis values. The values 106.00 mg/L, 60.00 mg/L and 62.00 mg/L for water samples at sites G, N and O for wet season were obtained from the analysis values. The means Calcium hardness values 75.65 mg/L, 46.65 mg/L and 42.27 mg/L for water samples at sites G, N and O were obtained from the analysis values. The Calcium hardness values were presented in Table 4.1, 4.4 and 4.7.

Inadequate calcium intake is associated with an increased risk of osteoporosis, nephrolithiasis (kidney stones), colorectal cancer, hypertension and stroke, coronary heart disease, insulin resistance and obesity (Buker et al., 2021). Calcium deficiency in drinking water appears to cause lower bone mass density (osteoporosis) and thus leads to a higher incidence of bone fractures (Buker et al., 2021).

Magnesium hardness values 66.30 mg/L, 25.00 mg/L and 41.65 mg/L for water samples at sites G, N and O for dry season were obtained from the analysis values. The values 14.00 mg/L, 28.00 mg/L and 44.00 mg/L for water samples at sites G, N

and O for wet season were obtained from the analysis values. The means Magnesium hardness values 40.15 mg/L, 26.50 mg/L and 42.83 mg/L for water samples at sites G, N and O were obtained from the analysis values. The Magnesium hardness values were presented in Table 4.1, 4.4 and 4.7.

Inadequate Magnesium intake is associated with hypertension, coronary heart disease, type 2 diabetes mellitus and metabolic syndrome (Buker et al., 2021). Magnesium deficiency is associated with the development of hypertension (Buker et al., 2021). Magnesium deficiency in drinking water appears to cause lower bone mass density (osteoporosis) and thus leads to a higher incidence of bone fractures (Buker et al., 2021).

The Chloride values 137.00 mg/L, 62.55 mg/L, 77.40 mg/L for water samples at sites G, N and O for dry season were obtained from the analysis values. The value 102.00 mg/L, 71.00 mg/L and 64.00 mg/L for water samples at sites G, N and O for wet season were obtained from the analysis values. The means Chloride values 119.50 mg/L, 66.78 mg/L and 70.70 mg/L for water samples at sites G, N and O were obtained from the analysis values. The Chloride values were presented in Table 4.1, 4.4 and 4.7.

The current surface water environmental quality standards have made significant contributions to human health, as well as water ecological safety (Hong et al., 2023). High concentrations of chloride ions in drinking water produce an unpleasant taste and harm human health (Hong et al., 2023). Human contact with water with high concentrations of chloride ions causes damage to the skin (Hong et al., 2023).

Total Iron values 0.01 mg/L, 0.01 mg/L and 0.01 mg/L for water samples at sites G, N and O for dry season were obtained from the analysis values. The values 0.02 mg/L,

0.02 mg/L and 0.04 mg/L for water samples at sites G, N and O for wet season were obtained from the analysis values. The means Total Iron values 0.02 mg/L, 0.02 mg/L and 0.03 mg/L for water samples at sites G, N and O were obtained from the analysis values. The Total Iron values were presented in Table 4.1, 4.4 and 4.7.

High level iron can cause adverse health risks including, Parkinson disease, Huntington disease, cardiovascular disease, hyperkeratosis, diabetes mellitus, pigmentation changes, Alzheimer disease, kidney, liver, respiratory and neurological disorders (Ghosh et al., 2020).

Calcium values 18.25 mg/L, 13.30 mg/L and 8.42 mg/L for water samples at sites G, N and O for dry season were obtained from the analysis values. The values 42.40 mg/L, 24.00 mg/L and 24.80 mg/L for water samples at sites G, N and O for wet season were obtained from the analysis values. The means Calcium values 29.34 mg/L, 18.65 mg/L and 16.61 mg/L for water samples at sites G, N and O were obtained from the analysis values. The Calcium values were presented in Table 4.1, 4.4 and 4.7.

There are many publications documenting increased incidence and mortality rates for cardiovascular diseases associated with a deficit of Calcium in drinking water (Rapant et al., 2017).

Sodium values 40.00 mg/L, 18.00 mg/L and 30.00 mg/L for water samples at sites G, N and O for dry season were obtained from the analysis values. The values 66.20 mg/L, 46.08 mg/L and 41.54 mg/L for water samples at sites G, N and O for wet season were obtained from the analysis values. The means Sodium values 52.10 mg/L, 32.04 mg/L and 35.77 mg/L for water samples at sites G, N and O were

obtained from the analysis values. The Sodium values were presented in Table 4.1, 4.4 and 4.7.

Very high oral doses of sodium chloride may cause nausea, vomiting, inflammation of the gastrointestinal tract, thirst, muscular twitching, convulsions and possibly death. For long-term, lower level exposures, the primary health effect of concern is increased blood pressure (hypertension). Hyponatremia occurs when your blood sodium level goes below 135 meq/L. When the sodium level in your blood is too low, extra water goes into your cells and makes them swell. This swelling can be dangerous especially in the brain, since the brain cannot expand past the skull. Wikipedia dictionary

Magnesium values 16.15 mg/L, 6.08 mg/L and 10.10 mg/L for water samples at sites G, N and O for dry season were obtained from the analysis values. The values 3.40 mg/L, 6.80 mg/L and 10.69 mg/L for water samples at sites G, N and O for wet season were obtained from the analysis values. The means Magnesium values 9.78 mg/L, 6.44 mg/L and 10.40 mg/L for water samples at sites G, N and O were obtained from the analysis values. The Magnesium values were presented in Table 4.1, 4.4 and 4.7.

There are many publications documenting increased incidence and mortality rates for cardiovascular diseases associated with a low of Magnesium in drinking water (Rapant et al., 2017).

Bicarbonate values 13.40 mg/L, 29.80 mg/L and 19.87 mg/L for water samples at sites G, N and O for dry season were obtained from the analysis values. The values 26.84 mg/L, 43.92 mg/L and 21.96 mg/L for water samples at sites G, N and O for wet season were obtained from the analysis values. The means Bicarbonate values 20.12 mg/L, 36.86 mg/L and 20.92 mg/L for water samples at sites G, N and O were

obtained from the analysis values. The Bicarbonate values were presented in Table 4.1, 4.4 and 4.7.

When someone takes too much sodium bicarbonate, the body tries to correct the balance of salt by drawing water into the digestive system. This causes diarrhoea and vomiting and if the body absorbs the sodium, it can cause dehydration. Wikipedia dictionary

Total Suspended Solids values 1.00 mg/L, 1.00 mg/L and 1.00 mg/L for water samples at sites G, N and O for dry season were obtained from the analysis values. The values Total Suspended Solids values for water samples at sites G, N and O for wet season were not detected. The Total Suspended Solids values were presented in Table 4.1, 4.4 and 4.7.

Total suspended solids in drinking water may affect human health, though it depends on what is being faced. Bacteria and algae, for instance, may cause gastrointestinal issues, while pollutants like metals could result in serious health effects or even death. Wikipedia dictionary.

The Copper values 0.02 mg/L, 0.22 mg/L and 0.03 mg/L for water samples at sites G, N and O for wet season were obtained from the analysis values. The Copper values were presented in Table 4.1, 4.4 and 4.7.

High copper intake at concentrations greater than the prescribed limit can cause acute health problems namely gastrointestinal disturbance, central nervous problems, mucosal irritation, Wilson's diseases, damage of liver and kidney, wide spread capillary damage, hepatic and renal damage (Manne al.,2022).

Manganese value 0.32 mg/L, 0.12 mg/L and 0.20 mg/L water samples at sites G, N and O for dry season were obtained from the analysis values. The value 0.43 mg/L, 0.12 mg/L and 0.20 mg/L water samples at G, N and O were obtained from the analysis values. The mean Manganese value 0.38 mg/L, 0.12 mg/L and 0.20 mg/L for water samples at sites N and O were obtained from the analysis values. The Manganese values were presented in Table 4.1, 4.4 and 4.7.

High level Manganese can cause adverse health risks including, Parkinson disease, Huntington disease, cardiovascular disease, hyperkeratosis, diabetes mellitus, pigmentation changes, Alzheimer disease, kidney, liver, respiratory and neurological disorders (Ghosh et al., 2020).

Fluoride values 0.18 mg/L, 0.14 mg/L and 0.17 mg/L for water samples at sites G, N and O for dry season were obtained from the analysis values. The value 0.10 mg/L for water samples at sites N for wet season was obtained from the analysis value but Fluoride values at sites G and O were not detected. The means Fluoride values 0.09 mg/L, 0.12 mg/L and 0.08 mg/L for water samples at sites G, N and O were obtained from the analysis values. The Fluoride values were presented in Table 4.1, 4.4 and 4.7.

Fluoride ion (F^-) in low quantities ($\leq$ 0.7 mg/L) is an essential component of normal mineralisation of bones and formation of dental enamel. However, excess F^- (> 1.5 mg/L) when ingested directly or indirectly, causes adverse physiological effects, leading to slow, progressive crippling of bones and teeth, a condition known as fluorosis, usually manifested as permanent brown tooth stains (Egor & Birungi, 2020).

