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AKENTEN APPIAH - MENKA UNIVERSITY OF SKILLS TRAINING AND ENTERPRENURIAL DEVELOPMENT

CHEMICAL AND MICROBIOLOGICAL QUALITY OF DRINKING WATER SOURCES IN THE MINING - IMPACTED AMANSIE WEST DISTRICT

BY

BOAH COLLINS

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A Thesis Submitted to the School of Graduate Studies, Department of Chemistry Education, of Faculty of Science Education, Akenten Appiah-Menka University of Skill Training and Entrepreneurial Development in partial fulfilment of the requirements for the award of a of Master of Philosophy degree in Chemistry Education

MAY, 2024

DECLARATION

Candidate's Declaration

I hereby declare that this thesis is the result of my own original work and that no part of it has been presented for another degree at this university or elsewhere.

Candidate's Name: BOAH COLLINS

Signature: ……………………………………. Date: …………………………….

Supervisor's Declaration

We hereby declare that the preparation and presentation of the thesis were supervised in accordance with the guidelines on supervision of thesis laid down by the Akenten Appiah-Menka University of Skills Training and Entrepreneurial Development

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DEDICATION

This work is dedicated to my special family: Madam Cecilia Gyamfuah, Mr. Joseph Erasmus Mintah, Mr. Nkrumah Afriyie, Madam Alice Nkrumah, Mr. Oppong Kofi, Gideon Mensah Banson, Richard Osei-Fosu, Richard Apana and Ruth Adu-Gyamfi. Then finally to Victoria Adoma (Vick) for her constant prayers and encouragement throughout the period of the work.

TABLE OF CONTENT

CHAPTER ONE

CHAPTER TWO

CHAPTER THREE

CHAPTER FOUR

CHAPTER FIVE

LIST OF TABLES

LIST OF FIGURES

LIST OF ABBREVIATIONS

UNICEF	United Nations International Children’s Emergency Fund
GMA	Ghana Meteorological Agency
ATSDR	Agency Toxic Substances and Disease Registry
ADD	Average Daily Dose
AT	Average lifetime
BIS	Bureau of India Standards
BW	Body Weight
CCME	Canadian Council of Minister for Environment
CDI	Chronic Daily Intake
CFU	Coliform Forming Unit
CR	Cancer Risk
CSF	Cancer Slope Factor
Cw	Concentration exposure
EC	Electrical Conductivity
ED	Exposure Duration
EF	Exposure Frequency
EPA	Environmental Protection Agency
FC	Faecal Coliforms
GWCL	Ghana Water Company Limited
HI	Hazard Index
HMPI	Heavy Metals Pollution Index
HQ	Hazard Quotient
JASP	Jeffrey’s Amazing Statistical Program
PCA	Principal Component Analysis

RfD	Reference Dose
SDGs	Sustainable Development Goals
SPSS	Statistical Package for Social Science
TC	Total Coliforms
TDS	Total Dissolved Solids
USEPA	United State Environmental Protection Agency
WHO	World Health Organization
WQI	Water Quality Index
IR	Ingestion Rate
MAL	Most Allowable Limit
MPN	Most Probable Number
E. Coli	Escherichia Coli
AAS	Atomic Absorption Spectrometry
MP-AES	Micro Plasma Atomic Emission Spectrometry
DPD	Diethyl -p-phenylenediamine
CCA	Chromocult Coliform Agar
BH	Borehole
TW	Tap water
WW	Well Water
SW	Surface Water
GMT	Greenwich Maridian Time
GSS	Ghana Statistical Service
ROS	Reactive Oxygen Species
DNA	Deoxyribonucleic acid

ABSTRACT

Ground and surface water sources are considered the primary sources of drinking water supply worldwide. However, human activities have compromised the quality of these water bodies by altering their properties such as physicochemical and microbial characteristics as well as heavy metals contamination. Seventy-three drinking water samples (boreholes, well, surface and tap) obtained from different sampling point in Amansie West District, in the Ashanti Region, Ghana were subjected to physicochemical, microbiological and heavy metal analyses. Temperature, electrical conductivity, total dissolved solids, turbidity, nitrates, nitrites, sulphates, chlorides, ammonia, ammonium, fluoride and pH were studied for physicochemical quality by Palintest procedures. Microbiological analyses were applied according to the Most Probable Method. Heavy metals such as arsenic, chromium, lead, copper and zinc concentrations were studied using microwave-plasma atomic emission spectrophotometer. Result indicates that the all-physicochemical qualities studied were all within World Health Organization (WHO) limit. Microbial load recorded ranged from 14.44 - 95.85cfu/l which was higher than World Health Organization (WHO) limit (0 cfu/l). Heavy metals concentrations, As for tap water (12.313 µg/l), borehole (12.348 µg/l), surface water (29.250 µg/l) and well water (18.143 µg/l), Cr for tap water (47.66 µg/l), borehole (61.37 µg/l), surface water (247.7µg/l) and well water (343.30 µg/l) and Pb for tap water (457.50 µg/l), borehole (303.80 µg/l), surface water (276.65 µg/l) and well water (352.29 µg/l) had their mean values higher than World Health Organization for all the water sources except Zn and Cu. The determined microbiological qualities and heavy metal content of all the samples were not suitable for drinking and may pose threat to public health. Water from the study area should be treated before drinking and other domestic use.

CHAPTER ONE

INTRODUCTION

1.1 Background to the study

Water is a vital resource for human and is indispensable as all life cycles ceased without water (Sonawane, et al., 2020). Additionally, water supports humankind in numerous ways, such as agriculture, household activities, origin of drinking sources, and industrial development (Su et al. 2020). However, human activities affect the quality of surface and groundwater bodies and their potential uses (Sharma et al., 2021).

The demand for freshwater by man has increased recently due increase in urbanization, industrialization, rapid human population growth, agricultural, small and large-scale mining activities (Büttner et al., 2020). Water quality supply has become a major issue over the years in most developed and underdeveloped countries globally, especially in Ghana (Li et al. 2018).

Therefore, these water does not require any further treatment. However, a study conducted by Li et al., (2017) also revealed that, groundwater sources (deep or shallow) when not treated may be induced by existence of pathogens and domestic runoff, even though water may be seems to be clean. Water quality is chiefly influenced by the parameters of physical (colour, odour temperature and turbidity), chemical (organic, inorganic, pH, nitrate, nitrite, chloride etc.), trace metals (arsenic, lead cadmium, mercury) and microbial existence such as bacteria, virus, protozoa and helminth (worms). Water contamination of the above parameters has been a major concern worldwide over the years (He et al., 2019, Amiri et al., 2021, Liu et al., 2022 & Wang et al., 2022). Honarbakhsh et al., (2019), identified the effects of poor water quality and sanitation on human health. Poor drinking water quality has been linked to many waterborne diseases globally (Li et al., 2019). The World Health Organization report (WHO, 2017) shows that poor drinking water may contain chemical contaminants like, chloride, cyanide, ammonia, copper and chromium and may cause adverse health effects. This could be due to the recent increase in artisanal small-scale mining activities especially within the Amansie West and its catchment areas.

Many miners within the community use toxic chemicals such as lead, mercury and cyanide for their activities. This can cause a severe public health risk when inhabitants are exposed to such elements (Kadam et al. 2022). When the quality of water resources such as boreholes, wells, rivers, lake and streams fail to meet the acceptable quality standard for drinking, the inhabitants in the community may stop using such resources. This can compel the people to resort to other unsafe water resources, which can later exacerbate to pose risk to their health (Calao-Ramos et al., 2023; Narangarvuu et al., 2023). This will make it extremely difficult to meet the Sustainable Development Goals (SDG) project that ensure sustainable environment (SDG 15), health improvement (SDG 3), quality water supply (SDG 6) and eradication of the poverty (SDG 1 and 2) in most developing countries where most people are extremely poor (Michael et al., 2022).

The importance of assessing physicochemical, microbiological and heavy metal pollution of surface and groundwater resources (borehole, tap water and well) in the community cannot be overlooked.

1.2 Statement of problem

The recent surge in Ghana's human population has resulted in significant urbanisation and heightened demands for essential requirements, including food, water, and shelter.

Access to these fundamental needs is essential for the enhancement of human life (Xu et al., 2022). The need for these fundamental necessities has escalated throughout the years due to the swift growth of human populations, necessitating expansion in human settlements and enterprises, including agriculture and industry.

In the Amansie West District, there are two principal economic sectors. These pertain to agricultural and artisanal small-scale mining. In humanity's pursuit of improved living conditions and convenience, numerous pollutants have been introduced into the natural environment within the district Masindi et al., (2018). This results from extensive agricultural practices and widespread artisanal and small-scale mining activity throughout the district. The extensive artisanal and small-scale mining activities have resulted in significant damage to our natural environment, including land and water bodies. Research conducted by Yeleliere et al. (2018) indicate that, about 60% of water bodies in Ghana are contaminated including Amansie West District where mining activities are rampant everywhere. Sources of water pollution in Ghana include domestic water usage in river bodies, household, municipal and industrial waste, and agricultural runoff (Yeleliere et al., 2018).

Pollution operations can modify the physical and chemical properties of water by introducing contaminants into ecosystem (Chowdhary et al.,2020). Waterborne contaminants can immediately enter the human body through consumption. These pollutants may present health risks to aquatic organisms if the water is inadequately treated (Adekiya et al., 2020 & Sinharoy et al., 2019). The persistence of heavy metals through bioaccumulation and biomagnification can result in adverse health effect in many living species within the environment once expose (Adusei-Mensah et al., 2019 & Ma, 2022).

Human exposure to heavy metals via oral or skin contact may result in detrimental health effects (Tay et al., 2019). A recent study by Asamoah et al. (2016) examined the impact of illegal mining activities on water resources in the Amansie west district. The study's results indicated that several physicochemical and heavy metal characteristics exceeded the permissible limits set by the World Health Organization (WHO, 2017). Pathogenic bacteria in drinking water sources are an indication for microbial water contamination (Jaywant et al., 2019). Most studies reveal that, the presence of *Salmonella spp., Shigella spp. and Yersinia spp*. in drinking water sources affect human wellbeing (Dekker et al., 2017). The occurrence of many antibiotic-resistance microorganisms/antimicrobial resistance (AMR) have been identified to pose risk health (Sanganyado et al., 2019).

The existence of pathogenic bacteria in water sources is a key public health concern and essential management of the quality of water to environmental sustainability. The microbiological pollutants present in the drinking water source may lead to waterborne diseases such as typhoid fever, dysentery, and diarrhoea upon consumption (WHO, 2017).

1.3 Aim and Objectives

The main aim of this research is to assess drinking water quality from some selected mining impacted areas in the Amansie West District in the Ashanti Region of Ghana.

1.3.1 Specific objectives of the study are to,

1. To measure some levels of physicochemical contents (Temperature, electrical conductivity, total dissolved solids, turbidity, pH, nitrate, nitrite, sulphates, chloride, ammonia, ammonium and fluoride from boreholes, hand –dug wells, tap water and surface water from Aboabo - Tetekaso, Mpatuam, Tetramu, Essuowin, Ahwerewa, Korko, Abodease, Manso-Moseaso and Esaase-Manhyia.
2. To determine microbial loads from the study samples.
3. To determine concentration levels of some selected heavy metals (Cd, Zn, Cu, Cr, As and Pb) in drinking water.
4. To determine water quality index from the study samples.
5. To determine health risk for heavy metals in drinking water sources.

1.4 Research questions

Below are some research questions that have been generated as a guide to the study.

1. What is the physicochemical state (nature) of drinking water sources from mining impacted areas in Ghana?
2. To what extents is the drinking water sources from mining impacted areas are polluted with both human and animal waste
3. To what level does small- and large-scale mining activities contribute to heavy metals pollution to water bodies in Ghana.
4. Does the water quality fall below or above permissible limits compare to the international guidelines for drinking water?
5. What are the health implications of consuming contaminated water?

1.5 Justification

The recent increase in agricultural and mining activities (small and large-scale mining) in Ghana especially in the Amansie west district and its environment has put a greater threat to our forest reserves, lands, and water bodies (Fan et al., 2022). Application of inorganic fertilizers, release of toxic substances such as sewage, untreated wastewater (domestic and hospitals) into the water bodies, and chemicals such as mercury and cyanide by formal miners and artisanal small-scale miners has become a major challenge worldwide (Batbayar et al., 2017).

In Ghana, most mining communities depend solely on groundwater and surface (hung dug wells and boreholes) as their main source of drinking. These water sources have been facing a lot of environmental and water crises challenges (Batsaikhan et al., 2017). Environmental impact of mining includes, loss of vegetations, land degradation, soil erosion and water pollution (Battogtokh et al., 2014 & Pfeiffer et al., 2015).

Many water resources from these mining-impacted areas are unhealthy and unsafe for human use as they may contain harmful physical, chemical, and biological contaminants through geochemical and other interactions may negatively influence the water quality and thus affecting human health and aquatic environment (Lu et al., 2015). The aforementioned information has emerged as a significant issue for the public and the residents. It is therefore important to assess the presence of heavy metals, physicochemical properties, and microbial quality in the water, which will serve as a reference for remediation efforts and to raise awareness regarding human exposure.

1.6 Significance of the study

The study's findings could provide empirical data on the chemical and microbial qualities of the accessible water sources within the selected communities. This information could assist policy makers, Minster of Land and Natural Resources and District Assembly with the quality of water exploited by the communities. Again, the studies will be helpful to concerned parties and citizens about the levels of microbial load and heavy metals concentration levels from the sources. The studies will also look at human health risks due to long - term exposure to heavy metal in drinking water. The research data obtained will help to reveal the water quality index in the study areas. This will help to categorize each water source into its intended purpose like irrigation, industrialization, and domestic by the people within the various studies communities. The research findings will also be useful to other researchers who may wish to conduct a comparable research work in similar or different locations. The studies will also add to the body of knowledge on quality assessment of drinking water sources from mining-impacted districts, which are already in accessible literature.

1.7 Scope of the Study

This research mainly focuses on assessing the physicochemical, bacteriological and heavy metals parameters using the laboratory test result from the selected areas in Amansie West District of drinking water quality by taking different water samples from the various towns and household level and compare against the World Health Organisation (WHO) guidelines and national standard. Identify sanitary risk through sanitary survey using WHO standard sanitary format, any health-related risks by combining laboratory test result and sanitary survey.

1.8 Limitations of the Study

The study could not cover all the communities within the district. However, the research findings could be an indicative of the situation in Ghana especially mining impacted areas. All physicochemical parameters were determined in laboratory with the exception of pH, which was measured on the field during sampling. Again, samples for microbial loads studies were not done on the field. This could have a slight difference in their physical, chemical and microbial qualities. Heavy metals digestion was not done on time and this could affect the outcome of the heavy metal results. In general, the studies did not cover all physical, chemical, microbial and heavy metals parameters. All these and many factors may contribute to the findings in this study.

1.9 Organization of the Study

This thesis report is structured into five principal chapters in accordance with the Monograph-based thesis policy standards established by Akenten Appian-Menka University of Skills Training and Entrepreneurial Development School of Graduate Studies. Chapter one provides a comprehensive introduction to the study, emphasising the context, problem statement, aims, research questions, research hypothesis, significance of the study, scope of the study, limits, and organisation of the study. Chapter Two presents a literature review pertinent to the subject. Chapter Three provides a summary of the study sites, methodologies, and tactics employed. Chapter Four delineates the results and conversations addressing all the specified objectives. Chapter Five comprises a summary of findings, pertinent recommendations, future study directions, and a conclusion.