Phosphate values 0.06 mg/L, 0.07 mg/L and 0.44 mg/L for water samples at sites G, N and O for dry season were obtained from the analysis values. The values 1.70 mg/L, 2.40 mg/L and 1.30 mg/L for water samples at sites G, N and O for wet season were obtained from the analysis values. The means Phosphate value 0.88 mg/L, 1.24 mg/L and 0.87 mg/L for water samples at sites G, N and O were obtained from the analysis values. The Phosphate values were presented in Table 4.1, 4.4 and 4.7.

High serum phosphate concentrations are related to renal calcification, increased kidney weight ratio, chronic kidney disease and cardiovascular disease (Jereb, Poljsak & Erzen 2017).

The Zinc values 0.64 mg/L and 0.06 mg/L for water samples at sites N and O for wet season were obtained from the analysis values but G was not detected. The Zinc values were presented in Table 4.1, 4.4 and 4.7.

High concentrations (675 mg/l and above), zinc can act as an intestinal irritant, causing nausea and vomiting. The manifestations of a moderate deficiency of zinc include growth retardation, male hypogonadism in adolescents, rough skin, poor appetite, mental lethargy, delayed wound healing, cell-mediated immune dysfunctions, and abnormal neurosensory changes. Wikipedia dictionary

The Cyanide values were not detected.

Cyanide is among the most harmful substances on Earth and it is harmful to humans (Kwaansa-Ansah et al., 2021).

The Chromium values 0.01 mg/L, 0.02 mg/L and 0.02 mg/L for water samples at sites G, N and O for wet season were obtained from the analysis values. The Chromium values were presented in Table 4.1, 4.4 and 4.7.

According to a related study conducted in the Greek region of Oinophyta, 'one in four fatalities in a community exposed to hexavalent chromium in drinking water was caused by the emergence of liver, lung, and genitourinary cancer'. Wikipedia dictionary.

Potassium values 20.90 mg/L, 13.95 mg/L and 21.65 mg/L at sites G, N and O respectively were obtained from the analysis values. The values 11.03 mg/L, 7.68 mg/L and 6.92 mg/L for water samples at sites G, N and O for wet season were obtained from the analysis values. The means Potassium values 11.03 mg/L, 7.68 mg/L and 6.92 mg/L for water samples at sites G, N and O were obtained from the analysis values. The Potassium values were presented in Table 4.1, 4.4 and 4.7.

Potassium is an essential nutrient that is needed for maintenance of total body fluid volume, acid and electrolyte balance, and normal cell function, (Aburto et al., 2013). The effect of increased potassium intake compared with lower intake on blood pressure, all-cause mortality, cardiovascular disease, stroke, and coronary heart disease in apparently healthy adults (Aburto et al., 2013).

The Arsenic values for water samples at sites G, N and O for wet season were not detected.

Long-term exposure to arsenic in drinking water can cause cancer in the skin, lungs, bladder and kidney. Wikipedia dictionary; https://www.greenfacts.org/en/arsenic/l-2/ar senic-7.htm.

Nitrate values 1.42 mg/L, 3.20 mg/L and 3.87 mg/L for water samples at site G, N and O for dry season were obtained from the analysis. The values 1.00 mg/L, 0.40 mg/L and 3.60 mg/L water samples at sites G, N and O for wet season water samples

were obtained from the analysis values. The means Nitrate values 1.21 mg/L, 1.80 mg/L and 3.74 mg/L for water samples at sites G, N and O were obtained from the analysis values. The Nitrate values were presented in Table 4.1, 4.4 and 4.7.

When water sources are polluted by nitrate, it creates concern because it can lead to methemoglonaemia in children which may also cause mental retardation if the child survives. (Isiuku & Enyoh, 2020). Consuming high levels of nitrates can cause Nitrate poisoning, symptoms include blue coloration of the skin, difficulty breathing, and fatigue. Wikipedia dictionary; https://etrlabs.com/what-are-the-effects-of-nitrate-in-drinking-water/

Nitrite values 0.002 mg/L, 0.006 mg/L and 0.006 mg/L for water samples at sites G, N and O for dry season were obtained from the analysis values. The values 0.01 mg/L and 0.02 mg/L for water samples at sites G and O for wet season were obtained from the analysis values but Nitrite value at N was not detected. The means Nitrite values 0.006 mg/L, 0.003 mg/L and 0.013 mg/L for water samples at sites G, N and O were obtained from the analysis values. The Nitrite values were presented in Table 4.1, 4.4 and 4.7.

High levels of nitrites are toxic to humans and animals, especially infants. It can enter the body as nitrate, a nutrient which is essential to plant growth and be converted into nitrite, which disrupts the oxygen delivering ability of hemoglobin in the bloodstream. Infants can develop a life- threatening blood disorder known as blue baby syndrome (methemoglobinemia) if exposed to it in water or formula mixed with water that is contaminated with nitrate. Wikipedia dictionary https://www.h2odistributors.com/ pages/contaminants/contaminant-nitrite.asp.

Ammonia values 0.001 mg/L, 0.001 mg/L and 0.001 mg/L for water samples at sites G, N and O for dry season were obtained from the analysis values. The 0.03 mg/L, 0.01 mg/L and 0.09 mg/L for water samples at sites G, N and O for wet season were obtained from the analysis values. The means Ammonia values 0.026 mg/L, 0.006 mg/L and 0.046 mg/L for water samples at sites G, N and O were obtained from the analysis values. The Ammonia values were presented in Table 4.1, 4.4 and 4.7.

Epidemiological and experimental studies suggest a range of adverse effects reported following exposure to ammonia, mostly those related to respiratory and dermal problems, but rarely on hematotoxic and nephrotoxic potentials of ammonia (Neghab et al., 2019). Low level occupational ammonia exposure is associated with chronic irreversible and acute reversible decrements in lungs' functional capacity. (Neghab et al., 2019).

Sulphate values 12.60 mg/L, 5.38 mg/L and 3.53 mg/L for water samples at sites G, N and O for dry season were obtained from the analysis values. The values 10.00 mg/L, 2.00 mg/L and 2.00 mg/L for water samples at sites G, N and O for wet season were obtained from the analysis values. The means Sulphate values 11.30 mg/L, 3.69 mg/L and 2.77 mg/L for water samples at sites G, N and O were obtained from the analysis values. The Sulphate values were presented in Table 4.1, 4.4 and 4.7.

The excessive presence of sulphate in drinking water can alter its taste during its consumption and large doses of sulphate in drinking water can have a laxative effect on the body and cause diarrhoea and severe abdominal pain in consumers (Sawadogo et al. 2022)

Table 4.10: Results for Bacteriological Water Analysis at Site G

Analysis	Unit	Dry Season Results Jan. / Feb.	Wet Season Results	
Total Coliforms	CFC/1ml	ND / ND	ND	
Faecal Coliforms	CFC/1ml	ND / ND	ND	
E. Coli	CFC/1ml	ND / ND	ND	
Heterotrophic Bacteria Count	CFC/1ml	1404 / 416	18	500
Pseudomonas Aeruginosa	CFC/1ml		ND	ND

Not detected (ND)

Table 4.11: Results for Bacteriological Water Analysis at Site N

Analysis	Unit	Dry Season Results Jan. / Feb.	Wet Season Results
Total Coliforms	CFC/1ml	ND / ND	ND
Faecal Coliforms	CFC/1ml	ND / ND	ND
E. Coli	CFC/1ml	ND / ND	ND
Heterotrophic Bacteria Count	CFC/1ml	55 / 260	5
Pseudomonas Aeruginosa	CFC/1ml		ND

Not detected (ND)

Table 4.12: Results for Bacteriological Water Analysis at Site O

Analysis	Unit	Dry Season Results Jan. / Feb.	Wet Season Results
Total Coliforms	CFC/1ml	ND / ND	ND
Faecal Coliforms	CFC/1ml	ND / ND	ND
E. Coli	CFC/1ml	ND / ND	ND
Heterotrophic Bacteria Count	CFC/1ml	1248 / 364	61
Pseudomonas Aeruginosa	CFC/1ml		ND

Not detected (ND)

Total Coliforms values were not detected

A person that has been exposed to these bacteria may have an upset stomach, vomiting, fever, or diarrhea. Wikipedia dictionary

Faecal Coliforms values were not detected

Faecal Coliform bacteria indicate the presence of sewage contamination of a waterway and the possible presence of other pathogenic organisms. Wikipedia dictionary

Faecal Coliform bacteria exist in the intestines of warm-blooded animals and humans and are found in bodily waste, animal droppings, and naturally in soil. Most of the faecal Coliform in faecal material comprised of E. coli, and the serotype E. coli 0157:H7 known to cause serious human illness (Health Canada, 2007).

The E. Coli values were not detected

Some kinds of E. coli can cause diarrhoea while others cause urinary tract infections, respiratory illness and pneumonia and other illnesses. Wikipedia dictionary

Heterotrophic Bacteria Count values 910 CFC/ml, 157.50 CFC/ml and 806 CFC/ml for water samples at sites G, N and O for dry season were obtained analysis value. The values 18.00 CFC/ml, 5.00 CFC/ml and 61.00 CFC/ml for water samples at sites G, N and O for wet season were obtained analysis value. The means Heterotrophic Bacteria Count values 464 CFC/ml, 81.23 CFC/ml and 433.50 CFC/ml for water samples at sites G, N and O were obtained analysis value. The Heterotrophic Bacteria Count values were presented in Table 4.10, 4.11 and 4.12.

Heterotrophic bacteria present in water poses no health risks to humans but a high Heterotrophic Plate Count is an indicator for ideal conditions for the growth of bacteria. This can be a breeding ground for more dangerous bacteria, such as Legionella or E. Coli. This causes foul-tasting water and leads to corrosion or slime growth in pipes. Wikipedia dictionary

The Pseudomonas Aeruginosa values were not detected.

Pseudomonas aeruginosa in water can cause endocarditis, osteomyelitis, pneumonia, urinary tract infections, gastrointestinal infections, and meningitis, and is a leading cause of septicemia. P. *aeruginosa* is also a major cause of folliculitis and ear infections acquired by exposure to recreational waters containing the bacterium. Wikipedia dictionary

CHAPTER FIVE

CONCLUSION, RECOMMENDATIONS AND SUGGESTIONS

5.0 Overview

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

5.1 Conclusion

Water samples collected from the three selected Boreholes in Asesewa-Ghana were analysed for Borehole water quality and its suitability for drinking and domestic purposes. It was also analysed for the levels of Physicochemical and Microbial presence. The results of the study showed that the Boreholes waters were all acidic, the pH values 4.60 pH unit, 4.93 pH unit and 4.95 pH unit were recorded during the dry season and 6.40 pH unit, 6.40 pH unit and 6.30 pH unit were recorded during the wet season at sites G, N and O as being acidic. The Silica value 10.14 mg/L and 12.71 mg/L for wet season at sites G and N respectively were obtained from the analysis results were high. Bicarbonate values 13.40 mg/L, 29.80 mg/L and 19.87 mg/L were recorded during the dry season and 26.84 mg/L, 43.92 mg/L and 21.96 mg/L were recorded during the wet season and 20.12 mg/L, 36.86 mg/L and 20.92 mg/L for the mean at sites G, N and O were high. and finally, Phosphate values 1.70 mg/L, 2.40 mg/L and 1.30 mg/L were recorded during the wet season and 0.88 mg/L, 1.24 mg/L and 0.87 mg/L mean at sites G, N and O respectively were found to be high. Potassium content 20.90 mg/L, 13.95 mg/L and 21.65 mg/L at sites G, N and O which were recorded during the dry season were high and the mean values 15.97 mg/L and 14.29 mg/L at sites G and O were also high. The Heterotrophic Bacteria Count 910 CFC/ml and 806 CFC/ml at sites G and O which were recorded during the dry season

were high. The rest of the elements' values and mean values and microbial content from all the sample sites were low.

The water quality index for dry season was calculated to be 25.73 and wet season 210.94 at site G. That of N which was calculated during the dry season was found to be 15.13 and wet season 267.14. Finally, at O 59.82 was recorded during the dry season and 157.23 during the wet season.

The water is used for comparative purpose of quality characteristics at different sampling sites and also to discuss the quality criteria of particular area in detail. The study clearly indicates that, the selected Borehole waters from the three sites in the Asesewa-Ghana should be treated and monitored regularly for Physicochemical contents.

5.2 Recommendations

From the results of this study, it is recommended that;

- The Boreholes water in Upper Manya Krobo District should be treated and there should be regular follow-up studies to measure the levels of Physicochemical contents, microbial presence and other toxic substances in the Borehole water.
- There should be increased environmental sanitation education by the Community water and Sanitation Agency and Upper Manya Krobo District Assembly to prevent further contamination of this water resource and onwards transmission of water-related and water-borne diseases.

5.3 Suggestions for Further Studies

A modern study of water on Physicochemical content and microbial levels in the Boreholes water throughout the Upper Manya Krobo District should be carried out to

ascertain the water quality in the District. In addition, the upcoming newly drilled Boreholes should be analysed to assess their water quality. The Community water and Sanitation Agency should also expand their water production volume and extend their treated water to the whole Asesewa township. A better understanding of Physicochemical content and microbial levels in the Boreholes water would help curb water-related diseases and improve good health in the Asesewa-Ghana.

REFERENCES

Abok, E. O., Yilgwa, C.S. & Yilgwan, G. (2018). *Department of Food Science, Nutrition and Technology, University of Nairobi.* University of Nairobi.

Aburto, N. J., Hanson S., Gutierrez H., Hooper L., Elliott P. & Cappuccio F. P. (2013). Effect of increased potassium intake on cardiovascular risk factors and disease: systematic review and meta-analyses. *BMJ. 3*, 346-1378.

Addisie, M. B. (2022). *Evaluating Drinking Water Quality Using Water Quality Parameters and Esthetic Attributes*. First Published February 11, 2022 Research Article. https://doi.org/10.1177/117862212210750

Adekola, O., Bashir A. & Abdul-Mumini K. (2015). Physicochemical characteristics of borehole water quality in Gassol Taraba State, Nigeria; Department of Geography, School of Environmental Sciences, Modibbo Adama University of Technology. *Environmental Sciences, 9*(2), 143-154.

Afiukwa, J. N. & Eboatu, A. N. (2007). *Analysis of spring water quality in Ebonyi South Zone and its health impact*. Department of Industrial Chemistry, Ebonyi State University Private Mail Bag 053, Abakaliki, Nigeria. Department of Pure and Industrial Chemistry, Nnamdi Azikiwe University, Awka, Anambra State, Nigeria. © 2013, Science Huβ, http://www.scihub.org/AJSIR; ISSN: 2153-649X, doi:10.5251/ajsir.2013.4.2.231.237

Agudelo-Vera, C., Avvedimento, S., Boxall, J. & Creaco E. (2020). Drinking Water Temperature around the Globe: Understanding, Policies, Challenges and Opportunities. *Journals Water, 12* (4)10-12.

Akhtar, N., IshakI. M.I., Bhawani, S. A & Umar, K. (2021). Various Natural and Anthropogenic Factors Responsible for Water Quality Degradation: A Review. *Journals Water, 13,* 1910-3390.

Akpoveta, O.V. Okoh, B.E. & Osakwe, S.A. (2011). Quality Assessment of Borehole Water used in the Vicinities of Benin, Edo State and Agbor, Delta State f Nigeria. *Current Research in Chemistry, 3,* 62-69.

Al Warawreh, A. M., Tamimi, Z. A. H, Al Qatawna M.A,Aseel A. A., Momani, A.A.A., Al Mhaidat M.R., Naji, W.S.E. & AlSaraireh, S. (2020). Prevalence of Dental Fluorosis among Southern Jordanian Population. *Int J Dent. 29,* 8890004. doi: 10.1155/2020/8890004. eCollection 2020.

Albaggar, A.A. (2021). Investigation of some physical, chemical, and bacteriological parameters of water quality in some dams in Albaha region, Saudi Arabia. *Environ Health Insights, 28*(8), 4605-4612.

American Public Health Association (APHA), (2012). American Public Health Association; American Water Works Association; Water Environment Federation Standard methods for exammination of water and wastewater.Washington, D.C.

Amevenku, F. K. Y., Kortatsi, B. K., & Anornu, G. K. (2012). Water Resources Assessment of the Manya Krobo District. Global Journal of Researches in Engineering Civil and Structural Engineering. *Global Journals Inc.* 2249-4596.

Amfo-Otu, R., Omari, S. & Boakye-Dede, E. (2012). Assessment of Physicochemical Quality of Groundwater Sources in Ga East Municipality of Ghana: Department of Environmental and Natural Resources Management, Presbyterian University College Ghana,Akropong Akuapem, Ghana.2 Abokobi Oyarifa Water and Sanitation ;Development Board, Abokobi Accra, Ghana, www.ccsenet.org/enrr. *Environment and Natural Resources Research, 2*, 3.

Amicizia, D., Micale, R. T., Pennati, B. M., Zangrillo, F., Iovine, M. Lecini,E., Marchini, F., Lai P.L. & Panatto, D. (2019). Burden of typhoid fever and cholera: similarities and differences. Prevention strategies for European travelers to endemic/epidemic areas. *J Prev Med Hyg, 60*(4), E271-E285.doi: 10.15167/2421-4248/jpmh2019.60.4.1333.

Amoako, J. (2011). Physicochemical quality of boreholes in Densu of Ghana. *Applied Water Science, 1,* 41–48.

Anderson, S. E. & Jean Meade, J. B. (2014). Potential Health Effects Associated with Dermal Exposure to Occupational Chemicals. *Environ Health Insights, 8*(1), 51–62. doi: 10.4137/EHI.S15258.

Apau, J. Agbovi, H. K. & Wemegah, D.D. (2013). assessment of the water quality of boreholes in the Aburi Municipality of Eastern Region of Ghana; Kwame Nkrumah University of Science and Technology (KNUST). *Journal of Science and Technology, 33*(3), 89-97 89.

Appiah-Effah, E., Ahenkorah, E.N., Duku, G. A. & Nyarko K.B (2021). Domestic drinking water management: Quality assessment in Oforikrom municipality, Ghana. *Sci Prog, 104*(3), 36-45. doi: 10.1177/00368504211035997.