CHAPTER TWO

LITERATURE REVIEW

2.1 Mining and Environmental Degradation

Mining activities encompass all techniques employed to obtain minerals and metals from the earth. A variety of metals and minerals are extracted through mining operations. Included are uranium, copper, manganese, gold, silver, diamond, iron, and coal (Baah & Kidido, 2020). Mining provides substantial contributions to economic and social advancement, job creation, provision of vital raw materials to society, and infrastructure development (Haddaway et al., 2019 & Asuamah ,2023).

Enterprises engaged in mining concessions for metals and other mineral extractions, such as gold and bauxite provide a direct and indirect financial benefit through employment (McQuilken & Hilson, 2016). Research indicates that mining in many African nations, including Ghana, has provided substantial economic advantages for rural populations and has increase from 9.6% in 2021 to 13.7% in 2022of Ghana Gross Domestic Product (GDP) (Ghana Statistical Service, 2023). Nonetheless, the incidence of its adverse effects is anticipated to increase significantly if rules and oversight are not rigorously implemented by legislators (Nakazawa et al., 2016).

Artisanal and small-scale mining operations necessitate the clearance of a substantial area of land prior to the exploration of gold minerals and for residential use. This leads to significant loss of flora, habitat for wildlife, carbon dioxide reduction, soil erosion and disruption of ecological balance (Asuamah, 2023).

According to Anim-Sackey (2021), loss of land, vegetations and many environmental resources within mining areas can limits the potentials for economic growth as many agricultural activities declined. Illegal mining operation can also have a detrimental effect on the livelihood of many affected areas, resulting to significant social-economic challenges and economic growth and development us many local populations are forced to abandon their homes and farmlands (Crawford & Botchwey, 2018).

Kausher et al., (2023) assert that surface water pollution which is one of the major challenges worldwide result from effluent discharges, flooding, waterlogging, and chemical contaminants. Mining operations adversely affect groundwater, perhaps causing permanent or temporary declines in the groundwater table, saline water intrusion, and aquifer contamination. Research indicates that heavy metals such as lead, mercury, cadmium and arsenic are among toxic elements, even in minimal quantities (Adusei-Mensah et al., 2019). Many of these heavy metals may occurred naturally and are release into the environment and water bodies through improper management of land (Amankwah & Anim-Sackey, 2021).

The Agency for Toxic Substances and Disease Registry (ATSDR, 2015) ranks the toxicological effects of these heavy metals in water as follows: cadmium (Cd), lead (Pb), and arsenic (As), in descending order of toxicity.

Amansie West District is among one of the agricultural areas within the Ashanti Region, Ghana. Excessive use of chemicals such as pesticides, fertilizers and additives mostly found in animal feeds by the farmers within the area may increase the chance of metal contaminants that may enter nearby surface water bodies (Zhang et al., 2022).

According to Lin et al., (2022), contaminated water can adversely impact human health, ecosystems (aquatic organisms), flora, economic development, and the supply of freshwater.

2.2 Impacts of Mining activities on the environment.

2.2.1 Water pollution:

Chemicals such as mercury, cyanide, sulfuric acid, arsenic, and methyl mercury are utilized in different phases of mining operations. When these substances are discharged into adjacent waterways or bodies of water, contamination of the water results. When chemicals are typically disposed of through tailings (pipes), there is always a substantial risk of chemical leakage into water bodies. When these chemicals slowly seep through the layers of the earth and reach the groundwater resources, they finally spill and contaminate the groundwater (Debopriya, 2012).

2.2.2 Loss of Aquatic life:

Toxic chemicals produced in the aquatic environment by mining activities cause loss or harm to the fauna and flora population in the polluted water bodies. During mining activities, large amount of acidic drainage containing heavy metals are release into the aquatic environment thereby altering the chemistry of the surface water that create health impacts on animals as well as other plants (Anju et al., 2022). According to manjo et al., (2021), bioaccumulation in the aquatic changes in chemical composition of can modify diatom communities, water insect and crustacean communities may result in low level of trophic competition with increase in predator species. Many studies such as (Appiah et al., 2014), revealed that, illegal mining activities pollute aquatic environment causing detrimental health impacts on both human and aquatic life. Availability of mercury in water may be taken up by microorganisms that may undergo biomagnification thus causing detrimental impacts of various degree of aquatic life (Attiogbe et al., 2020)

water environment

2.2.3 Spread of Diseases:

Mining as a whole plays a vital role in sustaining economic development. However, despite many gains from mining, these practices have been recorded to pose a significant environmental and many health-related challenges (Calao-Ramos et al., 2023 & Narangarvuu et al., 2023). Vegetations, soil and fresh water are damage in the cause of the activities, posing a severe threat to health risk including biodiversity (Huang et al., 2024; Kuffour et al., 2018 & Calao-Ramos et al., 2023). Many of the health-related diseases include, cancer (Calao-Ramos et al., 2023), renal damage, hypertension, and neurological disorders (Huang et al., 2024)

2.2.4 Effect on Land

Artisanal and small-scale mining play a major role to the destructions of most of our lands (Tay et al., 2019). Mining activities requires a greater portion of land for their operations and in Ghana one of the greatest challenges is uncovered of many lands used by these artisanal and small-scale miners (Charity et al., 2024). According to Sustainable Development Goals number 15, lands on earth through sustainably management of its natural resources must be protected and prevent loss of biodiversity and reversing desertification and land degradation (Lui et al, 2019). According to Curtis et al., (2018), reports, about 27% forest loss recorded between 2001 to 2015 globally was as results of commodity – driven whiles a land cover of 38,800 square kilometer which represent 17% land degradation was reported in the year 1975 which was later converted into agriculture in the year 2013 (Cotillon &Tappan, 2016).

2.3 An overview of water situation in Ghana

Ghana covers about 240,000 km^2 of land mass (Water Research Institute, 2010). The country is endowed with 3 river systems: the Volta River system, the South western river system and the Coastal River system (Bessah et al., 2022). The Volta River system covers 70% of Ghana's land area at 240,000 square kilometers while another 30% splits evenly between the South-western and Coastal River systems (Agodzo et al., 2014). Aidoo and colleagues (2021), state that annual rainfall runoff in Ghana generates about 15 billion m^3 of water from external sources which account for 34.1% of total quantities. According to Bessah et al., (2020), the Pra basin is the largest basin in the South-western River system, providing four regional capitals and being the nation's top producer of tuber crops. In contrast to home usage, groundwater abstraction for industry in the south part of Ghana around Kumasi and for irrigation whiles animal husbandry mostly takes place in the northern Volta Basin (UPGro - African Groundwater, 2020).

Poor enforcement and regulation, dearth of trustworthy data, drought and recharge due to climate change are the main causes of lack of groundwater availability. In comparison to renewable supplies, total withdrawals are relatively low, according to recent study on estimation of groundwater supply and withdrawals (WRC, 2018), Annual Report. According to (UN, 2021), inter-annual groundwater levels are comparatively stable, but seasonal fluctuations can vary from about one to seven meters, suggesting a high reliance on seasonal rainfall for recharge and possible drought susceptibility. Models predict that the effects of climate change, including increased evaporation rates, decreased rainfall, and drought, will drastically reduce groundwater recharge in a number of basins (Gampson et al.,2014).

In Ghana, fluoride and heavy metal content have been found in the Northern and southwest of the country where gold mining activities are higher. Heavy metals such as Lead, arsenic, and cadmium levels in drinking water within these areas have been reported to be higher than WHO recommended levels (Asare-Donkor et al., 2020 & Chegbeleh et al., 202). Most of this pollution, which are frequently linked to gold deposits, may be natural British Geological Survey (2021) report. According to British Geological Survey (2021), high level of arsenic metal concentration has been discovered in the vicinity of these gold mining areas Obuasi and Bolgatanga from river Pra and White Volta Basins. Therefore, improving and monitoring groundwater quality for public health concern, especially within the gold mining zones is required (Ganyaglo et al., 2019).

2.4 Potential Sources of Drinking Water

The potential sources of drinking water for any community can be divided into two categories, according Katsanou et al., (2022). Streams, canals, lakes, ponds, marshes, waterfalls, rivers, among others have been studied to be the main primary sources of surface water whiles groundwater includes wells, boreholes and springs (Uddin et al., 2021 & Bo et al., 2022).

Water extracted from these sources are mostly utilize in five major industrial sectors agriculture for irrigation and animal husbandry activities (Acharya et al., 2020 & Gholizadeh et al., 2016). Domestic sectors use it for drinking and other household purposes based on water availability (Balla et al., 2022), Pisciculture sector, often known as fisheries, is the science and related technical technique used to produce fish and other aquatic resources for human use (Amiri et al., 2021). Complex industries such as steel mills, paper mills, manufacturing industries, food processing industries, hydroelectricity generation, thermal power generation, and industrial use these available water sources for their daily (Sarkar et al., 2019).

According to Breen et al., (2018), water can be use in the non-consumptive field including leisure activities, and the movement of people and products (transportation). Unfortunately, water contamination mostly originates from these consumer sectors (Low et al., 2016). Majority of complex industries are constructed alongside riverbanks and release industrial effluents into the rivers directly with fully or partially treated (D'Agostino et al., 2020 & Sarker et al., 2021). According to De Souza et al., (2020), agricultural runoffs and the excessive and unregulated use of fertilizers and pesticides frequently end up in the surrounding lakes, ponds, and wet areas where farming activities are dominant.

In Ghana, the levels of water contamination have been reported to be so high that it poses a major risk to aquatic life, the environment, and the emergence of water-borne illnesses such cholera, diarrhoea, dysentery, hepatitis A, and many cancerous diseases to human (WHO, 2022).

2.5 Water Quality

The characteristics of water, physical, chemical, biological, and aesthetic are what define its quality and establish its suitability for a range of applications, such as safeguarding the aquatic ecology and public health (Luvhimbi et al., 2022). These properties (qualities) can be impacted by both natural and human-caused processes, and the majority of these characteristics are determined by substances that are either dissolved or suspended in the water (Hubert et al.,2015).

According to Lu et al., (2015), the ability of a population to maintain its sustainable access to sufficient amounts and acceptable quality of water for human well-being, socioeconomic growth, protecting against pollution, water-related disasters and as well as for preserving ecosystems determined by water security.

Water quality supply by Municipal should be evaluated against national standards, with the primary and secondary attributes considered. According to (WHO, 2017) guidelines, drinking water supply most be free from faecal indicator bacteria (FIB), particularly E. coli or thermotolerance coliforms (TTC) in every100 mL of drinking water samples.

Water quality can be harmed during collection, transportation, and storage at home, particularly with regard to the microbial content. Open field faeces, animal waste, commercial, industrial, and agricultural operations, household waste, and flooding are all potential causes of contaminated drinking water. In particular, any source of water is susceptible to this kind of contamination (Oljira et al., 2015). Literature have shown that, most of the underdeveloped countries of which Ghana is included drinking water often become re-contaminated after being collected and stored in households (Too et al., 2016).

Water quality can be impacted by toxic elements such cyanide, mercury, chromium, arsenic, nitrite, nitrate, and sulphate, which can eventually lead to health problems.

The chemical interactions that take place during the ion exchange and dissolution processes in water aquafers might lead to a decrease in water quality, as stated by (Subba et al., 2021). According to Akhtar et al., (2021), chemicals and waste from industries, households, municipal, agricultural landfills and hospitals sources can deteriorator water quality.

2.6 Requirement for drinking water, Ghana Standard

Settlement with the basic right of access to drinkable water stands essential for both health and overall wellbeing (Shaheed et al., 2014). The United Nations General Assembly specifically requested measures to establish ‘‘safe, clean, accessible and affordable drinking water and sanitation for all’’ through their declaration (UN Communications Group, 2017). In addition to incorporating national criteria specific to the nation's environmental setting, the requirements were developed based on the World Health Organization’s drinking water quality guidelines (WHO, 2017), as shown in Table 2.1.

Table 2.1: Guideline values for drinking water quality (WHO, 2017 and GSA, 2021).

PARAMETER	UNIT	WHO Limits	GSA STANDARD
TDS	mg/l	0-1000	500
Sulphate	mg/l	0-250	250
Turbidity	NTU	0-5	5
Conductivity	µS/cm	2000	-
Nitrate	mg/l	0-50	50
Nitrite	m°C°Cg/l	0-10	3
Chloride	mg/l	0-250	250
pH	pH-unit	6.5-8.5	8.5
Temperature	°C	25-30	-
Ammonia	mg/l	0-1.5	1.5
Ammonium	mg/l	0-35	35
Fluoride	mg/l	0-1.5	1.5
Total Coliform	l/100ml	0	0
Faecal Coliform	l/100ml	0	0

Source: (WHO, 2017) and (GSA, 2021)

2.7 Indicators of Groundwater Quality.

The conventional water quality indicators that are used to determine water qualities include physico-chemical qualities, microbial loads and heavy metal pollution. Water sources may contain different contaminant such as salinity, dissolved oxygen, pH, and nutrients levels (phosphorus, sulphate, fluoride), pesticides, organic and inorganic matters, herbicides, among other toxicants (Andzelika et al., 2024).

2.7.1 Physical characteristics

Water's appearance and physical attributes are indicated by its physical properties. These parameters include temperature, turbidity, color, taste, electrical conductivity, pH, and odor which are characteristics are measurable and observable without altering the substance's chemical makeup (Hussen et al., 2018). Unbalanced physical characteristics frequently result in contaminants that are unpleasant to the senses of taste, smell, or sight, rendering the water unfit for human consumption (Omer, 2019).

2.7.2 Total Dissolved Solids (TDS)

According to Omer (2019), turbidity is the presence of suspended particulates in water including plankton, finely divided organic material, silt, clay, and other inorganic elements. Studies have shown that, high organic matter, suspended and dissolved particles and other contaminants, can cause scaling and fouling problems in the desalination system. Higher operating expenses and lower product quality can result from fouling and scaling processes there by increase energy consumption, decrease efficiency, and damaging equipment (Martin et al., 2021). Elevated level TDS of water make it more difficult to remove salts and other materials since it takes more energy to pressurize the water flow through the membranes (Pushpalatha et al., 2021).

2.7.3 Turbidity

Turbidity is a physical characteristic of fluids that results in decreased optical penetration, and cloudiness due the presence of suspended material in the water bodies that prevents amount of light from entering according to (Matos et al., 2024). Man-made activity such as industrial discharges, urban runoff, pesticides, and microplastics as well as natural processes like erosion, particle transport and sedimentation are the two major of sources turbidity in water (Li, et al., 2019). High turbidity levels in water have a significant impact on light penetration, which is essential for many photosynthetic species. However, high turbidity of water can inhibit photosynthetic activities several aquatic plants and algae whereby disrupting their habitats (Bessell-Browne et al., 2017). High water turbidity can also reveal possible microbial contaminants in water and other existing contaminants that may impact affect taste, odour, and appearance of the water (De Roos et al., 2017).

2.7.4 Temperature.

One important physical factor that affects solubility, smells, chemical reactions, viscosity, and palatability of water is temperature (Omer, 2019). Biochemical processes such as sedimentation, chlorination and biosorption of dissolved heavy metals, and the biological oxygen demand (BOD), are similarly impacted by temperature (Arora, 2017). According to Sunday et al., (2018), warm-adapted species may benefit from a mild rise in temperature and may extend their ranges to higher latitudes or elevations (Gebert et al., 2022). Many aquatic insect populations, particularly those of Trichoptera (EPT) species, may suffer from rising temperatures (Baranov et al., 2020 & Piggott et al., 2015). Additionally, the beneficial impacts of temperature on species richness may be offset by the detrimental effects of the daily maximum temperature on aquatic insect dispersion features (Jourdan et al., 2019).

2.7.5 Electrical Conductivity

Electrical conductivity is an essential metric for evaluating and monitoring water quality. Studies have shown that electrical conductivity of water is greatly influenced by the number of dissolved ions such as salts, minerals, metals, and other dissolved solids present in water (Naiel et al., 2022). According to Liu et al., (2023), water with high elevated level of EC signifies high salinity levels, which negatively impact aquatic life, irrigation techniques and the water appropriateness for different applications. According), EC Measuring electrical conductivity along might not offer enough information about the water quality in terms of organic contaminants or specific non-ionic chemicals (Igboama et al., 2022). Changes in water temperature can have an impact on EC as most of the suspended particles and other organic or inorganic materials can dissolve to affect the quality of the water (Ghorbani et al., 2017). Therefore, assessing and monitoring the overall quality of the water and locating possible sources of contamination can be aided by electrical conductivity (Lakrout et al., 2022).

2.7.6 pH

The concentration of hydrogen ions in a solution is measured by pH. Since pH affects chemical and biological activities in water, it is a crucial metric for water quality evaluations. Water pH fluctuations primarily impact the solubility of organic and inorganic substances, nutrients and minerals availability for aquatic life (Hossain, et al., 2019). Sediments with a low pH can release poisonous elements, which can have a detrimental effect on aquatic life. Variation in water pH can impact aquatic creatures, such fish, that have adapted to a specific pH range (Wang et al., 2019). According to Wang et al., (2021), water with a pH above than 7 is regarded as basic and can result potential to cause a variety of health issues including irritated skin, gastrointestinal disorders, and more.

2.7 7 Chemical characteristics

According to Chormey et al., (2018), water undergoes molecular structural changes when it reacts with a variety of chemicals. Chemical properties of surface and groundwater water are influenced by various sources such as runoff from cities and farms, wastewater from municipal and industries, soils and rocks that water interact with (Hussen et al., 2018). Chemical characteristics such as chlorine, inorganic Toxic Substances, Fluoride, nitrate, nitrite, sulphate at the elevated level in drinking water may pose serious health risks to human and other aquatic organisms (Akter et al., 2016).

2.7.8 Fluoride

Because of its extreme reactivity, the basic form of fluoride does not exist, despite how prevalent it is. Fluorite (CaF_2), cryolite (Na_3AlF_6), and calcium fluorophosphate ($Ca_5(PO_4)_3F$) are only a few of the numerous types of fluoride that make up the about 0.3g/kg of Earth's crust. Fly ash deposition and the application of fertilizers containing phosphate compounds are two examples of anthropogenic activities that can contaminate groundwater sources with fluoride. Several geochemical factors, including low calcium concentrations, a basic pH, and the availability of high bicarbonate, may contribute to groundwater's high fluoride content (Sunkari et al., 2022). Calcium shortage, hormonal imbalance, cognitive decline, and dental cavities may result from prolonged exposure to extremely high fluoride concentrations inside fluoride-endemic zones, as shown by

(Bazeli et al., 2022). Research has shown that teeth fluorosis, weak bones, and osteosarcoma can result from geogenic fluoride contamination of groundwater (Akhtar et al., 2021 & Podgorski et al., 2022).

2.7.9 Chloride

Naturally, water contains chloride ions (Cl), which are generally safe for human health except for the potential to taste salty if present in large concentrations (Omer, 2019). The most widely used disinfectant for drinking water treatment is residual chlorine (Bensoltane et al., 2018). Due to its effectiveness against pathogenic infections, extended disinfection and durability in comparison to other disinfectants chlorine has been wildly recommended (Sharif et al.,2017).

According to World Health Organization (WHO, 2017), residual chlorine content in drinking water consumption of has been advised to 0.2–5 mg/l. The environmental buildup of anions like Cl^- has caused a great deal of concern because of the considerable effects it has on biological systems (Wei et al., 2024).

According to Roy et al., (2015), recent studies on Cl^- toxicity have concentrated on aquatic environments. When young freshwater mussels such as (*Lampsilis siliquoidea*) were exposed to groundwater with high Cl^- levels, their survival rate dropped dramatically. When Cl^- concentrations in the environment exceeds hazardous thresholds, green frog larvae death rate becomes high (Green et al., 2019).

2.8 Nitrate

Two significant nitrogen compounds that are essential to the nitrogen cycle, support plant nutrition as well as other ecological processes are nitrate (NO_3^-) and nitrite (NO_2^-)

(Valentina et al., 2025). Nitrous acid (HNO_2) produces nitrites, nitric acid (HNO_3) produces nitrates. These compounds are frequently found in the environment, particularly in food and water as a result of natural and human-caused (FAO, 2022). According to FAO, (2022), groundwater may contain high nitrates level which has the potentials of causing drinking water contamination and can endanger ecosystems and public health. Recent studies have demonstrated that persistent leaching of nitrate through soils and finally water bodies can create major implications for the long-term health to human aquatic organisms (Nouri et al., 2022). Long-term human exposure to nitrate through ingestion can impairs the ability of red blood cell to deliver oxygen there by threatening lives (Jones et al., 2015). The oversupply of nitrates in drinking water can induce blue baby syndrome in neonates and gastrointestinal cancer in adults and children (Ward et al., 2018). N-nitroso is a nitrate molecule found in drinking water that has the ability to cause cancer in humans (Alam et al., 2023).

2.8.1 Nitrites

Nitrite is one of the reduced forms of nitrogen compounds that has significant environmental impact on aquatic life (Qiang et al., 2020). Numerous investigations have demonstrated that elevated nitrite levels can impair immune function and change enzyme activity in the human immune system (Miao et al., 2018). Additionally, nitrite can lead to the production of nitroso compounds (NOCs), such as N-nitrosamines, which have been linked to stomach and intestinal cancer and direct contact with DNA can leads to deamination and nitration which is the main cause of carcinogenicity (Said et al.,2022). When the content of nitrite in groundwater is less than 0.03 mg/l, the water is deemed to be free of pollution, according to the World Health Organization (WHO, 2017). Human saliva and stomach microbes have an enzyme called reductase, which can break down nitrate molecules. Nitric oxide and carcinogenic compounds like nitrosamine can be produced under acidic conditions when high doses of nitrite combine with ammonia derivatives like amines, amides, and amino acids (Zhang, et al.,2019 & Nosuhi et al., 2018)

2.8.2 Ammonia

Ammonia can be released into surface waters through point and non-point sources (treated or untreated) wastewater. Point sources of nitrogen emissions include fertilizer application, and runoff and infiltration from industries waste disposal (Camargo et al., 2016). Non-point sources include things like animal manure, inorganic nitrogen fertilizers, and the cultivation of N_2-fixing crops (Xia et al., 2020). Ammonia and ammonium contamination is a major worldwide issue to the aquatic habitats and to safeguard local water supplies, strict water quality standards or criteria are required (Wang et al., 2020).

According to (Ding et al., 2021), non-ionic ammonia NH_3 is neutral and diffuses through biological cell membranes more readily than ammonium NH_4^+, it is therefore more hazardous than NH_4^+, for some aquatic plants and animals. However, at a certain condition, NH_4^+ is typically used to determine biotic toxicity at some point and cannot be disregarded (El-Greisy et al., 2016).

2.8.3 Sulphate

Sulphate is a prevalent anion in aquatic habitats, found in many different natural settings, and plays a significant role in biogeochemical cycles (Huawei et al., 2019). According to Ekholm et al. (2020), anthropogenic activities like, municipal sewage, fertilizer applications from agriculture and some other industrial processes are the main causes elevated concentrations of sulphate anion (SO_4^{2-}) in waterways. However, changes in climate, elevated atmospheric sulphur (S), and hydrological alteration in coastal zones are all contributor factors of sulphate loads (Johnson et al., 2019). High level of sulphate in freshwater bodies can result in water salinity according to Canedo-Argüelles et al., (2018). Biochemical cycles, water stratifications, nutrient and oxygen availability may be altered by high concentration of sulphate in water (Leppanen et al., 2017). Ingesting too much sulphate can lead to a number of illnesses, including gastrointestinal issues, diarrhoea, and dehydration, according to earlier research by (Man et al., 2014).

2.9 Heavy metals

The term ‘heavy metals’ according to Hazart et al., (2018) maybe defined as metals and metalloids associated with environmental pollution, toxicity that may have adverse health impact on the biota. Heavy metals such as iron, cobalt, copper and zinc are classified as essential nutrient, whiles metals such as ruthenium, silver and indium are considered to be relatively harmless. According to Narjala et al., (2020) & Achparaki et al., (2021), essential elements like copper and zinc when present in larger quantity of drinking water can cause health-related issues like, gastrointestinal disorder, abdominal disorder and abnormal functioning of the liver.

On the other hand, heavy metals such as arsenic, cadmium, mercury and lead are classified as highly poisonous due to their health effect. Low level of IQ in children, nerve damage, cognitive impairments etc has been link to heavy metal lead (Sonone et al., 2021 & Griswold et al., 2019). According to Gautam et al., (2015), high level of heavy metal arsenic in drinking water can result in vomiting, gastric discomfort and abdominal pains whiles cadmium metal is responsible for kidney and lungs damages, fragile bone and prostate cancer (Griswold et al., 2019 & Narjala et al., 2020).

2.9.1 Sources of heavy metals contamination in water

Heavy metals get into our water bodies through the natural and anthropogenic means. The natural sources include; volcanic eruptions, weathering of sedimentary rocks etc according to Singh et al., (2022). According to Maruti et al., (2024), anthropogenic sources of heavy metals in water bodies (surface or groundwater) may come from, industrial sources, mining sources, power plant sources, biomedical waste, domestic sewage, electronic waste etc. For instant, heavy metals such as lead, cadmium, mercury, arsenic and nickel may come from electronic waste (Waleed et al., 2021).

2.9.2 Toxic Effects of Heavy Metals on Humans

2.9.2.1 Lead

The natural presence of lead in the environment increases primarily due to human activities according to Shahid et al., (2015). Lead is removed from airborne contaminants when rain hits the atmosphere before transferring into soil or reaching surface water. Lead applications as pesticide occur during vegetable and fruit cultivation according to Gall et al. (2015). An increase in Pb concentration occurs because of Temperature, humidity, bioavailability, Mobility, Environmental acidification, solar radiation and temperature associated with Mobility (Khan et al.,2015). The geochemical and anthropogenic Pb cycles resulted in transformations of Pb forms and its utilization purposes by humans. (MAO et al., 2014). Following a 30-day period of circulation through blood cells lead distribution occurs mainly in soft tissues especially the kidneys brain and liver until bone tissue phosphates entrap it. The human kidneys absorb lead compounds first before the brain and liver receive them and the final distribution occurs within bones and teeth and hair as lead phosphate (Engwa et al., 2019). Nervous system damage from lead exposure stands out as the most severe adverse effect it causes within the human body among all the other organ systems. When lead toxicity advances symptoms develop into paralysis which eventually leads to coma or brings about death (Gilani et al., 2015). Brain cells undergo apoptosis after nano-meter quantities of Pb^{2+} disrupt mitochondrial functions (Yang et al., 2014). Studies show BPb concentrations escalating by 10 µg/dL leads to a decrease in measured IQ points between 1 and 5 (Reuben et al., 2017).

2.9.2.2 Arsenic

Heavy metals together with arsenic in drinking water create a noteworthy danger to human existence because they are toxic substances which increase in concentration in living organisms while maintaining a long-lasting presence in the environment (Rajeshkumar et al., 2018 & Sany et al, 2015). Drinking water gets contaminated with heavy metals through natural processes as well as industrial and agricultural operations together with mining and road traffic activities (Hashemi et al., 2018 & Wongsasuluk et al.,2014). World Health Organization (WHO, 2015), reports that 71% of the global population accesses drinking water resources that meet safety standards guidelines. The combination of proper water source management with natural and anthropogenic pollution factors generates harmful elements in the water supply, particularly the domestic treatment system, chemical use in water processing, damaged pipelines, elemental leakage from distribution channels, and inadequate home water storage containers (Saha et al., 2017). The contamination of toxic heavy metals and arsenic has been documented across Mexico and Saudi Arabia as well as India, Bangladesh, China, Chile, Thailand and Iran (Rajeshkumar et al, 2018). Drinking one litre daily water with arsenic at 50µg/L combined with chromium levels between 8.3 and 51 during an entire life may result in lung, liver, bladder and kidney cancer (Chowdhury et al., 2016).

2.9.2.3 Cadmium (Cd)

Cadmium occurs naturally minerals and soil as sulphide and sulphates ores, chloride, and hydroxide salts as well as in water. It has an oxidation state of +2 as in the metal form. Cadmium metal has been found to be useful to mankind in a diverse way such as an anticorrosive and electroplating on steel. Cadmium sulphide and selenide are commonly used as pigment in paint. Cadmium heavy metal in the human environment may originate from many sources including, combustion of fossil fuel, nickel smelting and refining, electronic waste recycle, use of phosphate fertilizer (anthropogenic sources). Abrasion of rocks, soil and forest fires are among few natural activities that releases cadmium into the living environment. Cadmium in human have been studied to have a variety of adverse effect. Hepatic dysfunction, pulmonary edema, testicular damage, osteomalacia and other health issues are caused by cadmium (Tinkov et al., 2018). Drinking water containing a minute quality of cadmium heavy metal either long-term or short term may interfer with certain mechanisms in human body (Jiang, 2015).

2.9.2.4 Chromium

The heavy metals chromium (Cr) cadmium (Cd) and thallium (Th) stand as principal elements which harm human health being toxic or carcinogenic (Singh - Sankhla et al., 2020). Medical studies reveal that chromium causes numerous health problems with hexavalent chromium represents the most dangerous chromium form since it penetrates cellular barriers without difficulties (Harada et al., 2016). Genetic variations which cause health issues emerge when the body encounters chromium (Shekhawat et al., 2015). Both nasal septum perforation and lung cancer together with dermatitis allergies such as, asthma, lung disease, nasal ulcers, cancer, skin allergies, developmental and reproductive abnormalities contribute to the adverse effects of this element (Mohanty et al., 2023 & Zhao et al., 2023;). Hexavalent chromium exposure affects workers during metallurgical operations in addition to paint manufacturing, mechanical alloying, dyeing of animal skins, and electronic component manufacturing industries (Lu et al., 2017). The combined operations of metallurgy electroplating and leather tanning require Cr as part of their production. Industries utilize chromium (Cr) as one of their main components during tanning operations and electroplating and metallurgy processes. The water receives this substance as an industrial discharge. During the industrial phase chromium enters multiple body systems ranging from surface waters to groundwater (Scarazzato et al., 2017).

The increase of Cr content in the system leads to soil degradation. reduced soil fertility and lower agricultural production worldwide. High Cr (VI) concentrations in the soil create devastating limitations for natural microbial activities that also deteriorate vegetation output by disruption of soil microorganisms particularly autotrophic bacteria (Narendrula-Kotha et al., 2019). Research has established that exposure to chromium can impact physiological operations including photosynthesis, water regulations, mineral nutrition, oxidative balance, and enzyme activity suppression, plant metabolic including dysregulation. This stress caused by chromium exposure by plant can leads to oxidative damage in plants according to Kumar et al. (2016).

2.9.2.5 Copper

The critical chemical element which is copper needs strict homeostatic control systems to function properly. The set regulations cover multiple biological operations which start from gastrointestinal copper uptake then continue to cellular copper enzyme targeting and lastly copper removal through biliary processes. The body uses the biliary tract for copper excess removal while maintaining a proper transport of copper to the brain throughout growth and development stages (Kaler et al., 2013).