Araya, D. (2022). Fluoride contamination of groundwater resources in Ghana: Country-wide hazard modeling and estimated population at risk. *Water Res. 1*, 212: 118083. doi: 10.1016/j.watres.2022.118083. Epub 2022 Jan 17.

Aremu, M. O., Olaofe, O., Ikokoh, P.P. & Yakubu, M. M. (2011). Physicochemical characteristics of stream, well and borehole water sources in Eggon, Nasarawa State. Nigeria. *Journal of Chemical Society Nigeria, 36*(1), 13 1-136.

Armah, F. A., Ekumah, B., Yawson, D. O., Odoi, J. O., Afitiri, A. & Nyieku F. E. (2018). Access to improved water and sanitation in sub-Saharan Africa in a quarter century. *Heliyon., 4*(11), e00931. doi: 10.1016/j.heliyon.2018.e00931.

Armstrong, L. E. & Johnson, E. C. (2018). Water Intake, Water Balance, and the Elusive Daily Water Requirement. *J. Acad. Nutr. Diet. 112*, 1056–1061. doi: 10.3390/nu10121928

Avila, D. S., Puntel, R. L. & Schner, M. (2013). Manganese in Health and Disease. *Met Ions Life Sci., 13,* 199–227.doi: 10.1007/978-94-007-7500-8_7.

Azuonwu, O. (2020). *Department of Medical Laboratory Science*. Nigeria: Faculty of Science, River State University, Nkpolu Oroworukwo Port Harcourt.

Bakobie, N., Ibrahim, A. R. & Duwiejuah, A. B. (2020). Sanitation Practices and Microbial Quality of Drinking Water In Open Defaecation Free and Open Defaecation Communities in the Savelugu Municipality. *Ghana J. Sci, 61*(2), 1 – 12. https://dx.doi.org/10.4314/gjs.v61i2.

Bannari, A. & Al-Ali, Z.M. (2017). Assessing Climate Change Impact on Soil Salinity Dynamics between 1987–2017 in Arid Landscape Using Landsat TM, ETM+ and OLI Data. Department of Natural Resources and Environment, College of Graduate Studies, Arabian Gulf University, Manama. *Journals Remote Sensing, 12* 1710.3390/rs12172794

Behailu, T. W., Badessa, T. S. & Tewodros, B. A. (2018). Analysis of physical and chemical parameters in ground water consumed within Konso area. *Southwestern Ethiopia, 12*(3), 106-114. DOI:10.5897/AJEST2017.2419

Biswas, A. K & Sweetharam, K. E. (2008). Achieving Water Security for Asia. *Water Resources Development, 24*(1), 145–176

Bjorklund, G., Chartrand M.S. & Aaseth J. (2017). Manganese exposure and neurotoxic effects in children Environ. *Res., 155*, 380-384.

Boadi, N. O. (2020). *Safety of borehole water as an alternative drinking water source*. https://doi.org/10.1016/j.sciaf.2020.e00657

Bodoczi, A. (2010). The Seasonal Quantitative Distribution of Coliform Germs in The Aries River (Romania) Water Affected by Pollution. *Environmental Pollution,* 32-141.

Bouchard, M. F. (2018). Low level exposure to manganese from drinking water and cognition in school-age children. *Neurotoxicology, 64*(2018), 110-117.

Bouslah S., Djemili L., Houichi L. (2017). Water quality index assessment of

Koudiat Medouar Reservoir, northeast Algeria using weighted arithmetic index method. Journal of Water and Land Development. No. 35p. 221–228. DOI: 10.1515/jwld-2017-0087.

Bouwman, A. F., Drecht, V. G, Knoop, J. M, Meinard, C. & Beusen, A. (2001). Global pollution of surface waters from point and nonpoint sources of nitrogen. *Environmental Pollution, 2*, 632-641. doi: 10.1100/tsw.2001.326.

Brazier, Y. (2018). Medically reviewed by Karen Cross FNP, MSN Written by Fluoride is found naturally in soil, water, and foods. It is also produced synthetically for use in drinking water, toothpaste, mouthwashes and various chemical products. *Int Dent J, 72*(6), 853–858.d oi: 10.1016/j.identj .2022.04.010

Bricheno, L. M., Wolf, J. & Sun, Y. (2021). *Saline intrusion in the Ganges-Brahmaputra-Meghna megadelta*. 529882/1/1-s2.0-S0272771421000822-

Briffa, J. (2020). Heavy metal pollution in the environment and their toxicological effects on humans. *Environmental Pollution,* 6(9), 04691. doi: 10.1016/j. heliyon.2020.e04691

Brindha, K., Paul, R., Walter, J., Tan M. L. & Singh M. K. (2020). Trace metals contamination in groundwater and implications on human health. *Comprehensive Assessment using Hydrogeochemical and Geostatistical Methods, 42*(11):3819-3839. doi: 10.1007/s10653-020-00637-9.

Buker, O. Stolt, K., Kroner, C., Benkova, M. Pavlas, J. & Seypka, V. (2021). Investigations on the Influence of Total Water Hardness and pH Value on the Measurement Accuracy of Domestic Cold Water Meters. *Journals Water, 13*, 19. 10.3390/w13192701

Castano-Sanchez, A., Hose, G. C. & Reboleira, A. S. P. S. (2020). Salinity and temperature increase impact groundwater crustaceans. *Scientific Reports 10*, Article number: 12328 (2020), Published: 23 July 2020.

Chaplin, M. F. (2001). *Biochernisty and Molecular Biology Education*. Water: its importance to life. School of Applied Science, South Bank University.

Charles, K. J., Nowicki, S., & Bartram, J. K (2020). *A framework for monitoring the safety of water services*: from measurements to security.

Charrois, J. W. A. (2010). Private drinking water supplies: challenges for public health. *Canadian Medical Association Journal, 182*(10).

Chegbeleh, L. P., Akurugu, B. A & Yidana, S. M. (2020). Assessment of Groundwater Quality in the Talensi District, Northern Ghana. 2020 Apr 10. *Scientific World Journal, 10*, 845-860. doi: 10.1155/2020/8450860.

Chew, J. F., Korlin L., Ona, F., Pinto, S., Fenyi-Baah, S., Osei, B. G. & Gute, D. M. (2019). Water Source Preferences and Water Quality Perceptions among Women in the Eastern Region, Ghana: A Grounded Theory Study. *Int. J. Environ. Res. Public Health, 16*, 3835

Chigor, V. N., Umoh, V. J., Okuofu, C. A., Ameh, J. B., Igbinosa, E. O. & Okoh, A. I. (2012). Water quality assessment: surface water sources used for drinking and irrigation in Zaria, Nigeria is a public health hazard. Environ Monit Assess. *Environ Monit Assess., 184*(5), 3389-400. doi: 10.1007/s10661-011-2396-9.

Cobbina, S. J., Duwiejuah, A. B., Quansah, R., Obiri, S. & Bakobie, N. (2015). Comparative Assessment of Heavy Metals in Drinking Water Sources in Two Small-Scale Mining Communities in Northern Ghana. *Int J Environ Res Public Health, 12*(9), 10620–10634. Published online 2015 Aug 28.

Colour comparator, Wikipedia dictionary, https://en.wikipedia.org › wiki › Forel-Ule_scale

Community & Public Health. (2019). Health risks of nitrates in drinking water. *Environ Health, 22,* 9. doi: 10.1186/s12940-023-00960-5

Cunningham, G. B., Wicker, P. & McCullough, B. P. (2020). Pollution, Health, and the Moderating Role of Physical Activity Opportunities; Center for Sport Management Research and Education, Department of Health and Kinesiology, Texas A&M University, College Station, TX 77843-4243, USA, Department of Sports Science, Bielefeld University, 33615 Bielefeld, Germany. *Int. J. Environ. Res. Public Health, 17*(17), 6272.

Dampare, S. B., Ameyaw, Y., Adotey, D. K., Osae, S., Serfor-Armah, Y., Nyarko, B. J. B., & Adomako, D. (2006). Seasonal trend of potentially toxic trace elements in soils supporting medicinal plants in the eastern region of Ghana. *Water, Air, and Soil Pollution, 169*(1), 185-206.

Danso-Boateng, E. & Frimpong, I. (2013). Quality analysis of plastic sachet and bottled water brands produced or sold in Kumasi, Ghana. *International Journal of Development and Sustainability, 2*(4), 2222-2232.

De Franca D. (2010). Factors Influencing Public Perception of Drinking Water Quality. *Syst Rev. 8*, 111. v.8; 2019 PMC6511211. doi: 10.1186/s13643-019-1013-9

Deal, P. & Sabatini, D. (2020). Evaluating the Level of the Household Water Service Provided by a Private Water Enterprise in Ghana. *Water, 12*(3), 693; https://doi.org/10.3390/w12030693.

DeGabriele, J. (2002). *Improving Community Based Management of Boreholes, A Case Study from Malawi; Broadening Access and Strengthening Input Market Systems*. University of Wisconsin-Madison, wisc.eduhttp://www.wisc. edu/ltc/ basis.html.

Demelash, H. Beyene, A., Abebe, Z. & Melese, A. (2019). Fluoride concentration in fluorosis in Ethiopian Rift Valley: systematic review and meta-analysis. *BMC Public Health, 19*(1), 1298. doi: 10.1186/s12889-019-7646-8.