Copper-transporting ATP known as ATP7A and ATP7B carry out the main operational tasks of these functions. Due to its redox characteristics copper offers both beneficial and harmful potential effects to cellular functions. Copper exists primarily as Cu (I) state throughout the reducing cytoplasmic environments but exists also as Cu (II) state (Brady et al., 2014). When exposed to superoxide radicals together with the oxidant hydroxyl radicals and singlet oxygen cells experience permanent structural modifications of DNA and proteins (Su et al., 2019). Scientific investigations have discovered that abnormal copper levels serve as a factor in developing cancer, gallbladder, and thyroid cancer, in contrast to healthy counterparts (Baltaci et al., 2017 & Aubert et al., 2020). The elevation of copper levels in the body can help cancer cells achieve faster growth proliferation, angiogenesis, and metastasis (Wang et al., 2023).

2.9.2.6 Zinc

Zinc exists as an abundant earth compound since it covers approximately two thirds of the earth’s surface (Ramesh et al., 2014). Human societies have no access to water that is simultaneously unadulterated pure and safe (Bresline et al.,2017). Human activities that include municipal waste discharge alongside coal plant emissions and metal-related industrial processes and atmospheric pollutants function as principal sources of Zinc contaminants in the environment contamination (Pertsemli et al., 2014). Surface and subsurface environments become contaminated by high levels of zinc discharge leading to damages in groundwater quality. The locations near sulphide mineral mines usually display severe groundwater pollution (Ghadimi et al.,2016). Insufficient sewage management in unhygienic areas leads to no effective waste disposal systems thereby facilitating the spread of waterborne illnesses (Beuchat et al., 2018). Industrial waste products represent the primary pollutants of water resources. Extremely toxic pollutants affect both human beings as well as the environment according to recent research (Jain et al., 2017). Manufacturing plants and wastewater treatment centers discharge contaminated water into water bodies such as lakes and rivers and groundwaters through their freshwater consumption in industrial processes

According to Sankhla et al., (2016). Different research reports that the consumption of polluted water and breathing zinc elements within the digestive system approximately 3 grains of zinc chloride can start gastrointestinal issues and tissue changes in patient may displayed intense symptoms within the first few moments along with mouth and oesophageal burning and vomiting with pain (Bagul et al.,2015). Research found has study a correlation between broncho alveolar lavage liquid T cell counts alongside zinc concentration in patients which indicate the initiation of metal smoke infection at breathing stage (Batayneh et al., 2018).

2.10 Microbiological indicators for groundwater quality.

In most developing countries in Africa, bacterial contamination of drinking water is a major cause of most water-borne diseases in rural areas where community shares water supplies (Delaire et al., 2017) and is exposed to multiple faecal-oral transmission pathways in nearby borders (Jung et al., 2017). Infections caused by *Escherichia coli* (E. coli) that are connected to drinking contaminated water remain a major public health problem globally since their presence suggests the occurrence of fatal illnesses such diarrhoea (Martínez-Santos et al., 2017). The World Health Organization (WHO,2017), estimates that exposure to tainted drinking water and inadequate sanitation and hygiene practices account for about 25% of detected cases of diarrhoea illness worldwide. Drinking water supplies in Ghana, Africa are still susceptible to faecal pollution because of ecosystems decline and high rates of open defecation (Harris et al., 2017, and Njuguna et al., 2016).

According to Njuguna et al., (2016), about 215 million individuals in most developing countries engage in open defecation which is a significant way for bacteria growth that causes diarrheal illnesses to spread. (Gizaw et al., 2018), the majority of intestinal parasite infections in Africa are faecal-oral, and a higher percentage of these infections are linked to inadequate water, sanitation, and hygiene conditions. According to Harris et al., (2017), most water contamination challenges globally are connected to poor sanitation in rural due to low cleanliness practices. Communities with low socio-economic level are more likely to engage in unsanitary activities and open defecation, which facilitates the spread of bacterial pathogens into water sources (Berendes et al., 2020).

Rainwater has been found to include the protozoa *Giardia lamblia, Salmonella spp.,* and *Escherichia coli*. As a result, pollutants in the form of these microorganisms may be present in much higher proportions in the first stream of roof runoff water (Proctor et al., 2015). Organic materials, dust, animal and bird waste are among the chemical and microbiological contaminants that come into contact with rainwater as a runoff which form part of major contribution to microbiological contamination (Amin et al., 2016).

Table 2.2: Waterborne diseases and causative microorganisms

Causative microorganisms	Waterborne diseases
Salmonella (eg. S. dysentyphi)	Typhoid, paratyphoid and gastroenteritis
Shigella (eg.S. dysenteriae, S. boydii, S. Sneei, S. flexneri)	Bacillary dysentery (a diarrhea that produces bloody stool)
Vibrio cholera	Diarrhea, vomiting and a very rapid loss of fluids and may result to death
Escherichia coli	Gastroenteritis, profuse watery diarrhea, nausea, vomiting, abdominal cramps.
Campylobacter (eg. C. fetus, C. jejuni, C. coli, C. lari)	Acute gastroenteritis (fever, nausea, vomiting, diarrhea, abdominal cramps
Leptospira	Leptospirosisa
Legionella pnemophila	Acte pneumonia

Source: Amaning Kwarteng Nana Kwaku, 2016

2.10.1 Total Coliforms

The main public health hazard from bacteria in water stems from drinking contaminated liquids that include animal excrement or human faecal waste. The human faecal waste contains both bacteria and viruses as well as protozoa together with helminths (Ramani et al., 2022). The treatment procedure requires disinfection as this protective measure stops multiple types of microorganisms from passing through. The microorganisms called coliform belong to the gram-negative non-spore-forming rod-shaped bacteria group with the ability to ferment lactose producing acid and gas under anaerobic or aerobic conditions at 35 °C (32–37 °C) and within 48 h time interval (Martin et al., 2016). Drinking water containing coliform requires further testing since these bacteria indicate infectious pathogens are present in the water supply system. Most people encounter different levels of health problems when they consume water containing pollution starting with no symptoms through gastrointestinal distress which results in diarrhoea. The existence of pathogens results in inferior water quality standards.

The presence of coliform bacteria in water supply records both inadequate water filtration methods and water contamination throughout distribution systems according to quality reports (Bahagian et al., 2019). Faeces serve as a carrier of harmful bacteria and viruses together with protozoa and helminths. The water treatment depends on disinfection for its vital process which effectively stops many pathogens from passing through (Sadiq, et al., 2017). Pathogens transmit through two transmitting pathways which include human-to-human transmission as well as animal-to-human transmission. About one million people suffer annual deaths from vector-host infections which constitute 17% of total infectious diseases. Tropical and sub-tropical regions together with communities lacking proper sanitation and water scarcity record most infectious disease outbreaks (Cotruvo et al., 2017).

2.10.2 Faecal coliforms

Within the subgroup of coliforms that develop at 44.5°C is the faecal or thermotolerant coliforms. Specifically, faecal coliforms are bacteria naturally present in the intestines of humans and other warm-blooded animals. Water microbiological quality is predominantly assessed by faecal coliform indicator bacteria such as *Escherichia coli* (*E. coli*), which serve as pivotal markers for contamination (Shah et al., 2023). Testing groundwater samples for microbiological parameters like *E. coli* helps indicate the presence of various pathogenic bacteria and potentially viruses originating from human and animal waste. Sources of *E. coli* contamination include farmyard effluent, septic tanks, and surface runoff. Additionally, the presence of birds and landfill sites has been reported as contributing factors to microbial pollution in water bodies (Ngounouno et al., 2022).

The presence of faecal bacteria and viruses in water poses significant health risks to humans. Although the absence of *E. coli* in water is reassuring, it does not guarantee the complete absence of all pathogens. Conversely, detection of *E. coli* indicates recent faecal contamination and necessitates immediate precautionary measures, such as detailed water quality assessments and consumer protection interventions (Obiri-Yeboah et al., 2021). According to Shah et al. (2023), water sources with faecal coliform counts exceeding 200 colonies per 100 millilitres should be considered unsafe for human contact. Two primary microbiological methods commonly employed for assessing coliform densities are the membrane filtration technique and the Most Probable Number (MPN) method. The MPN approach estimates the bacterial concentration based on gas production in multiple fermentation tubes, whereas the membrane filter method allows for direct enumeration of bacterial colonies (Ngounouno et al., 2022).

2.11 Water Quality Index (WQI)

The Water Quality Index (WQI) is an important tool widely employed to summarise the complex characteristics of water quality into a single composite value. It incorporates physical, chemical, and biological indicators to provide an overall assessment of water status (Dippong & Resz, 2024). Selection of parameters for WQI calculation typically depends on the specific environmental attributes and management objectives of the study area, considering factors like oxygen levels, nutrient enrichment, turbidity, and contaminant concentrations (Owusu et al., 2024).

Standardisation of raw data into a non-dimensional scale is crucial, ensuring that different measurement units, such as milligrams per litre (mg/L) or percentage saturation, can be aggregated coherently into a unified index (Bishnu et al., 2024). Subsequently, individual parameters are assigned weights according to their relative significance in influencing water quality before the final WQI is computed (Haghighizadeh et al., 2024).

Various WQI models have been adopted globally to support water quality assessment and communication, including the National Sanitation Foundation Water Quality Index (NSFWQI), the Canadian Council of Ministers of Environment Water Quality Index (CCME-WQI), and others (Ngounouno et al., 2022). The Canadian Council of Ministers of Environment Water Quality Index (CCME-WQI) is employed in this study to evaluate the suitability of drinking water sources in the Amansie West District. The CCME-WQI method simplifies complex datasets by comparing measured water quality parameters against established guidelines and summarising findings into an easily interpretable index (Dippong & Resz, 2024).

2.11.1 Water Pollution

Water pollution refers to the alteration of the physical, chemical, or biological characteristics of water, often rendering it unsafe for human consumption or detrimental to aquatic ecosystems (Dippong & Resz, 2024). Significant contributors to water pollution include anthropogenic activities such as illegal mining, agricultural runoff, domestic effluents, and industrial discharges, particularly in developing countries (Obiri-Yeboah et al., 2021). As Moghimi Dehkordi et al. (2024) observe that, mining and industrial activities contribute extensively to the contamination of surface and groundwater through the release of heavy metals like arsenic, cadmium, lead, and mercury.

In many cases, untreated waste is discharged into water bodies, posing serious threats to human health and environmental stability (Apau et al., 2022). Water pollution leads to toxicity, depletion of dissolved oxygen, spread of waterborne diseases, and degradation of aquatic habitats (Arcentales-Ríos et al., 2022).

2.11.2.1 Groundwater Pollution

Groundwater pollution occurs when contaminants infiltrate aquifers through natural fissures or anthropogenic sources such as landfills, septic systems, and agricultural activities. Dehkordi et al., (2024) note that mining tailings and chemical leachates are common pollutants affecting groundwater quality. As groundwater is a major source of drinking water, its contamination poses significant public health risks (Soceanu et al., 2021). Pollutants like pesticides, nitrates, and heavy metals infiltrate underground aquifers and are extremely difficult and costly to remove once contamination occurs. Consequently, contaminated aquifers may remain unsafe for centuries (Awogbami et al., 2022).

2.11.2.2 Surface Water Pollution

Surface water, covering about 70% of the Earth's surface, is increasingly threatened by nutrient enrichment and industrial waste discharge. Agricultural runoff rich in nitrates and phosphates remains a dominant source of pollution (Apau et al., 2022). Although nutrients are essential for plant growth, excessive levels lead to eutrophication, loss of biodiversity, and water quality deterioration (Dippong & Resz, 2024). Industrial effluents and improper waste disposal further compound surface water contamination, endangering water security in many regions, including Ghana (Obiri-Yeboah et al., 2021).

2.11.2.3 Ocean Pollution

Approximately 80% of marine pollution originates from land-based activities, including agricultural runoff, industrial waste, and urban effluents. These contaminants are transported via rivers and drainage systems into oceans (Moghimi et al., 2024). Plastic pollution, oil spills, and nutrient loads exacerbate ocean degradation. Additionally, oceans absorb atmospheric carbon emissions, intensifying acidification and disrupting marine ecosystems (Dippong & Resz, 2024).

2.11.3.1 Potential Sources of Water Contamination

The quality of water bodies varies depending on natural geological formations and anthropogenic impacts. Mining activities, industrial emissions, agricultural runoff (pesticides and fertilizers), and urban waste are significant contributors to contamination (Obiri-Yeboah et al., 2021 & Dehkordi et al., 2024). Rainfall and runoff processes facilitate the transfer of these pollutants into rivers, lakes, and aquifers (Arcentales-Ríos et al.,2022). Additionally, inadequate waste management systems, particularly in developing countries, exacerbate contamination levels (Soceanu et al., 2021).

2.11.3.2 Natural Sources of Water Contamination

Natural events such as earthquakes, floods, and volcanic activities significantly influence water quality. According to Dippong & Resz (2024), geogenic processes like rock weathering and mineral dissolution release harmful substances such as arsenic, fluoride, and heavy metals into aquifers. Awogbami et al., (2022) also highlight the role of natural groundwater-surface water interactions and climate change in altering water chemistry. Naturally occurring minerals like fluorite (CaF_2) and apatite ($Ca_5(PO_4)_3F$) can contribute fluoride and phosphate contamination, especially in volcanic and sedimentary regions (Moghimi et al., 2024). These natural pollutants can pose serious health risks if not properly monitored and managed.

2.11.3.3 Agricultural Practices.

The demand for increased agricultural output by humans has resulted in pollution. Producers utilise agrochemicals, including herbicides, insecticides, fertilisers, and minerals such as phosphates and nitrates, during fertiliser applications. Gamage et al. (2023) assert that nitrate (NO_3^-) is a crucial nutrient for plant growth and enhances agricultural productivity. Nitrate from nitrogen-based fertilisers, when applied to plants, will contaminate the soil, water, or air (Lee et al., 2021). A minimal fraction of the nutrients provided is utilised by plants, resulting in soil deposition. Runoff introduces nitrate compounds into surface water, which then infiltrate the soil and, following heavy rainfall, access the aquifers. These processes lead to the contamination of surface and groundwater. Research indicates that in 2020, the United States, India, and China were the leading countries globally in nutrient utilisation for plant growth. Among the three, China utilised 45 million tonnes of nutrients, surpassing all other nations. India utilised 32.54 million tonnes, whilst the United States consumed 20.96 million tonnes, the lowest quantity. These nations have augmented their fertiliser application to meet the demands of the expanding population.

Phosphorus is considered the second most crucial nutrient for plants, following nitrogen, which is essential for growth and development. Phosphorus exists in two forms: orthophosphate and dihydrogen phosphate. Orthophosphate is the most crucial type of phosphorus for plant growth, as it comprises the bulk of the necessary molecules for this process (Rout, et al., 2014). Eutrophication occurs due to soluble orthophosphate entering aquatic systems and being unused by agricultural crops (Rout et al., 2016). Phosphate infiltrates aquatic systems from multiple sources, including domestic wastewater, livestock, agricultural runoff, soil erosion, and rock weathering, as noted by Rout et al., (2017).

The application of pesticides constitutes an additional source of toxins originating from agricultural practices that pollute water. Pesticides, a category of agrochemical chemicals that encompasses insecticides, weedicides, herbicides, fungicides, and nematicides, are predominantly utilised in agriculture to combat plant diseases, eliminate insects, and regulate weeds (Pradhan, et al., 2023). Groundwater contamination transpires when the extensively utilised pesticide, dichlorodiphenyltrichloroethane (DDT), infiltrates groundwater sources at an accelerated rate (Priyadarshini, et al., 2021).

2.11.3.4 Disposal of Hazardous Waste Product

Hazardous wastes, including blood, chemicals, waste from healthcare facilities, radioactive materials from nuclear plants, and runoffs from commercial activities such as car washes, hotels, and marketplaces, pose a major threat to water quality if improperly managed. Such wastes often contain harmful organic and inorganic pollutants, heavy metals, ammonia, and fluoride, which can leach into groundwater and surface water (Arcentales-Ríos et al., 2022). The leachate from these waste materials, especially when containing elevated levels of heavy metals, can severely impair aquatic ecosystems and public health (Moghimi et al., 2024). Common heavy metals detected in contaminated waters include arsenic, lead, chromium, cadmium, nickel, antimony, and mercury. Exposure to these contaminants can occur through ingestion of polluted water, inhalation of contaminated air, or dermal contact, leading to significant health risks (Obiri-Yeboah et al., 2021 & Apau et al., 2022).

2.11.3.5 Disposal from Municipal Waste

Globally, the volume of solid waste has risen dramatically due to increasing industrialization, urbanization, and modern lifestyles. In Ghana, improper disposal of municipal waste, particularly in rural and peri-urban areas, exacerbates environmental degradation and human health risks (Obiri-Yeboah et al., 2021). Municipal waste comprises various contaminants, including cleaning chemicals, pharmaceuticals, electronic waste, biodegradable substances, plastics, and industrial and biomedical residues (Moghimi et al., 2024). Products such as personal care items anti-dandruff shampoos, fluoride toothpastes, moisturisers, deodorants, and hair removal creams also contribute significantly to water pollution when discarded improperly (Arcentales-Ríos et al., 2022).

The degradation of municipal solid waste often produces leachate through hydrolysis and decomposition processes. This contaminated liquid can infiltrate surrounding soil layers, eventually seeping into groundwater reservoirs, thus posing considerable health hazards, especially for communities near landfill sites (Awogbami et al., 2022). Persistent pollutants from such waste streams can lead to long-term groundwater contamination, impacting potable water sources and agricultural productivity.

2.11.4 Effect of Water contaminations

2.11.4.1 Human Health.

Drinking water that is unfit for human consumption has grave effects on human health. According to the UNESCO (2021), World Water Development Report, water-related diseases mostly diarrhoea which can be brought on by contaminated water, inadequate sanitation, and poor hand hygiene cause approximately 829 thousand deaths annually. This report contains around 300,000 children under the age of five, who die annually. In humans, the primary means of transmission for water-related diseases are skin contact and ingestion. Research by Alam et al., (2023) indicates nitrate is a soluble nitrogen molecule both a required plant nutrient and a probable carcinogen to people. By drinking water with a high nitrate concentration, adults and children can acquire gastrointestinal cancer; new-borns can have blue baby syndrome (Ward, et al., 2018). According to the Fluoride is recognised as a vital mineral necessary for human growth and development, especially in strengthening bones and teeth. Nevertheless, excessive fluoride levels in drinking water can lead to dental fluorosis among young children (Gintamo et al., 2022). Therefore, the monitoring of fluoride concentrations in potable water is crucial for public health protection.

Pathogenic bacteria such as *Vibrio cholerae*, *Escherichia coli*, and *Salmonella typhi* have been linked to waterborne diseases like cholera, typhoid, and diarrhoea (Ngounouno et al., 2022 & Gintamo et al., 2022). *Escherichia coli* remains the most frequently encountered bacterium in contaminated drinking water supplies and is a primary faecal contamination indicator due to its natural abundance in the human intestinal flora (Gintamo et al., 2022). Moreover, enterotoxigenic strains of *E. coli* originating from cattle and human faeces present significant health risks when water sources are contaminated (Ngounouno et al., 2022).

Industrial activities, including textile dyeing, electroplating, and tanning, are among the sources that can release chromium into groundwater, posing substantial carcinogenic risks (Aziz et al., 2023). Chromium exists in multiple forms, with hexavalent chromium Cr (VI) being highly toxic and implicated in the increased risk of lung, bladder, kidney, and other cancers (Aziz *et al.*, 2023). Cr (VI) promotes oxidative stress and the production of reactive oxygen species (ROS), which can damage lipids and DNA in human cells (Bishnu *et al.*, 2024).

Zinc is an essential trace mineral that supports numerous biological processes, including immune function and wound healing. However, excessive ingestion of zinc through drinking water can result in gastrointestinal symptoms such as nausea and vomiting, although zinc is not inherently toxic (Gintamo et al., 2022). High levels of zinc ions contribute to undesirable taste in water, and deficiency in zinc intake is associated with growth retardation, impaired immune function, and complications during pregnancy (Bishnu et al., 2024).

Lead contamination of drinking water is a serious public health issue. Concentrations of lead exceeding 10 µg/L are known to impair neurological, biological, and cognitive functions (Ngounouno et al., 2022 & Gintamo et al., 2022). Prolonged exposure to lead may cause cardiovascular disease, renal dysfunction, and neuropsychiatric disorders. Lead can be absorbed through ingestion, inhalation, or dermal contact, eventually accumulating in the kidneys, central nervous system, and bones, leading to severe toxic effects (Bishnu et al., 2024). Children are particularly vulnerable, experiencing developmental delays, cognitive impairments, and behavioural problems upon exposure (Gintamo et al., 2022). Cadmium exposure through contaminated drinking water has been linked to adverse health outcomes such as reduced sperm count, lower birth weight, hypertension, and organ damage (Aziz et al., 2023 & Bishnu et al., 2024). Chronic cadmium ingestion can result in neurotoxicity, liver and kidney dysfunction, respiratory issues, nausea, vomiting, and loss of consciousness. Copper is another essential micronutrient for humans, vital for enzymatic functions and overall health. However, excessive copper intake through food or water can lead to acute liver damage and gastrointestinal symptoms such as cramps, abdominal pain, and diarrhoea (Bishnu et al., 2024).

2.11.4.2 Effects on aquatic Ecosystems

Increase in population and industrial revolution has made aquatic ecosystem become a reservoir for most contaminants. High levels of pollutants from agricultural practices, industrial processing, and domestic waste get into water bodies (aquatic environment). According to (Saito, et al., 2022), chemicals such as detergent, dyes, volatile organic compounds, heavy metals, microfibers, plastic, and microplastics affect aquatic environment when they reach water bodies. An aquatic ecosystem consists of freshwater ecosystems and marine ecosystems. The marine ecosystem comprises of earth’s surface water such as oceans, coral reefs, estuaries, and coastal ecosystems representing about 70% of the earth water bodies whiles wetland, lentic and lotic ecosystem constitutes 1% of the freshwater (Bashir, et al., 2020).

Anthropogenic activities responsible for water pollution include; deforestation, road and bridge construction and other industrial activities while agricultural is considered to be the main aquatic ecosystem damage. Studies have shown, rivers and stream, wetlands and lakes pollution in the USA was as a result of agricultural activities. In Chain, surface and groundwater pollution was due agricultural practices. Excessive nutrient application such as nitrate, phosphate and organic manure by farmers eventually leans into the groundwater through the soil (Bashir, et al., 2020). During heavy rainfall, these contaminants get reach to the water bodies and accelerates nutrient concentration in the water bodies, causing eutrophication. High level of nutrient content in water increases algal blooms, and other aquatic plants will be grown in the ecosystem. In recent years, harmful algal blooms (HABs) have resulted in water quality degradation, killing many microorganisms and aquatic species and public health risks (Karunanidhi, et al., 2022). Cyanobacteria are one of the main HABS found in the freshwater ecosystem and are responsible in poisoning cattle, animals and humans and also creates off-flavour in domestic water supplies.

2.11.4.3 Freshwater Scarcity

Changes in the climate will increase the severity of water shortage problems together with water availability challenges (IPCC, 2023). According to Kummu et al., (2016), high consumption of water causes water stress to develop simultaneously and affecting its availability (Kummu et al., 2016). Water scarcity creates severe economic impact on industries such as electricity production, nuclear hydropower plants as well as Agriculture depend on water (EEA, 2021). Numerous waterborne diseases can arise from groundwater contamination and water scarcity in low- and poor-income nations (Lin, et al., 2022). Water shortage of water will also drive animals and people to migrate, making the greater land area unusable for other activities like farming.

2.11.4.4 Effect on Vegetation

Mining stands as the most harmful human-caused operation which damages nearly all ecological systems (Chaturvedi & Singh, 2017). The practice creates damage to geomorphology and geological structures (Arenas-Lago et al., 2014) while dismantling living habitats. Deficiency of nutrients such as N, P, K among others occurs in metal mines while high metal concentrations emerge from such activities according to Farjana et al., 2019, Moiseenko & Gashkina, 2018). Zhang et al., (2019) demonstrate how these metals persist through geobiochemical circulation. Along with ecosystem destruction, the basic operations succumb to loss just as vegetation destruction (Oktavia et al., 2015) becomes visible.

CHAPTER THREE

MATERIALS AND METHODS

3.1 Study Area

This chapter describes the study area and methods used for sampling collection, analytical procedure and data collection adopted for analysis of available water sources (surface and groundwater) samples from Amansie West District in the Ashanti region of Ghana. The area covers a total land mass of 1141km^2 that constitute nearly 3.4% of the total land of the region and has a population of 109,416 (GSS, 2021). Specifically, the district is located within latitude 6.05° west, 6.35° north, 1.40° south and 2.05° east.

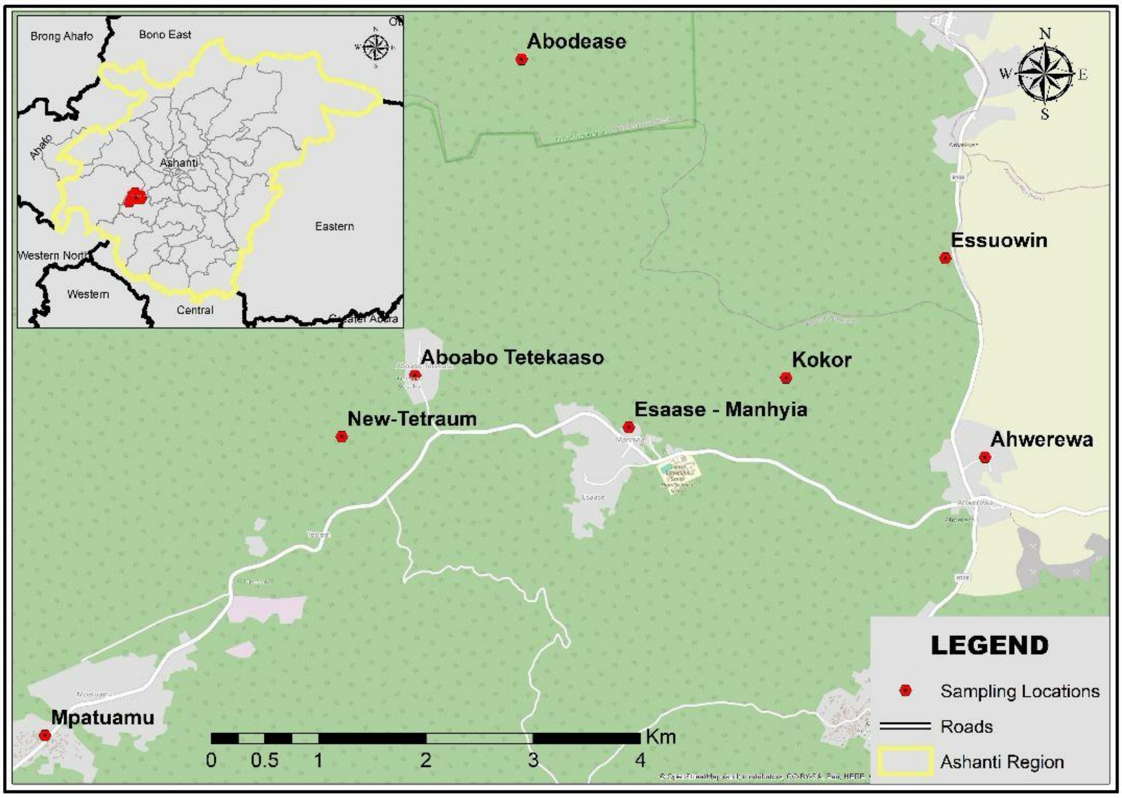

Figure 3.1: A map showing study locations and sampling area

Table 3.1. Sampling locations with their GPS coordinate

Location	Latitude	Longitude
Esaase – Manhyia	N06° 33.828’	W001° 53.271’
Mpatuamu	N06° 32.281’	W001° 56.205’
New-Tetraum	N06° 33.781’	W001° 54.714’
Aboabo Tetekaaso	N06° 34.090’	W001° 54.345’
Ahwerewa	N06° 33.678’	W001° 51.480’
Kokor	N06° 34.078’	W001° 52.480’
Abodease	N06° 35.678’	W001° 53.810’
Essuowin	N06° 34.678’	W001° 51.680’
Manso-Moseaso	N06° 33.678’	W001° 51.580’

3.1.2 Relief and Drainage

An average of 210 meters above sea level, the district's terrain is undulating. The hill range that runs throughout the district's northwest, particularly in the areas of Manso-Nkwanta and Manso-Abore, stands out the most. The height of this hill ranges from 560 to 630 meters. Jeni, Pumpin, and Emuna are tributaries of the Offin and Oda rivers, which drain the area to the north. Rice, vegetable, and fish crops can all benefit from the district's drainage system, which can be used for irrigation purposes (Amansie West District Assembly, 2022).

3.1.3 Climate

This geographic area receives rainfall as part of its rainy semi-arid climate. The heaviest rain falls occur during March and July followed by a second period of rainy weather from September through November. A single rainfall pattern appears twice during the year. The yearly rainfall amounts between 855 mm and 1,500 mm on average. Rainfall occurs for 110 to 120 days throughout the year across the district. The winter months of

December to March present hot dry conditions followed by foggy mornings and cold climatic conditions. The district experiences temperatures approximately 27◦c during every month while heat levels remain elevated throughout the year. The district maintained a relatively humid state from beginning to end during its wet season. On the other hand, the months of December through February experience exceptionally low humidity levels. Tropical fruits, vegetables, citrus fruits, citronella grass, cocoa, and plantain together with other income crops flourish in this climate zone (GSS, 2017).

3.1.4 Vegetation

The district shows most vegetation containing wet semideciduous characteristics which falls under rain forest classification. Its rich soil enables the district to become a superb area for cultivating food and monetary crops including cassava and cocoa with additional rice and citrus together with oil palm and diverse other food products. The primary forest reserves within the district exist of The Oda River Forest Reserve and Apanprama Forest Reserve together with Jimira Forest Reserve and Gyeni River Forest Reserve. The Bekwai - Oda compound Association resides in the northern Abore region together with Dome-Keniago (Baffour-Kyei, Mensah, & Owusu, 2018). The south-west section of the district starting from Nyamebekyere and extending to Bricherkrom and reaching its endpoint in the Adagya area hosts the Ahawam - Kakum-Chichiwere Association. The district comprises six main types of soils. The Mim-Oda compound lies within the southern parts of Datano and Aboaboso soil areas. Esaase in the northern section of the district houses the fourth soil type that goes by the name Bekwai-Zongo-Oda complex. The Kobeda-Eschiem-Subinso-Oda complex together with the Nyanoo-Tinkong Association create the fifth and sixth soil types in the area. Research by Aborah (2014) indicates that both of these groups exist within the mountainous area. Abore mountainous province contains one type of soil and the other type exists within the northern Manso-Nkwanta vicinity near Essuowin.