DenBesten, P. & Li, W. (2011). Chronic Fluoride Toxicity: Dental Fluorosis. *Monogr Oral Sci. 22,* 81–96. doi: 10.1159/000327028

Diersing, N. (2009). "Water Quality: Frequently Asked Questions". *Appl Water Sci 11*, 46. https://doi.org/10.1007/s13201-021-01376-7

Dietrich, P. & Leven, C. (2006). Investigation of the geochemical impact of CO_2 on shallow *groundwater. Direct Push-Technologies Journal 10*(3), 955-973

Dinka, M. O. (2018). *Safe Drinking Water: Concepts, Benefits, Principles and Standards*. IntechOpen, London, 163-181.

Edokpayi, J. N., Enitan, A. M., Mutileni, N. & Odiyo, J. O. (2018). Evaluation of water quality and human risk assessment due to heavy metals in groundwater around Muledane area of Vhembe District, Limpopo Province, South AfricaEDTA Titration. *Chem Cent J. 12*(1), 2. doi: 10.1186/s13065-017-0369-y.

Egor, M. & Birungi, G. (2020). *Fluoride contamination and its optimum upper limit in groundwater from Sukulu Hills, Tororo District, Uganda*. Volume 7, March 2020, e00241; https://doi.org/10.1016/j.sciaf.2019.e00241

Everett, E. T. (2011). Fluoride's Effects on the Formation of Teeth and Bones, and the Influence of Genetics. *J Dent Res. 90*(5), 552–560. doi: 10.1177/0022034510384626

Fatoki, O. S. & Muyima, N. Y. (2003). *Situational Analysis of the Health related Water Quality Problems of the Umtata River*. WRC Report No.1067/1/03. South-Africa: Water Research Commission of South-Africa.

Francis, M. R., Nagarajan, G., Sarakar, R., Mohan, V. R., Kang, G. & Balraj, V. (2015). Perception of drinking water safety and factors influencing acceptance and sustainability of a water quality intervention in rural southern India. *BMC Public Health, 15*, 731.doi: 10.1186/s12889-015-1974-0.

Freeman M. C. Garn, J. V., Sclar, G. D., Boisson, S., Medlicot, K., Alexander, K. T., Penakalapati, G. Anderson, D., Mahtani, A G., Grimes, J. T., Rehfuess, E, A. (2017). The impact of sanitation on infectious disease and nutritional status: A systematic review and meta-analysis. *Int J Hyg Environ Health, 6*, 928-949. doi: 10.1016/j.ijheh.2017.05.007.

Frisbie, S. H., Mitchell, E. J., Dustin, H., Maynard, D. M. & Sarkar. (2012). *World Health Organization Discontinues.* Its Drinking-Water Guideline for Manganese Published:1 June 2012.

Ganyaglo, S. Y., Banoeng-Yakubo, B., Osae, S., Dampare, S. B., & Fianko, J. R. (2011). Water quality assessment of groundwater in some rock types in parts of the eastern region of Ghana. *Environmental Earth Sciences, 62*(5), 1055-1069.

Gemeda, S. T. (2021). The importance of water quality in classifying basic water services: The case of Ethiopia, SDG6.1, and safe drinking water. *PLoS One, 16*(8), 248-944. doi: 10.1371/journal.pone.0248944

Ghosh, C. G. et al. (2020). Human health risk assessment of elevated and variable iron and manganese intake with arsenic-safe groundwater in Jashore, Bangladesh. *Sci Rep. 10*(1), 5206. doi: 10.1038/s41598-020-62187-5.

Gizaw, Z., Adane, J., Azanaw, J., Adisu, A. & Haile, D. (2018). Childhood intestinal parasitic infection and sanitation predictors in rural Dembiya, northwest Ethiopia. Department of Environmental and Occupational Health and Safety, Institute of Public Health, College of Medicine and Health Sciences, University of Gondar, Gondar, Ethiopia. *Environ Health Prev Med, 23*(1), 26. doi: 10.1186/s12199-018-0714-3.

Granados-Chichinlla F. Mena, S. P. & Arias, L. M. (2015). Inorganic contaminants and composition analysis of commercial feed grade mineral compounds available in Costa Rica. *Food Contamination, 2*, 8 (2015). https://doi.org/10. 1186/s405 50-015-0015-1

Green, T. R. (2016). *Linking Climate Change and Groundwater*. DOI:10.1007/978-3-319-23576-9_5

GSA-Ghana Standards Authority (2009). *Limits for Drinking water* (GS 175-1:2009 /3rd Ed.)

Guyonnet, G. S, Andrieu, S. & Vellas B. (2007). *The potential influence of silica present in drinking water on Alzheimer's disease and associated disorders*.

Gyamfi, E. T., Ackah, M., Anim, A. K., Hanson, J. K., Kpattah, L., Enti-Brown, S., & Nyarko, E. S. (2012). chemical analysis of Portable Water samples fromselected suburbs of Accra. *Proceedings of the Inational Academy of Ecology and Environmental Science*, *2*(2), 118-127.

Habiyakare, T., Schurer J. M., Poole B., Murcott S., Migabo, B., Birori Mardochee, B., Amuguni H. J. & John P. Morgan, J. P. (2021). Dental fluorosis among people and livestock living on Gihaya Island In Lake Kivu, Rwanda. *One Health Outlook, 3*(1), 23. doi: 10.1186/s42522-021-00054-7.

Hassan, I. & Aziz, S. A. (2019). Spatial and Temporal Variation of Groundwater Quality within Omdurman Locality Geological Zone. *Applied Water Science*, *3*, 4 doi:10.3274/OAJESS.2019.03.000169. Pub 9, 10, 2019

Health Canada, (2007). Total, Fecal & E. coli Bacteria in Groundwater. *Water Stewardship Information Series, 16* 12. *Int J Environ Res Public Health. 7*(10), 3657–3703. doi: 10.3390/ijerph7103657

Herberg, J., Pahari, A., Walters S. & Levin M. (2019). Infectious Diseases and the Kidney. *Pediatric Nephrology,* 1235–1273. doi: 10.1007/978-3-540-76341-3_52

Hong, Y., Zhu, Z., Liao, W., Yan, Z., Feng C. & Xu, D. (2023). Freshwater Water-Quality Criteria for Chloride and Guidance for the Revision of the Water-Quality Standard in China. *Int J Environ Res Public Health. 2023 Feb; 20*(4), 2875.doi: 10.3390/ijerph20042875

Hosetti, B. (2011). Metabolic changes in the freshwater fish Catla Catla, under copper cyanide intoxication. *Int J Pharm Biol Arch, 2*, 874–9.

Hrudey, S. E. & Hrudey, E. J. (2007). Published case studies of waterborne disease outbreaks—Evidence of a recurrent threat. *Water Environment Research. 79*(3), 233–245.

Hrudey, S. E. & Hrudey, E. J. (2004). *Safe drinking water. Lessons from recent outbreaks in affluent nations*. London, UK: IWA Publishing; 2004. https://doi.org/10.5772/intechopen.71352

Hussain, A., Sulehria, A. Q., Ejaz, M., & Maqbool, A. (2013). Monthly variations in physicochemical parameters of a flood plain reservoir on River Ravi near Balloki Headworks (Pakistan). *Biologia (Pakistan), 59*(2), 371-377.

Ige, O. O., Ameh, H. O. & Olaleye, I. M. (2021). *Borehole inventory, groundwater potential and water quality studies in Ayede Ekiti, Southwestern Nigeria*. 1, Article No. 2. https://doi.org/10.1007/s43832-020-00001-z

Igwe, P. U., Chukwudi, C. C., Ifenatuorah, F. C., Fagbeja, I. F., & Okeke, C. A. (2017). A review of environmental effects of surface water pollution. *International Journal of Advanced Engineering Research and Science*, *4*(12), 237340.

Ikem, A. Osibanjo, O. Sridhar, M. K. C. & Sobande, (2002). Evaluation of Groundwater Quality Characteristics near Two Waste Sites in Ibadan and Lagos, Nigeria. *Water, Air, and Soil Pollution, 140*, 307–333.

Ishaku, J. M. (2011). Assessment of groundwater quality index for jimeta- yola area. *Northeastern Nigeria. J. Geol. Min. Res*, *3*(9), 219–231.Available online

Isiuku, B. O. & Enyoh, C. E. (2020). *Pollution and health risks assessment of nitrate and phosphate concentrations in water bodies in South Eastern, Nigeria*. https://doi.org/10.1016/j.envadv.2020.100018

Itah, A. Y. & Akpan, C. E. (2005). Portability of Drinking Water in an Oil Impacted Community in Southern Nigeria. *Journal of Applied Science and Environmental Management, 91*(1), 35-74.

Jaishankar, M., Tseten, T., Anbalagan, N., Mathew, B.B. & Beeregowna K. N. (2014). Toxicity, mechanism and health effects of some heavy metals. *Interdiscip Toxicol., 7*(2), 60–72. doi: 10.2478/intox-2014-0009

Jereb, G, Poljsak, B. & Erzen, I. (2017). Contribution of Drinking Water Softeners to Daily Phosphate Intake in Slovenia. *Int J Environ Res Public Health, 14*(10), 1186. doi: 10.3390/ijerph14101186.

Kamara, J. K., Galukande, M., Maeda, F., Luboga, S. & Renzaho, A. M. N. (2017). Understanding the Challenges of Improving Sanitation and Hygiene Outcomes in a Community Based Intervention: A Cross-Sectional Study in Rural Tanzania. *Int J Environ Res Public Health, 14*(6), 602. doi: 10.3390/ ijerph14060602

Kanamarlapudi, S. L. R. K., Chintalpudi, V. K. & Muddada, S. (2018). *Application of Biosorption for Removal of Heavy Metals from Wastewater*. Published: July 18th, 2018; DOI: 10.5772/intechopen.77315.

Kanduti, D. Sterbenk, P. & Artnik, B. (2016). Fluoride: A Review of Use and Effects on Health. *Mater Sociomed, 28*(2), 133-7. doi: 10.5455/msm. 2016.28.133-137. Epub 2016 Mar 25.

Kaushal, S. S., Likens, G. E., Pace, M. L., Reimer, J. E., Maas, C. M., Gadella, J. C., Utz, R. M., Duah, S., Kryger, J. R.., Yaculak, A. M., Boger, W. L., Bailey, N. W., Haq, S., Wood, K.S., Wessel, B.M., Park, C. E., Collison, D. C., Aisins, B.Y. I., Gedeon, T. M., Chaudhary, S. K., Widmer, J., Blackwood, C. R., Bolster, C. M., Devilbiss, M. L. & Woglo S. (2021). Freshwater salinization syndrome: from emerging global problem to managing risks. *Biogeochemistry*. https://doi.org/10.1007/s10533-021-00784-w

Kebede, A., Retta, N., Abuye, C., Whiting, S., Kassaw, M., Zeru, T., Tessema, M. & Kjellevold. (2016). Dietary Fluoride Intake and Associated Skeletal and Dental Fluorosis in School Age Children in Rural Ethiopian Rift Valley. *Int J Environ Res Public Health, 13*(8), 756.doi: 10.3390/ijerph13080756.

Khan, K. (2011). Manganese exposure from drinking water and children's classroom behaviour in Bangladesh. *Environ Health Perspect, 119*, 1501–1506.

Khatri, N. & Tyagi, S. (2014). *Influences of natural and anthropogenic factors on surface and groundwater quality in rural and urban areas*. Frontiers in Life Science, 8, 23-39. https://doi.org/10.1080/21553769.2014.933716

Kierdorf, U. (2016). Developmental and Post-Eruptive Defects in Molar Enamel of Free-Ranging Eastern Grey Kangaroos (Macropus giganteus) Exposed to High Environmental Levels of Fluoride. *Journal. Pone 11*(2), 147-427.

Kılıç, Z. (2020). The importance of water and conscious use of water. Department of Civil Engineering, Engineering Faculty, Adıyaman University, Turkey. Correspondence.: Zeyneb Kılıç, Department of Civil Engineering, Engineering Faculty, Adıyaman University, Adıyaman, Turkey. 223 3843. *International Journal of eISSN*: 2576-4454.

Kim, K. M., Choi S.H. Lim, S., Moon, J. H., Kim, J. H., Kim, S. W., Jang, H. C. & Shin C. S. (2014). Interactions Between Dietary Calcium Intake and Bone. *J Clin Endocrinol Metab. 99*(7), 2409-17. doi: 10.1210/jc.2014-1006.

Kortatsi, B. K. (2007). Hydrochemical framework of groundwater in the Ankobra Basin, Ghana. *Aquatic Geochemistry Volume 13*, 41–74.

Kuddus, M.A., Tynan, E. & McBryde, E. (2020). Urbanization: a problem for the rich and the poor. *Public Health Rev. 2020 Jan 2*, 41:1. doi: 10.1186/s40985-019-0116-0. eCollection 2020.

Kullar, S. S. (2019). A benchmark concentration analysis for manganese in drinking water and IQ deficits in children. *Environment International, 130*, 104-889.

Kura, N.U. Kura, N. U., Ramli, M. F., Sulaiman, W. N. A., Ibrahim, S., Aris, A. Z. & Mustapha, A. (2013). Evaluation of Factors Influencing the Groundwater Chemistry in a Small Tropical Island of Malaysia. Environmental Forensics Research Centre, Faculty of Environmental Studies, Universiti Putra Malaysia. *Int. J. Environ. Res. Public Health, 10*(5), 1861-1881; https://doi.org/ 10.3390/ ijerph10051861.

Kwaansa-Ansah, E. E. Kwaansa-Ansah, E. E., Amenorfe, L. P., Armah E. K., & Opoku F. (2021), Human health risk assessment of cyanide levels in water and tuber crops from Kenyasi, a mining community in the Brong Ahafo Region of Ghana. Environmental Forensics Research Centre, Faculty of Environmental Studies, Universiti Putra Malaysia, 43400 UPM Serdang, Selangor, Malaysia. *International Journal of Food Contamination, 4,* 16.

Lemo, O. (2002). *Bacteriology Determination of Water with long term storage (BSc. Thesis)*. Abeokuta, UNAAB

Levallois, P. & Villanueva, C.M. (2019). Drinking Water Quality and Human Health. *Int J Environ Res Public Health, 16*(4), 631. doi: 10.3390/ijerph16040631

Lin L., Yang H. & Xu X, (2022). Effects of Water Pollution on Human Health and Disease Heterogeneity: A Review Front Environ. Sci., 30 June 2022.Sec. Water and Wastewater Management. Volume 10 – 2022. https://doi.org/10. 3389/fenvs.2022.880246

Liu, S., Zhu, Y. & Gegen, T. (2020). Micromorphological analysis and bond strength comparison of two adhesives for different degrees of dental fluorosis. *Applied Adhesion Science, 8*, 6.

Lugo, E.R. Lugo, J. L., Lugo, E. R. & Puente, M. (2020). A systematic review of microorganisms as indicators of recreational water quality in natural and drinking water systems. *J. Water Health, 19*(1), 20–28.

Lutterodt, G., Vossenberg, J. V., Hoiting, Y., Kamara, A. K., Oduro-Kwarteng, S. & Foppen, J. W. A. (2018). Microbial Groundwater Quality Status of Hand-Dug Wells and Boreholes in the Dodowa Area of Ghana. *Int. J. Environ. Res. Public Health, 15*(4), 730. https://doi.org/10.3390/ijerph15040730

Luvhimbi, N., Tshitangano, T. G., Mabunda, J. T., Olaniyi, F. C. & Edokpayi, J.N. (2022). Water quality assessment and evaluation of human health risk of drinking water from source to point of use at Thulamela municipality, Limpopo Province. *Sci Rep 12*, 6059. https://doi.org/10.1038/s41598-022-100 92-4.

Ma, J., Wu, S., Shekhar, R. N. V., Biswas, S.& Sahu A. K. (2020). *Determination of Physicochemical Parameters and Levels of Heavy Metals in Food Waste Water with Environmental Effects*. https://doi.org/10.1155/2020/8886093

Magana-Arachchi, D. N. & Wanigatunge, R. P. (2020). Ubiquitous waterborne pathogens. Elsevier Public Health Emergency Collection. *Waterborne Pathogens,* 15–42. doi: 10.1016/B978-0-12-818783-8.00002-5

Mann, A. G., Ta, C. C., Haggins, C. D. & Rodrigues L. (2007). The association between drinking water turbidity and gastrointestinal illness: a systematic review. *J Water Health, 2-56*

Manne, R.., Kumaradoss, M. M. R M., Iska R. S. R., Devarajan, A. & Mekala, N. (2022). Water quality and risk assessment of copper content in drinking water Stored in copper container. *Applied Water Science, 27*, 120-122

Mara, D., Lane, J., Scott, B. & Trouba, D. (2010). Sanitation and Health. *PLoS Medicine, 7*, e1000363. http://dx.doi.org/ 10.1371/ journal.pmed.1000363

Masindi, V. & Foteinis, S. (2021). Groundwater contamination in sub-Saharan Africa: Implications for groundwater protection in developing countries. *Cleaner Engineering and Technology, 2*, 100-138. https://doi.org/10.1016/j .clet.2020. 100038.

Mateo-Sagasta, J., Evans, A. E. V., Qadir, M. Boelee E. & Ippolito, A. (2017). Water pollution from agriculture: a global review; the Food and Agriculture Organization of the United Nations Rome, 2017 and the International Water Management Institute on behalf of the Water Land and Ecosystems research program Colombo, 2017. Agricultural water pollution: key knowledge gaps and research needs. *Current opinion in environmental sustainability 36*, 20-27

Matveeva, V. A, Alekseenko, A. V., Karthe, D. & Puzanov, A. V. (2022). Manganese Pollution in Mining-Influenced Rivers and Lakes: Current State and Forecast under Climate Change in the Russian Arctic. *Water, 14*(7), 1091.

McMahon, P. B., Belitz K., Reddy J. E., & Johnson T. D. (2019). Elevated manganese concentrations in United States groundwater, role of land surface-soil-aquifer connections. *Environ Sci Technol, 53* (1), 129-138.