3.1.5 Economic Activity

The district operates primarily within an agrarian framework because agriculture and forestry together with fishing sections contribute 59.2% to the local economic output. Two primary forest reserves in the district feature magnificent plant and wildlife elements that welcome tourists including residents and external visitors (Amansie West District Assembly, 2018). There exist limited agro-industrial operations in the district involving cassava processing (gari making) while additionally conducting oil extraction and soap making activities. Nearly 85% of economic activities in the district originate from mineral (gold) extraction throughout its different communities.

3.2 Water sampling

Water sampling took place from ten Ghanaian communities consisting of Esaase – Manhyia, Mpatuamu, New-Tetraum, Aboabo -Tetekaaso, Ahwerewa, Kokor, Manso-Moseaso, Abodease, Essuowin which were all located in Amansie West District within the Ashanti Region because mining was prevalent at the time of investigation (Fig.3.1). Seventy-three (73) water samples with four (4) surface, sixteen (16) boreholes, seven (7) wells and forty-six (46) taps were collected for analysis. Plastic bottles of 1.5 L capacity used for water collection had undergone pre-cleaning and sterilization procedures. The water samples functioned first as cleaning agents for the plastic containers which later received the study sample. Surface and well water collections reached 15cm into the water depth. Borehole and tap water samples were collected at 05: 30 and 7: 00 GMT during the morning period before water source disturbance occurred and received the designations SW and BH for surface water and borehole water while well water samples were classified as TW. The sample containers containing ice were taken to Akenten Appiah–Menka University of Skills Training and Entrepreneurial Development Department of Chemistry where laboratory tests took place.

3.3 Preparation of samples for analysis

3.3.1 Physical parameters

Laboratory analysis of water quality was performed using Palintest protocol details at the Department of Chemistry in Mampong Kumasi at Akenten Appiah–Menka University of Skills Training and Entrepreneurial Development. The investigated physical properties within this study consisted of pH, electrical conductivity (EC), total dissolved solids (TDS) and turbidity. A Hanna HI (2300) auto – ranging microprocessor determined the measurement of electrical conductivity (EC) as well as total dissolved solids (TDS). The turbidity measurements were performed using Hach Turbidity meter model 2100 P through procedures described in Chu et al. (2023). Palintest pH probe assessed the pH of samples with proper validation through pH buffer solutions at 4, 7 and 10.

3.3.2 Analysis of nutrient levels

The analysis of water nutrients in this report included fluoride, ammonia, ammonium, sulphate, nitrate, and nitrite using the Palintest water quality protocols described in (Osei-Akoto et al, 2014) as well as in the Assessment of Ground Water Quality method described in “Standard methods for the examination of water and wastewater of American Public Health Association (APHA, 1992).

Nitrate

A 1 mL water sample was measured with a syringe before the researcher added it to a 20 mL nitrates tube and then introduced deionized water. The analysis was performed using Palintest photometer 7500 (UK), Direct Reading. One spoonful nitrate powder was added to the sample right before its reaction with a nitrate test tablet. A complete settlement of the solution was achieved by gently mixing the content three times before allowing it to stand for two minutes as per the Palintest water quality procedure. The liquid solution received transfer into a 10 mL test tube made of cuvette. A nitricol tablet was first crushed before dissolving it by mixing and left to stand for ten minutes. Instruments were evaluated through a blank analysis to check their operational performance. The solution's concentration measurement took place at automatic wavelength absorbance before reading as NO3- -N mg/l after following the prescribe protocol as in the Assessment of Ground Water Quality method described in “Standard methods for the examination of water and wastewater of American Public Health Association (APHA, 1992).

Nitrite

Staff employed the direct reading system of Palintest photometer 7500 (UK) for their analysis. A 10 mL mark in the cuvette test tube received sample water. The sample received one nitricol tablet which was crushed before mixing for dissolution. An appropriate time of ten minutes allowed the content to develop its coloration. The measure of nitrite concentration occurred within the photometer instrument using the automatic wavelength absorbance method for NO2- -N mg/l determination. The procedures were performed at all water sampling sites of the study following the Assessment of Ground Water Quality method described in “Standard methods for the examination of water and wastewater of American Public Health Association (APHA, 1992).

Free – Chloride

The Palintest photometer 7500 (UK) operated through Direct Reading to measure the free chloride levels. The test tubes used in the Cuvette test received washed sample water. Test tube residue consisted of a small amount of sample water after using it for rinsing. A Diethyl-p-phenylenediamine (DPD number one) tablet was placed in the water sample while it was crushed. The test tube received 10ml of water for tablet dissolution until the mark. Instant analysis of chloride concentration took place to prevent composition changes that could occur upon sample maintenance. After performing the total chloride test the addition of Diethyl-p-phenylenediamine (DPD number three) tablet followed with crushing and mixing for dissolution allowed two minutes for full colour development. Free chloride concentration values were calculated by subtracting total chloride results from the residual chloride concentrations as describe in the Assessment of Ground Water Quality method described in “Standard methods for the examination of water and wastewater of American Public Health Association (APHA, 1992).

Sulphate

The Palintest photometer 7500 from UK operated as a Direct Reading device. The analyst added the sample solution to reach the 10 mL mark within the test tube. A single sulphate turbidity test tablet along with a tube measurement to 10 mL received the tablet addition of crushing and subsequent mixing for dissolving. After adding all components to the tube, the mixture required five minutes of standing time to show colour development. The photometer instrument at an automatic wavelength measured sulphate concentration after the mixture went through it as per the Assessment of Ground Water Quality method described in “Standard methods for the examination of water and wastewater of American Public Health Association (APHA, 1992).

3.4. Heavy metals

A solution of 5 mL concentrated HNO_3 was used to preserve each 250 mL sample of water. The sample digestion proceeded through boiling 10mL concentrated HNO_3 added to the contents while reducing them to 20mL. When the solution reached ambient temperature a filtration process took place through Watman’s No. 42 filter paper. Analysis proceeded by volumetrically diluting the adjusted volume to 50mL with distilled water according to the procedure of Adusei-Mensah et al. (2019).

The analysis of total dissolved metal contents at the Department of Environmental Science, Kwame Nkrumah University of Science and Technology, Kumasi used Microwave Plasma Atomic Emission Spectrophotometer (MP-AES, Agilent 4210 model, Germany). First the instrument received calibration using distilled water as both blank solution and standard reference solutions after lamp installation. The technology required additional adjustment after reaching the target calibration precision. A series of samples became part of the examination procedure after adjusting calibration until researchers determined the target metal concentration.

3.4.1 Microbial parameters

A measurement of 34.5g chromocult coliform agar (CCA) media powder allowed dissolving in 1L of purified water. We heated the medium using boiling water before allowing agitation to dissolve all contents within the water. The medium reached 45-

50⁰C by placing it into the controlled water bath. The graded petri dish received a 4mm layer by pouring the liquid media while keeping the lid on for prevention of external bacteria contamination.

The protocol outlined in (Chauhan et al., 2017 & Some et al., 2021) established the procedure for passing 100 mL of water sample through filter funnel onto a filter Membrane Unit (FU). The membrane filter contains small pores which enable easy passage of water samples while effectively trapping bacteria from the water sample. The suction pump was activated through a power connection before it transferred the vacuum pressure to the filter funnel for filtration processes to start. The filter funnel required its rubber base to be removed prior to membrane filter extraction by using both sterilised forceps. The bacteria culture spread in petri dishes under aerobic conditions-maintained 37◦c temperature for 18 to 24 hours of incubation as per the Assessment of Ground Water Quality method described in "Standard methods for the examination of water and wastewater of American Public Health Association (APHA, 1992). After incubation, bacteria growth that included both total coliforms and faecal coliforms were counting and determined using (eq.1) according to Appiah-Effah et al., (2021).

$$\text{cfu/mL} = \frac{\text{Colonies counted}}{\text{Volume plated}} \times \text{dilution factor} \qquad \text{Eq. 1}$$

3.4.2 Quality Assurance and Quality Control

In this present work, several quality assurance (QA) and quality control (QC) procedures were used to assure the accuracy, precision, completeness, comparability, and representativeness of the sampled data. To avoid any contamination and minimize errors during this study, field sampling, storage, handling, and laboratory analysis were carefully considered using standard reference materials that were acquired from Standard

Global Services of Ghana, which is accredited by the Ghana Standards Authority GSA/HRD/33 (Douglas et a., 2023). To prevent field sampling contamination for instance, samples were placed in 1.5L plastic bottled washed with concentrated HNO_3 acid that were sealed and identified with permanent ink. Samples were stored under a temperature of 4℃ and transported to the lab for analysis. The same sampling and laboratory procedure was used in this study and compared with reference sample. This was performed to ensure accuracy. The sample analysis was done triplicate from the same location taken at the same to evaluate the repeatability (precision).

3.5 Statistical analysis

In this study, Jeffrey's Amazing Statistics Program (JASP) and Minitab Statistical Software Package version 22.1.0 was employed for all the computations of the descriptive statistics. The mean, range, standard deviation, minimum, and maximum values of the selected physicochemical, microbiological, and heavy metals parameters from the samples. Principal component analysis (PCA), descriptive statistics, and Pearson correlation coefficient matrix (PCCM) are the two statistical tests performed for the study. The average concentrations, standard deviation, and range of all samples used for this study were calculated. PCA tools were performed on the data to reduce the number of dimensions to significantly lower without any much loss of information (Khan et al., 2016).

The person correlation coefficient matrix for physicochemical and heavy metal concentrations for water samples was done to show any positive, negative, or no correlation relationships among samples parameters determined. The physicochemical, heavy metal, and microbiological parameters recorded from all the samples (borehole, well, surface, and tap water) analysed were compared with World Health Organization, and United State Enivronmental Protection Agency. This was studied to enable the researcher to determine the quality and portability of the groundwater consumptions by the communities within the study area.

Table 3.2: Shows water quality standard

Parameters	(WHO, 2017)	USEPA (2023)
pH	6.5–8.5	6.5–8.5
TDS (mg/l)	1000	500
Turbidity (NTU)	5	5
EC (µS/cm)	2000	-
NO_2^- (mg/l)	10	1
NO_3^-(mg/l)	50	10
NH_4^+(mg/l)	35	17
Cl^- (mg/l)	250	250
F^-(mg/l)	1.5	4
NH_3 (mg/l)	1.5	-
SO_4^{2-}(mg/l)	250	250
Cd(µg/l)	3	3
Cu(µg/l)	2000	1300
Cr(µg/l)	50	100
Pb(µg/l)	10	15
Zn(µg/l)	3000	1000
As(µg/l)	10	10

3.6 Contamination assessment method

The quality of water was computed from the collected data and compared to background reference data set - up WHO, EPA and other organization bodies. With this, one can determine the extents of potentially harmful water contamination parameters. In this research study, groundwater and surface water contamination was assess using water quality indices and comparison of study data to the background reference data. In other to determine the quality of water used by the community members, contamination assessment method was used to determine the combined effect of the several water qualities selected which may be considered harmful to household water were compared to their corresponding maximum permissible limits using Canadian Council of the Minister of the Environment (CCME-WQI, 2001) adopted from (Lamare and Singh, 2016) and Heavy metal pollution index (Mohan et al., 1996) from Jackson et al., 2024). The maximum permissible limit is the level of pollution within the water bodies that should protect living organisms within the ecosystem from toxic substance that may cause harm to the organisms in their habitat.

3.7 Waterer Quality Indices (WQI)

Change in quality of water can be detected by monitoring its physical, chemical and biological parameters (Bhateria et al.,2016). Water quality index is one of the indices techniques that is widely use in water quality analysis. The indices can simplify large data into a single data that gives a simplified understanding to the public about the health status of the water bodies (Rana et al.,2018). In this study, the Canadian Council of Ministers of the Environment Water Quality Index (CCME WQI) as detailed in (Lamare and Singh, 2016) was adopted to reveal the overall water quality status from selected mining and small scale –mining communities in Amansie West District in the Ashanti Region of Ghana. The CCME -WQI consists of three main factors F1, F2, and F3, which can be computed directly using Eq. (2) to (7) as shown in (Lamare & Singh, 2016) studies.

$$F_1 = \frac{\textbf{Number of failed variables(parameters)}}{\textbf{Total number of variables}} * 100 \qquad \text{(Eq. 2)}$$

Where scope is represented by F_1, indicating the level of non-compliance with water quality guidelines over relevant timeframe. The number of failed variables means the parameters which failed and the total number of parameters tested using (Eq.2)

The measure for frequency is F_2. This indicates the percentage of the individual tests which did not meet the goals during the test at all (failed tests) and this is calculated by using eq. 2 (Lamare & Singh, 2016).

$$\mathbf{F_2} = \frac{\textbf{Number of failed test}}{\textbf{Total number of test}} * \mathbf{100} \qquad \text{(Eq.3)}$$

To measure for the Amplitude F_3, demonstrates the extents by which an unsuccessful (failed test) do not meet their reference values (objectives) and this is evaluated by following three stages.

Step 1- Calculation of Excursion

The number of times by which an individual parameter concentration is higher or lower than the objective ‘’excursion’’ are expressed in equation 3 and 4 according to (Lamare & Singh, 2016).

(a) When test value must not be higher than objective or reference value.

$$\mathbf{Excursion_i} = \frac{\textbf{failed test valuei}}{\textbf{Objectivei}} - \mathbf{1} \qquad \text{(Eq.4)}$$

(b) When the test value must not fall below the objective or reference value was calculated according Lamare & Singh, (2016).

$$\mathbf{Excursion_i} = \frac{\textbf{Objective}}{\boldsymbol{Failed\ test\ value}} - \mathbf{1} \qquad \text{(Eq.5)}$$

Step 2. Calculation of Normalized Sum of Excursions

Collective amount of excursion or individual test which are out of the compliance is evaluated by summing the excursion of individual test from their objectives and dividing it by the overall tests (number of test) for both cases which meet the objective and those which do not meet the objective (reference values). These variables are referred to as the normalized addition of excursions (nse), and is determined using eq. 6 (Lamare & Singh, 2016).

$$\mathbf{nse} = \frac{\sum_{i=1}^{n} \text{excursion}}{\text{Total number of test}} \qquad \text{(Eq.6)}$$

Step 3-Calculation of F_3.

The amplitude stage was calculated using equation 6, the (asymptotic function), that scales the normalized addition of the individual test from the reference objectives values (nse), to yield a range of values between 0 to 100.

$$\mathbf{F_3} = \frac{\text{nse}}{0.01nse+0.01} \qquad \text{(Eq.7)}$$

After completing all these three stages or factors (F_1, F_2 and F_3). The approach treats the index in a three-dimensional form as defined by each factor along one axis in space. With this effect, the change in index is proportional to the factors.

Finally, the (CCME – WQI) was computed using equation 8 according to (Lamare & Singh, 2016).

$$\textbf{CCME - WQI} = 100 - \frac{\sqrt{F1^2+F2^2+F3^2}}{1.732} \qquad \text{(Eq.8)}$$

The index range values computed from the final stage (F_3) in compliance with above equations used in Canadian Council of Ministers of the Environmental (CCME) Water Quality Index and is presented in (Table 3.2).

Table 3.3. The summary of water quality index according to CCME – WQI Index.

CCME –WQI Range	Water Quality Interpretation
0 – 44	Poor
45 – 59	Marginal
60 – 79	Fair
80 – 94	Good
95 – 100	Excellent

Source, (Paun et al., 2016, Lumb et al., 2016 & Mahagamagea et al., 2014).

3.7.1 Heavy Metal Pollution Index (HPI)

To assess the level of heavy metal contaminations and the extent to which water sample is contaminated with heavy metals. Heavy Metal Pollution Index (HPI) developed by (Mohan et al., 1996) was used. This method has been widely used by most researchers such as Milivojevic' et al., (2016) to assess water quality. The heavy metal pollution index consists of two main parts: the unit weight index (Wi) and sub-index value (Qi) (Uddin et al., 2022). Equations, 8 and 9 were used to evaluate the extent of heavy metal pollution index from the studied samples.

a) Unit weight Index (Wi),

$$\mathbf{w_i} = \frac{\mathbf{K}}{\mathbf{Si}} \qquad \text{(Eq. 8)}$$

Where K is constant or sometimes = 1 or unity

S_i is standard permissible limit value of the i^{th} parameters.

b) The sub-index (Q_i) for the i^{th} parameters is given as.

$$\mathbf{Q_i} = \frac{\sum_{i=1}^{n}(Mi-Ii)}{\sum_{i=1}^{n}(Si-Ii)} * \mathbf{100} \qquad (Eq. 9)$$

Where, Mi, Ii, and Si denote measured value, idea or tolerable and standard or allowable value respectively.

Heavy metal pollution index was evaluated by combination of unit weight index and sub-weight index (Eqs. (8) and (9) using (Dippong et al.,2023 & WHO,2022) guidelines.

$$\mathbf{HPI} = \frac{\sum_{i=1}^{n} Wi\, Qi}{\sum_{i=1}^{n} Wi} \qquad (Eq. 10)$$

Where w_i is the weight index unit of the parameters evaluated, Q_i signifies the sub-index value of the i^{th} parameters and n represents the number of parameters.

HPI results were used to ascertain the effect of contamination of the individual heavy metals in the water bodies and the extent by which the water is polluted by the heavy metal(s). The final HPI values were compared to other international bodies like, Bureau of Indian Standards (BIS), World Health Organization (WHO) and Environmental Protection Agency (EPA) guidelines for drinking water, (Table 3.3). Unlike, other pollution indices, HIP has no specific classifications such as good, excellent or poor quality in which the calculated value of HPI will represent a specific range or level.

Table 3.4. Heavy Metals Water Quality standard limit BIS/WHO/EPA

Metals	Acceptable Limit(mg/L)	Permissible Limit(mg/L)	WHO	EPA
Arsenic	0.01	0.05	0.006	0.002
Copper	0.05	1.5	2	NA
Cadmium	0.003	No relaxation	0.003	0.005
Chromium	0.05	No relaxation	0.05	NA
Lead	0.01	No relaxation	0.01	0.0015
Zinc	5	15	NA	5

Source, BIS, 2012, WHO, 2017 and EPA, 2022).

3.7.2 Health Risk Assessment

To evaluate the degree of exposure to some selected heavy metals from the study area. The average daily dose (ADD) of heavy metals from drinking by human through ingestion, inhalation and dermal contact absorption rate depends on six main key factors mean exposure concentration (Cw), ingestion rate (IR), exposure frequency (EF), exposure duration (ED), body weight (Bw) and average lifetime (AT) of the individual that may be exposed to heavy metals (Xiao et al., 2019). To determine the heavy metal contamination in water on human health, heavy metals pollution index was classified into two categories: carcinogenic and non- carcinogenic risk. Average daily dose (ADD), hazard quotient (HQ), cancer risk (CR) and hazard index (HI) were among few essential features of metrics instrument used for measuring health risk assessment in this study (Keramati et al. 2018 & Li et al. 2019).

Heavy metals such, Cd, As, Pb, Cu, Cr and Zn were determined from the study area. Average daily dose (ADD, mgkg^{-1} day^{-1})) where studied to estimate for the values of both carcinogenic and non-carcinogenic risk assessment of heavy metals contamination was computed using Eq. (11) according to Nyambura et al., (2020) modified equation.

$$\mathbf{ADD} = \frac{(\mathrm{Cw})(\boldsymbol{IR})(\boldsymbol{EF})(\boldsymbol{ED})}{(\boldsymbol{BW})(\boldsymbol{AT})} \qquad Eq.11$$

Where;

ADD is average daily dose measured in (mg/kg^{-1}day).

C_W is the mean exposure concentration in water over the period (mg/L).

IR is the ingestion rate (2 L/day for adults and 1.5 L/day for children) (Brindha et al.,2016).

EF is exposure frequency.

ED is exposure duration (days/year).

B_W is the body weight (in kg per person), 70kg for adult and 20kg for children (Tyagi et al., 2020 & Qasemi et al., 2018)

AT is the average life- time (ED*365 days for carcinogenic risk) (USEPA, 2023).

Non- carcinogenic risk assessment was computed by using hazard quotient (HQ) for a single substance/element and hazard index (HI) for multiples substances/elements assessed. The hazard quotient (HQ) expressed as a ratio of average daily does (ADD) (mg/kg^{-1}day) during exposure time to the reference dose (R_fD) (mg/kg^{-1}day^{-1}). The hazard quotient was calculated using Eq. 12 to ascertain the level of non – carcinogenic risk associated with consumption of polluted groundwater by heavy metals (Li et al., 2020 & Ji et al., 2020).

$$\textbf{Hazard quotient } (\boldsymbol{HQ}) = \frac{\mathbf{ADD}}{\mathbf{RfD}} \qquad (eq. 12)$$

Where;

HQ is hazard quotient

R_fD is the reference dosage measured in mg/kg/day.

ADD is the average daily dose.

Hazard Index was performed on water samples exposed to heavy metals using eq. (13). This was used to estimate the possibilities of potential non- carcinogenic consequences that may be occurred in the sampled water as a result of heavy metals. Hazard index was estimated to assess the likely non-carcinogenic from the individual hazard quotients according to USEPA (2013) as in Eq. (13).

HI = Sum of all hazard quotient

$$\mathbf{HI} = \sum_{\mathbf{i=1}}^{\mathbf{n}} \mathbf{HQCd + HQZn + HQPb + HQCu + HQAs\ \ HQCr} \qquad \text{(Eq. 13)}$$

The Hazard Index value was use as reference to show both carcinogenic and non-carcinogenic after the exposure to heavy metals.

3.7.3 Cancer risk assessment (CR)

The probability of acquiring cancer as a result of exposure to a certain quality dose for heavy metal in drinking water throughout the individual lifetime (Shams et al., 2020), whereas the carcinogenic risk index is the total of all the cancer risk for individual metal. Eq. (14) can be used to deduce the carcinogenic risk (USEPA, 2013).

CR = CSF (cancer slope factor) x ADD (Eq.14)

Where;

CR is the carcinogenic risk for an individual heavy metal

CSF is the cancer slope factor

ADD is the average daily dose (Table 3.5).

The permissible limits are 10^{-6} to 10^{-4} for a single carcinogenic element and 10^{-5} for carcinogenic risk index (for multiple element carcinogens) (Cao et al., 2014).

Table 3.5. Shows Cancer slope factor (CSF) and Reference dose (RfD) for drinking water

Element	RfD (mg/kg/day)	CSF (mg/kg/day)
As	3.0×10^{-4}	1.5
Cr	3.0×10^{-3}	0.5
Cu	5.0×10^{-3}	N/A
Cd	5.0×10^{-4}	3.8×10^{-1}
Pb	3.6×10^{-3}	8.5×10^{-4}
Zn	3.0×10^{-1}	N/A

Source: USEPA, 2013 NA — Not Available

CHAPTER FOUR

RESULTS AND DISCUSSIONS

4.1 Introduction

Physical, chemical, biological and heavy metals quality parameters measured are presented in this section for the different water sampling sources. Comparison between the measured parameters for the sampling type were also studied.

4.2 Data Presentation

The data obtained from descriptive statistics, principal component analysis and Pearson correlation analysis of the selected physicochemical, nutrient loads, heavy metals contents and microbial loads are shown in this chapter. Descriptive statistics recorded includes; Mean, minimum, maximum values and range for physicochemical (pH, Temperature, TDS, EC, NO_2^-, NO_3^-, SO_4^{2-}, NH_3, NH_4, Turbidity, F^- and Cl^-), heavy metals (Cu, As, Pb, Zn, Cd and Cr) and microbial loads of the sampled water.

4.3 Descriptive Analysis of physical parameters from the study samples

According to (Figure 4.1), electrical conductivity (EC) values recorded from all the study samples were observed to be higher in borehole water than the remaining sampling sources. The mean value recorded from borehole was 550.87±128.34 µS/cm compared to tap water, well water and surface water with corresponding mean values of 508.42±99.34, 523.80±158.5 and 371±87.34 in µS/cm respectively. However, the electrical conductivity recorded from this study were all higher compared to the mean values recorded by Amaning-Kwarteng (2016) from Kibi in the Eastern Region of Ghana and Akoto et al., (2014) from Owabi treatments water plant in the Ashanti Region of Ghana. Their findings were 151.33±51.61 µS/cm and 319±156.88 µS/cm from borehole and hand dug-well for Amaning-Kwarteng and 324.40 ±17.98 µS/cm for raw water, 328±22.98 µS/cm for settled water, 327.40 ±19.69 µS/cm for filtered water and 331.90±14.48 µS/cm for distribution water for Akoto et al (2014). High level of electrical conductivity recorded from the study samples may be due to high dissolution of organic and inorganic salts present in the water as a result of high level of temperature and pH recorded from studies may have caused these changes. All the mean values recorded from the study samples were all lower than drinking water guidelines value of 2000 µS/cm according to World Health Organization (WHO, 2017).

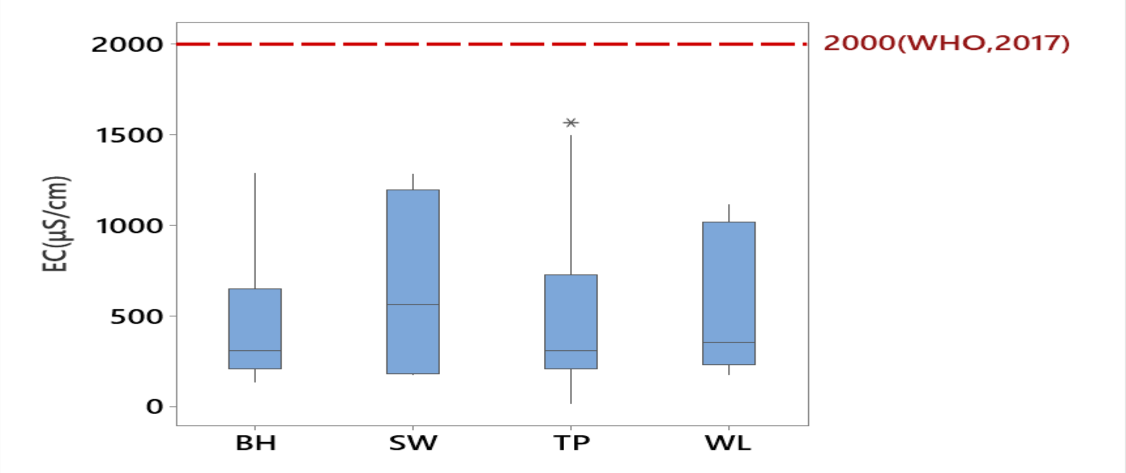

Figure 4.1: Electrical conductivity levels from the water samples

For total dissolve solids (TDS), the average mean concentrations of the observed water samples ranged from 97.72 to 272.0 mg/l. The highest TDS value was recorded in borehole water as 272.0 ± 79.13 mg/l with surface water recording the least average mean value 97.7 ± 20.69 mg/l. The second highest mean value was determined to be 161.04 ± 45.49 mg/l for well water followed by tap water with an average mean value of 156.0 ± 14.39 mg/l. Water with high level of total dissolved solids may have unpleasant taste and sometimes affect household appliances such as dishwashers and laundry machines etc. High levels of TDS in water are generally not harmful to human but high concentration may affect individuals suffering from kidney and heart disease and also causes laxative effects Sasikaran et al., (2012).

The observed mean values were higher than Charity et al., (2024) and Saeed et al., (2022) findings. Charity's (TDS) mean value recorded was 241 mg/l from Amansie West District in Ashanti Region of Ghana whiles a mean value of 135 mg/l was recorded by Saeed et al., (2022) from Tano North Municipal in the Ahafo Region, Ghana. However, none of the study mean findings for TDS exceeded WHO (2017) permissible limits of drinking water 1000 mg/l. Electrical conductivity (EC) and total dissolved solids (TDS) were observed to be significant in borehole, tap water and well but show no significant in surface water. The remaining parameters from the study samples did not show any sign of significant differences to EC and TDS in all the water samples.

The average temperature of water samples recorded were within the WHO range of 22 – 29 ℃. The highest average temperature mean was recorded as, 27.43 ± 0.40 ℃ for well water whiles the lowest average temperature was observed in surface water as 26.3 ± 0.85 ℃. Boreholes and tap water recorded an average mean value of 27.23 ± 0.37 ℃ and 27.29 ± 0.22 ℃ respectively.

The temperature recorded in this study were less than the mean temperature 28.49 ℃ observed by Yirdaw et al., (2016) from Wondo genet campus in Ethiopia. However, no significant difference was observed between temperature parameter turbidity and total dissolve solids in all the water samples at $p < 0.05$ except for borehole water where temperature was observed to be statistically significant to EC.

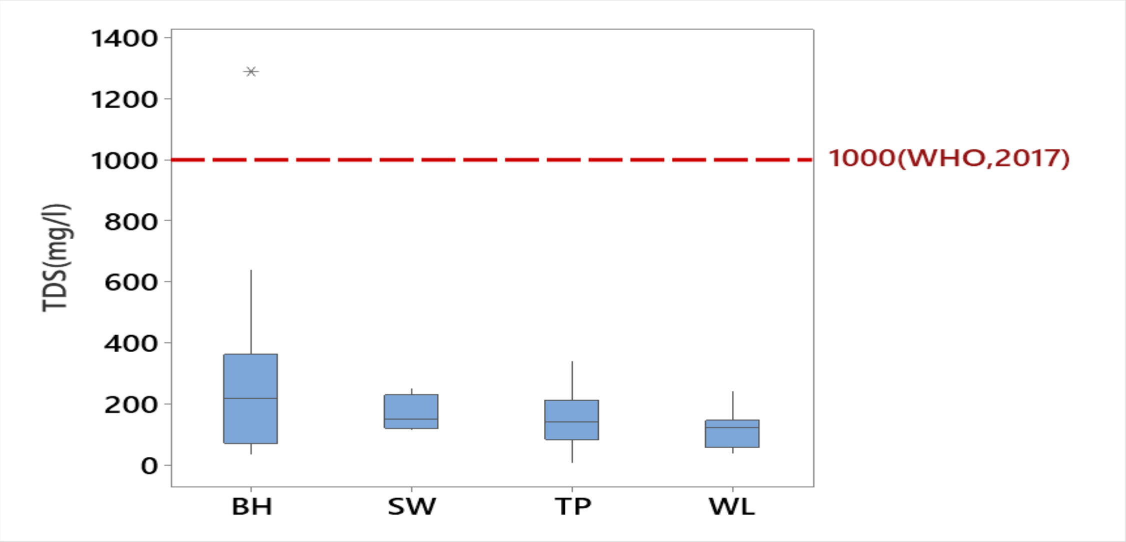

Figure 4.2: Levels of TDS in the study samples

According to (Figure 4.3) below, the mean concentration for turbidity parameter recorded for borehole water for study samples was 0.663±0.141 NTU. The maximum value recorded during the statistical analysis was 2.05 NTU whiles minimum turbidity value of 0.19 NTU was recorded for borehole water. Surface water had a mean of 116.50±56.92 NTU with a maximum and minimum values of 276.0 NTU and 18.70 NTU respectively. Well water recorded a maximum value of 46.60 NTU and a minimum value of 3.55 NTU.