Medudhula, T. (2012). Analysis of water quality using physico-chemical parameters in lower Manair Reservoir of Karimnagar District,Andhra Pradesh. *Int. J. Environ. Sci, 3*(1), 172-180.

Meride, Y. & Ayenew, B. (2016). Drinking water quality assessment and its effects on residents' health in Wondo genet campus, Ethiopia. *Journal of Geoscience and Environment Protection, 6*(12), 90-118. https://doi.org/10.1186/s40068-016-0053-6

Mishra, B. K. (2021). Water Security in a Changing Environment: Concept, Challenges and Solutions; School of Engineering, Pokhara University, Pokhara 33700. *Nepal Journals Water, 13*(4), 10.3390/w13040490

Molina-Frechero, N., Nevarez-Rascon, M., Nevarez-Rascon, A., Gonzalez-Gonzalez, R.., Irigoyen-Camacho, M. E., Sanchez-Perez, L., Lopez-Verdin, S. & Bologna-Molina, R. (2017). Impact of Dental Fluorosis, Socioeconomic Status and Self-Perception in Adolescents Exposed to a High Level of Fluoride in Water. *Int J Environ Res Public Health, 14*(1), 73. doi: 10.3390/ ijerph1 4010073.

Mugagga, F. & Nabaasa, B.B. (2016). The centrality of water resources to the realization of Sustainable Development Goals (SDG). A review of potentials and constraints on the African continent. *International Soil and Water Conservation Research*, *4*(3), 215-223.

Nawrot Nawrot, N., Wojciechowska, E., Rezania, S., Walkusz-Miotk, J. & Pazdro, K. (2020). The effects of urban vehicle traffic on heavy metal contamination In Road sweeping waste and bottom sediments of retention tanks. *Sci Total Environ., 749*, 141-511. doi: 10.1016/j.scitotenv.2020.141511. Epub 2020 Aug 4.

Ncube, J. E., & Schutte, C. F. (2005). The occurrence of fluoride in South African groundwater: A water quality and health problem. *Water S.A., 31*(1). DOI: 10. 4314/wsa.v31i1.5118

Nedellec, V., Rabl, A. & Dab, W. (2016). Public health and chronic low chlordecone exposure in Guadeloupe, Part 1: hazards, exposure-response functions, and exposures. *Environ Health. 15*(1), 78. doi: 10.1186/s12940-016-0159-3.

Neghab,M., Mirzaei, A., Jalilian, H. Jahangiri, M., Zahedi, J. & Yousefinejad, S. (2019). Effects of Low-level Occupational Exposure to Ammonia on Hematological Parameters and Kidney Function. *Int J Occup Environ Med. 10*(2), 80–88. doi: 10.15171/ijoem.2019.1527

Nkansah, M. A., Boadi, N. O. & Badu, M. (2010). Assessment of the quality of water from hand-dug wells in Ghana. *Environ Health Insights, 26*(4), 7-12. doi: 10.4137/ehi.s3149.

O'Neal, S. L. & Zheng, W. (2015). Manganese Toxicity Upon Overexposure: a Decade in Review. *Current Environmental Health Reports, 2*, 315–328.

Obot, E. E. & Edi, D. B. (2012). Spatial variation of borehole water quality with depth in Uyo Municipality, Nigeria. Int J Environ Sci Manag Eng Res. 2012; 1: 1–9.

Odiyo, J. O, Mathoni, M. M. & Makungo, R. (2020). Department of Hydrology and Water Resources, University of Venda, Thohoyandou 0950, South Africa. *Water SA, 38*(5), 731-736.

Ohwoghere, A. O. (2012). Heavy metals distribution in degraded land forms in Delta State of the Niger Delta. *J Geolgy Min Res., 4*(3), 43–50.

Omarova, A., Tussupova, K., Hjorth, P., Kalishev, M. & Dosmagambetova, R. (2019). Water Supply Challenges in Rural Areas: A Case Study from Central Kazakhstan. *Int J Environ Res Public Health, 16*(5), 688. doi:10.3390/ijerph1 6050 688.

Omer, N. H. (2019). Water Quality Parameters; Published: October 16th, 2019. *Microbiol. Res, 4*(1), e2; https://doi.org/10.4081/mr.2013.e2

Ovem, H. H., Ovem, M. I. & Usese, I. A. (2015). Iron, manganese, cadmium, chromium, zinc and arsenic groundwater contents of Agbor and Owa communities of Nigeria, Published online 2015 Mar 1. *Springerplus, 4,* 104. doi: 10.1186/s40064-015-0867-0

Owusu, P. A., Asumadu-Sarkodie, S. & Ameyo, P. (2016). A review of Ghana's water resource management and the future prospect. *Cogent Engineering*, *3*(1), 1164275.

Oyiboka F. I. (2014). *Effects of Landfill Sites on Groundwater Quality in Igando, Alimosho Local government Area, Lagos State submitted in accordance with the requirements for the degree of Master of Science in the subject Environmental Science*. RI: http://hdl.handle.net/10500/18733; Date: 2014-03

Pastore, N., Cherubini, C., Doglioni, A., Giasi C.I. & Simeone, V. (2020). Modelling of the Complex Groundwater Level Dynamics during Episodic Rainfall Events of a Surficial Aquifer in Southern Italy. Article belongs to the Special Issue Soil Sciences and Water Table). *Water, 12*(10), 2916; https:// doi.org/10.3390/w12102916

Peckham, S. & Awofeso, N. (2014). Water Fluoridation: A Critical Review of the Physiological Effects of Ingested Fluoride as a Public Health Intervention. *Scientific World Journal, 14*, 293-219. doi: 10.1155/2014/293019

Petrosino, V., Motta G., Tenore,G., Coletta, M., Guariglia A. & Testa, D. (2018). The role of heavy metals and polychlorinated biphenyls (PCBs) in the oncogenesis of head and neck tumors and thyroid diseases: a pilot study. *Biometals, 31*(2), 285-295. doi: 10.1007/s10534-018-0091-9. Epub 2018 Mar 8.

Pruss-Ustun, A. (2019). Burden of disease from inadequate water, sanitation and hygiene for selected adverse health outcomes: An updated analysis with a focus on low- and middle-income countries. *Int J Hyg Environ Health, 222*(5), 765-777. doi: 10.1016/j.ijheh.2019.05.004. Epub 2019 May 12.

Rahmanian, N., Siti Hajar Bt Ali, S. H. B., Homayoonfard, M., Ali, N. J., Rehan, M., Sadef, Y. & Nizami, A.S. (2015). "Analysis of Physiochemical Parameters to Evaluate the Drinking Water Quality in the State of Perak, Malaysia". *Journal of Chemistry*, *10*, 2015.

Rajashekar, T. S. & Okade, R. (2013). Irritant Contact Dermatitis to Accidental Exposure of Cyanide. *Indian J Dermatol., 58*(2), 162.doi: 10.4103/0019-5154.108098

Ramirez-Castillo, F. Y. (2015). Waterborne Pathogens: Detection Methods and Challenges. *Pathogens, 4*(2), 307–334. doi: 10.3390/pathogens4020 307

Rapant, S., Cvekcova, V., Fajcikova, K., Sedlakova, D. & Stehlikova, B. (2017). Impact of Calcium and Magnesium in Groundwater and Drinking Water on the Health of Inhabitants of the Slovak Republic. *Int J Environ Res Public Health. 14*(3), 278. doi: 10.3390/ijerph14030278

Rauf, A. U. Rauf, A. U., Mallongi, A., Daud, A., Hatta, M. & Astuti, R. D. P.(2021). Ecological risk assessment of hexavalent chromium and silicon dioxide in well water in Maros Regency, Indonesia. *Gac Sanit., 35*(1), S4-S8. doi: 10.1016/j.gaceta. 2020.12 .002

Reynolds, K. A. Mena, K. D. & Gerba, C. P. (2008). Risk of Waterborne Illness Via Drinking Water in the United States. *Reviews of Environmental Contamination and Toxicology, 192,* 117–158. doi: 10.1007/978-0-387-71724-1_4.

Roosbroeck, P. V. & Amlalo, D. S. (2006). Country Environmental Profile of Ghana, final draft. *IRE Journals, 3* (3), 2456-8880.

Rosinger, A. Y., Bethancourt, H., Swanson, Z., Nzunza,R., Saunders, J., Dhanasekar, S.5 W., Kenney, L., Hu, K., Douglass, M., Ndiema, E., Braun,D. R. & Pontzer, H. (2021). Drinking water salinity is associated with hypertension and hyperdilute urine among Daasanach pastoralists in Northern Kenya. *Sci Total Environ., 770*, 144667. doi: 10.1016/j.scitotenv.2020.144667

Ross, A. C. (2011). *Dietary Reference Intakes for Calcium and Vitamin D. Institute of Medicine (US) Committee to Review Dietary Reference Intakes for Vitamin D and Calcium; Editors: A Catharine Ross, Christine L Taylor, Ann L Yaktine, and Heather B Del Valle*. Washington (DC): National Academies Press.

Saifur, S. & Gardner, C.M. (2021). Loading, transport, and treatment of emerging chemical and biological contaminants of concern in stormwater. *Water Sci Technol, 83*(12), 2863-2885. doi: 10.2166/wst.2021.187.

Sam, A. (2007). *Mercury and Cadmium Budgets of The Pra Estuary In The Western Region Of Ghana*. University Of Cape Coast; A Thesis submitted to the Department of Chemistry of the School of Physical Sciences, University of Cape Coast in partial fulfillment of the requirement for the award of Master of Philosophy (M. Phil) in Chemistry.

Samlafo, V. B. & Ofoe, E. O. (2017). Water Quality Assessment of River Bonsa in Tarkwa, a Mining-impacted Area of Ghana; Department of Chemistry Education, University of Education, Winneba, Box 25, Winneba, Ghana. Blessed Tutorial College, Box WU 324, Kasoa, Ghana. *Chemical Science International Journal 20*(4), 1-8. DOI:10.9734/CSJI/2017/37251.

Santa-Rosa, T.T.D.A. (2014). Impact of aesthetic restorative treatment on anterior teeth with fluorosis among residents of an endemic area in Brazil: intervention study. *BMC Oral Health, 13*,14, 52. doi: 10.1186/1472-6831-14-52.

Sargen, M. (2019). Alternative splicing of the Wnt trafficking protein, Wntless and its effects on protein-protein interactions. *BMC Molecular and Cell Biology*, *20*(1), 1-9. Retrieved from Sitn.hms.Harvard.edu.

Sawadogo, B Sawadogo, B., Konate,Y., Seyram Kossi Sossou, Saidou, N. F. A., Moussa, A. W. N., & Karambiri, H. (2022). Removal of Sulphate Ions from Borehole Water Using Nanofiltration and Reverse Osmosis. *Water, 14*(21), 3422. https://doi.org/10.3390/w14213422

Sazakli, E. Sazakli,E., Villanueva, C. M., Kogevinas, M., Maltezis, K., Mouzaki, A. & Leotsinidis, M. (2014). Chromium in Drinking Water. *Association with Biomarkers of Exposure and Effect Public Health, 11*(10), 10125-10145.

Sharma, P., Singh, S. P., Parakh, S. K. & Tong, Y. W. (2022). Health hazards of hexavalent chromium (Cr (VI)) and its microbial reduction. *Bioengineered, 13*(3), 4923–4938.doi: 10.1080/21655979.2022.2037273.

Sharma, S. & Bhattacharya, A. (2016). Drinking water contamination and treatment techniques. *Applied Water Science, 7*(3). DOI:10.1007/s13201-016-0455-7

Sharma S. T. B., Prashant Singh P., & Dobhal R., (2013), "Water Quality Assessment in Terms of Water Quality Index." *American Journal of Water Resources, 1,* 3 (2013): 34-38. doi:10.12691/ajwr-1-3-3. Vol. 1, No. 3, 34-38. Available online at http://pubs.sciepub.com/ajwr/1/3/3. © Science and Education Publishing

Shmeis, R. M. A. (2018). Water Chemistry and Microbiology. *Comprehensive Analytical Chemistry, 81*, 1–56. doi: 10.1016/bs.coac.2018.02.001

Siabi, W.K. (2004). Application of Mwacafe plant for the removal of Iron and Manganese. *Proc. 30th WEDC Int. Conf*. 632–636.

Simon, M. J.K., Beil, F.T., Ruther, W., Busse, B. T Koehne, T., Steiner, M., Pogoda, P., A Ignatius, A., Amling, M. Oheim, R. (2014). High fluoride and low calcium levels in drinking water is associated with low bone mass, reduced bone quality and fragility fractures in sheep. *Osteoporos Int. 2014 Jul, 25*(7), 1891-903. doi: 10.1007/s00198-014-2707-4. Epub 2014 Apr 29

Skrzypek, G. Dogramaci, S. & Grier Son, P. F. (2013). Geochemical and hydrological processes controlling groundwater salinity of a large inland wetland of northwest Australia, *357*, 164-177

Smith, R. P. (2009). *The Blue Baby Syndromes. Did environment or infection cause a blood disorder in newborns*? *97*(2) 94. DOI: 10.1511/2009.77.94

Syafrudin, M., Kristanti, R. A., Yuniarto, A., Hadibarata, T., Rhee,J., Al-onazi, W. A., Algarni, T. S. Almarri, A. H. & Al-Mohaimeed, A. M. (2021). Pesticides in Drinking Water—A Review. The United Nations Children's Fund (2010). The Accelerated Child Survival and Development programme in west Africa: a retrospective evaluation. *Int J Environ Res Public Health, 18*(2), 468. doi: 10.3390/ijerph18020468.

Tetteh, J. D., Templeton, M. R., Cavanaugh, A., Bixby, H., Owusu, G., Yidana, S. M., Moulds, S., Robinson, B., Baumgartner, J., Annim, S. K., Quartey, R., Mintah, S. R., Bawah, A. A., Arku, R. E., Ezzati M. & Samuel Agyei-Mensah, S. (2022). Spatial heterogeneity in drinking water sources in the Greater Accra Metropolitan Area (GAMA), Ghana. *Population and Environment, 44*, 46–76.

The United Nations Children's Fund (2010). The Accelerated Child Survival and Development programme in west Africa: a retrospective evaluation retrieved 04/04/2022 from https://www.thelancet.com/journals/lancet/article/ PIIS0140-6736(09)62060-2/references.

Therdkiattikul, N., Ratpukdi, T., Kidkhunthod, P., Chanlek N. & Siripattanakul-Siripattanakul-Ratpukdicorresponding, S. (2020). Manganese-contaminated groundwater treatment by novel bacterial isolates: kinetic study and mechanism analysis using synchrotron-based. *Techniques, Scientific Reports, 10*, 13-91.

Treacy, J. (2017). *Drinking Water Treatment and Challenges in Developing Countries*. *Int J Environ Res Public Health 1*): 5438-5439:10.5772/i tech open.80780.

Tumolo, M., Ancona, V., De Paola, D., Losacco,D., Campanale,C., Massarelli, C. & Uricchio, V. F. (2020). Chromium Pollution in European Water, Sources, Health Risk, and Remediation Strategies: An Overview. *Int J Environ Res Public Health 17*(15): 5438. doi: 10.3390/ijerph17155438.

United Nation, (2010). *General Assembly Adopts Resolution Recognizing Access to clean water, Sanitation as Human Right, by Recorded vote of 122 in Favour, None against, 41 abstentions*. General Assembly GA/10967. Department of Public Information. News and Media Division. New York. Sixty-fourth General Assembly.

U.S. National Science Foundation-funded scientists at Tufts University (2021*). New filtering method promises safer drinking water, improved industrial production*.

United States Environmental Protection Agency (EPA) (2017). Drinking Water: that are the trends in the quality of drinking water and their effects on human health?, retrieved from https://www.epa.gov/report-environment/drinking-water).

Upper Manya Krobo District Assembly Composite Budget for (2019-2022). Programme Based Budget Estimates for 2019, Pages 3 And 4.

Vasanthavigar, M. (2010). Application of water quality index for groundwater quality assessment: Thirumanimuttar sub-basin, Tamilnadu, India. *Environ Monit Assess, 171*, 595–609.

Villanueva, C. M., Kogevinas, M., Cordier, S., Templeton, M. R., Vermeulen, Nuckols, J. R., Nieuwenhuijsen, M. J. & Levallois, P. (2014). Assessing Exposure and Health Consequences of Chemicals in Drinking Water: Current State of Knowledge and Research Needs. *Environ Health Perspect, 122*(3), 213–221. doi: 10.1289/ehp.1206229.

W.H.O. (2011). *Nitrate and nitrite in drinking-water*. WHO/SDE/ WSH/07. 01/16/Rev/1, Geneva: W.H.O.

Wilson, C. P. (2012). *Water Quality: Alkalinity and Hardness*. University of Florida. Publication #SL 332; 18/11/2019

World Health Organisation (2003). *Guidelines for safe recreational water environments: Coastal and fresh waters* (Vol. 1). World Health Organisation.

World Health Organisation (2006). *Guideline for Drinking-Water Quality Recommendation*. World Health Organization.

World Health Organisation (2011). *Guidelines for Drinking-water Quality*- fourth edition. World Health Organization.

World Health Organisation (2011). *Hardness in Drinking-water Background Document For development of WHO Guidelines for Drinking-water Quality* WHO/HSE/WSH/10.01/10/Rev/1.

World Health Organisation (2021). *Water Sanitation and Health: Water-related diseases Fluorosis; Our vision and mission are the attainment by all peoples of the lowest possible burden of water and sanitation-related disease through primary prevention*. World Health Organisation

Wuana, R.A. & Okieimen, F.E. (2011). *Heavy Metals in Contaminated Soils: A Review of Sources, Chemistry, Risks and Best Available Strategies for Remediation*. https://doi.org/10.5402/2011/402647

Yasin, M., Ketema. T. & Bacha, K. (2015). Physicochemical and bacteriological quality of drinking water of different sources, Jimma zone, Southwest Ethiopia. *BMC Research, 8*, 541.

Yongsi, B. N. H. (2010). Suffering for Water, Suffering from Water: Access to Drinking-water and Associated Health Risks in Cameroon. *J Health Popul Nutr. 2010 Oct, 28*(5), 424–435.