The average turbidity mean concentration for well water was 20.92±5.91 NTU. Tap water recorded a mean value of 1.06 ± 0.183 NTU with a range of 3.15 - 5.57 NTU. Surface water samples had the highest turbidity mean value of 116.50 ± 56.92 NTU whiles the lowest value was observed for boreholes water as 0.663±0.141 NTU. The turbidity mean concentration recorded for borehole and tap water were all below the standards value of 5 NTU for drinking water (WHO,2017).

Well and surface water turbidity average concentrations were observed to be higher than WHO turbidity standard limit. The study findings for both well and surface water agrees well with similar studies conducted by Amaning-Kwarteng, (2016) study, Kibi in the Eastern Region of Ghana but does not agree well with Saeed et al., (2020) Tano North Municipal in the Ahafo Region, Ghana. The mean values recorded from their studies were 20.67 NTU for borehole and 7.50NTU for hand dug - well by Amaning-Kwarteng, (2016) whiles a mean value of 1.80 NTU recorded by Saeed et al., (2020).

The high level of turbidity in well and surface water may come from biological growth (algae, zooplankton and cyanobacteria), the release of inorganic particles by weathered rocks which may affect the appearance and taste of the water quality and industrial and livestock a major source of pathogenic microorganisms. Differences between the means of all the physical parameters were not significant at ($p < 0.05$).

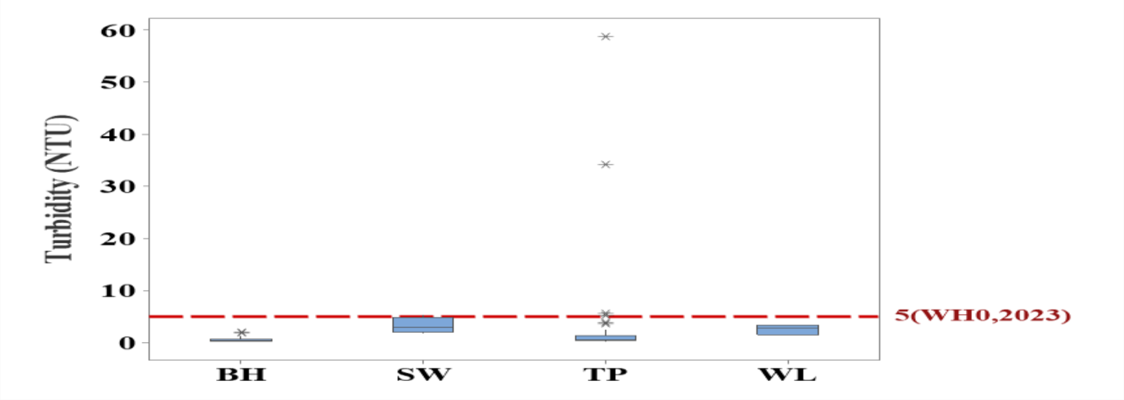

Figure 4.3: Turbidity levels from the water samples studied

From (Figure 4.4), the pH means values ranged from 5.67-7.00 for borehole, 5.90- 7.50 for tap water, 5.80- 6.90 for well water and 6.41- 7.30 for surface water respectively. The range of pH from the studies indicates that, the water samples were slightly acidic. The highest average mean concentration value for pH was observed in surface water

6.86±0.21 followed by tap water 6.73±0.061 and 6.52±0.40 for well water with borehole water recording the least average means concentration value of 6.27±0.34 respectively.

The pH values recorded for all the water were higher than the pH values observed by Amaning -Kwarteng, (2016), a mean of 5.71±0.67 for borehole and 5.98±0.6 for hand dug wells in Kibi. However, the mean concentration recorded in this study were lower than the average mean pH value of 7.44 recorded by Asamoah et al., (2014) from Amansie West District in the Ashanti Region of Ghana, a mining impacted area. The hydrogen ion concentration average means (pH) values observed from the study area were all within pH permissible limits for drinking water 6.5 – 8.5 set by WHO (2017).

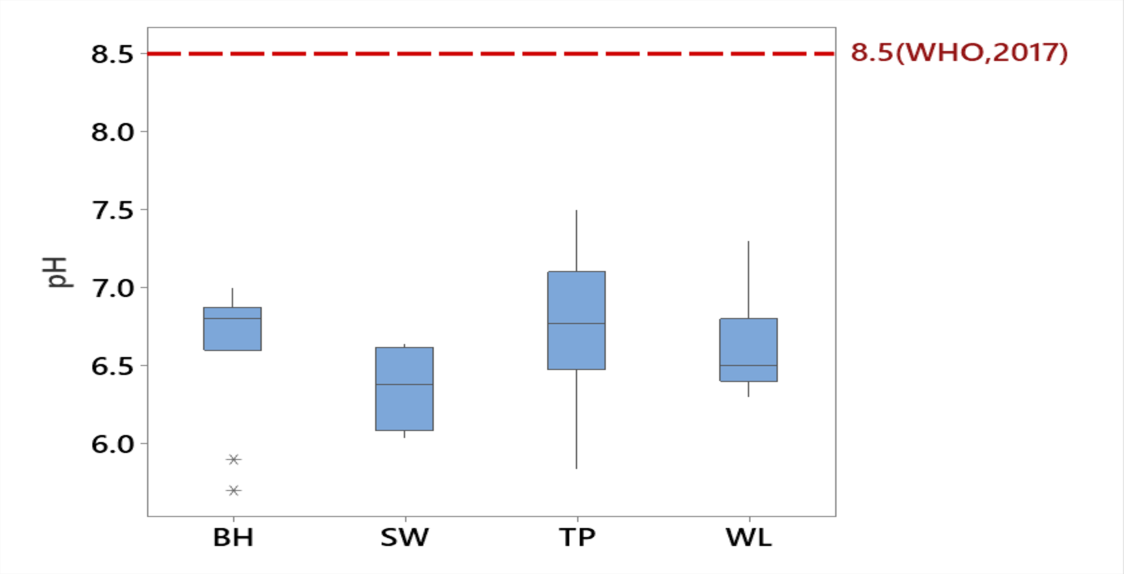

Figure 4.4: Level of pH from the water samples

4.4 Descriptive analysis of nutrient levels from water samples

Nitrate is one of the nitrogen-containing substances that plants need. In comparison to borehole, well, and surface water sources, the mean nitrate ion concentration found in the study samples was greater in tap water (30.14 ± 28.81 mg/l) (Table 4.1). The rise in nitrate levels in tap water could be caused by seepage from fertilized agricultural areas close to the tap water supply point source, runoff, or septic tank leaks. (Table 4.1) shows that the lowest average mean nitrate ion concentration was 24.20 ± 9.96 mg/l for surface water.

The average nitrate concentration in well water was 28.91±23.29 mg/l, with minimum and highest values of 14.00 and 80.00 mg/l, respectively. The changes in concentrations of nitrate levels from the study samples may be as a result of decrease in farming operations over the years in the study area (Adusei-Mensah et al.,2019). However, the mean value of the borehole water sample was slightly higher than that of the surface water, at 25.48 ± 19.10 mg/l. These variations in average nitrate concentrations in borehole water were found to be much greater than the average concentration of 0.25 ± 0.14 mg/l found in a borehole water in Kibi, Ghana, by Amaning-Kwarteng (2016). All of the water samples from the research area had mean nitrate ion concentrations below the maximum allowable level of 50 mg/l for drinking water (WHO, 2017).

Table 4.1 Mean concentration of nitrate from water samples

	NO_3^-			
	BH	**SW**	**TP**	**WL**
Valid	16	4	46	7
Mean	25.475	24.200	30.139	28.914
Std. Deviation	19.160	19.913	26.807	23.293
Minimum	5.200	12.400	2.400	14.000
Maximum	84.000	54.000	140.000	80.000

4.4.1 Nitrite concentrations from the sample study

Nitrite levels in borehole water samples were found to be 0.00 mg/l at the maximum and 0.160 mg/l at the minimum, with a mean of 0.0069 ± 0.0041 mg/l. According to (Table 4.2), the average mean concentrations of nitrite ion (NO2-) found in tap water, well water, and surface water were 0.008 ± 0.005 mg/l, 0.043 ± 0.16 mg/l, and 0.34 ± 0.014 mg/l, respectively. In addition, the maximum and minimum readings for tap water, well water, and surface water samples were 0.16 mg/l and 0.00 mg/l, 0.20 mg/l and 0.00 mg/l, and 0.02 mg/l and 0.00 mg/l, respectively.

The average nitrite mean content in surface water was the highest of all the water samples examined, measuring 0.34 mg/l, while the lowest was found in borehole water, measuring 0.0069 mg/l. The WHO's (2017) tolerable limits of 10 mg/l of nitrate in drinking water were exceeded by all mean values detected. This indicates that there won't be any health risks for the newborn in the research region, such as blue baby syndrome, which can be brought on by water that contains a lot of nitrites (Ward et al., 2018).

Table 4.2. Descriptive Statistics of nitrite levels

	NO_2^-			
	BH	**SW**	**TP**	**WL**
Valid	16	4	46	7
Mean	0.007	0.034	0.047	0.043
Std. Deviation	0.016	0.029	0.295	0.068
Minimum	0.000	0.000	0.000	0.000
Maximum	0.060	0.070	2.000	0.160

4.4.2 Concentration of sulphate ions

The sulphate ion (SO_4^{2-}) concentrations from the study samples ranged 0.008 to 45.50 mg/l. The average mean of sulphate ion varies from one sample source to the other sources as surface water recorded the highest mean value of 46.50 ± 56.0 mg/l followed by well water 24.14 ± 16.07 mg/l and tap water 19.91 ± 22.4 mg/l whiles borehole water recorded the lowest sulphate ion average mean concentration of 0.008 ± 0.023 mg/l respectively according to (Table 4.3). The result obtained from the study samples were all found to be higher than reported by Abubakar (2014). The high level of sulphate in surface could be attributed to natural process such as dissolution of pyrite and gypsum and human activities such as application fertilizer containing of sulphate Yousefi et al., 2019). The mean values recorded in this study were all below threshold limit for sulphate in drinking water 250 mg/l according to (WHO, 2017).

Table 4.3 Mean concentration of sulphate ion from the study samples

	SO_4^{2-}			
	BH	**SW**	**TP**	**WL**
Samples (N)	16	4	46	7
Mean	0.008	46.500	19.913	24.143
Std. Deviation	0.023	56.003	22.444	16.067
Minimum	0.000	11.000	3.000	7.000
Maximum	0.090	130.000	112.000	47.000

Chlorine is a useful chemical in water treatment for killing harmful microorganisms which may cause water related diseases such as typhoid, cholera, hepatitis and giardiasis, blood pressure Solanki, et al, (2022). In this current study, chloride ion concentration was detected from all the water samples. Surface water recorded an average mean concentration of chloride ion as 0.955mg/l (Table 4.4) which ranges from 0.11 – 2.4 mg/l. Well water from the study sampled recorded mean concentration ranging from 0.134-

0.282 mg/l. this could due to low treatment of well water within the study area (Akoto et al., 2014).

The mean concentrations recorded for tap water and borehole were 0.01mg/l and 25.563mg/l (Table 4.4). However, the highest mean concentration of borehole water could be due to large amount of chloride that was added to the water during treatment. The mean concentrations recorded from the study area were all lower than Nyantakyi et al., 2024) except borehole water. The findings from this study were observed to be lower than WHO (2017) permissible limits of drinking water 250 mg/l. High level of chloride in drinking water may result in hypertension and kidney stone formation (Kumar et al., 2017). However, no statistical difference was established between chloride ions and other parameters in all the water samples studied.

Table 4.4: Mean concentration of chloride ions

	Cl^-			
	BH	**SW**	**TP**	**WL**
Samples (N)	16	4	46	7
Mean	25.563	0.955	0.010	0.134
Std. Deviation	38.519	1.032	0.016	0.282
Minimum	3.000	0.110	0.000	0.000
Maximum	142.000	2.400	0.050	0.770

From (Figure 4.5), fluoride ion was detected in all the water samples studied. The average concentrations of fluoride ion from the study samples were higher in tap water compared to the other samples. The mean value recorded for tap water was 0.264 ± 0.284 mg/l with a range of 0.00 – 1.06 mg/l. Surface water concentration was recorded to be the lowest in term of fluoride content as 0.033 ± 0.065 mg/l (Table 4.5). Borehole water recorded the second highest mean concentration for fluoride ion as 0.096 ± 0.282 mg/l which agrees well with (Pinar et al., 2022). This means, the naturally occurring fluoride level may not pose any health issues (Chuah et al.,2016 & Prasad et al., 2018).

The mean concentration recorded from well water samples studied was 0.033 ± 0.067 mg/l was observed to be lower than (Pinar *et al.,* 2016) study. The concentration of fluoride ion content determined from all the water samples were lower than Akoto et al., (2014) findings which range from 1.10 to 1.28 mg/l. None of the study samples mean exceeded the recommended limit of fluoride in drinking water 1.5 mg/l by WHO (2017). This means that, water from the study area will not cause any dental fluorosis to consumers.

Table 4.5 Descriptive Statistic of fluoride concentration (mg/l)

	F^-			
	BH	**SW**	**TP**	**WL**
Samples (N)	16	4	46	7
Mean	0.096	0.033	0.264	0.033
Std. Deviation	0.282	0.065	0.284	0.067
Minimum	0.000	0.000	0.000	0.000
Maximum	1.050	0.130	1.060	0.180

4.4.3 Mean Concentration of Ammonia

Drinking water containing ammonia at levels above the WHO recommended guideline of 1.5 mg/l may be more harmful to aquatic life. According to (Table 4.6), the concentration of ammonia (NH_3-N) found in all water sample sources were higher in tap and surface water than well and borehole water. Tap, surface, well and borehole water were found to have average mean values of 3.098±6.70 mg/l, 0.522±0.346 mg/l, 0.017± 0.029 mg/l, and 0.004± 0.010 mg/l, respectively. The higher levels of ammonia in both tap and surface water may be the use of fertilizer containing inorganic nitrogen, that may have seps into the surface water and any leakage pipeline from the study (Nyantakyi et al., 2019). According to El-Greisy et al., (2016), non-ionic ammonia diffuses readily through biological cell membranes due to its neutrality hence at high level, non-ionic ammonia may be harmful to aquatic organisms.

Table 4.6: Level of from the study area

	NH_3			
	BH	**SW**	**TP**	**WL**
Samples (N)	16	4	46	7
Mean	0.004	0.522	3.098	0.017
Std. Deviation	0.010	0.346	6.700	0.029
Minimum	0.000	0.130	0.003	0.000
Maximum	0.031	0.970	33.000	0.060

4.4.4 Level of ammonium nutrient from the study samples

Ammonium (NH_4-N) concentrations in drinking water at higher level greater than WHO acceptable limit of 35 mg/l may be more toxic in the aquatic biota. The non-ionic ammonia because of its neutrality, diffuses easily through the biological cell membranes in aquatic biota than the ionic form (NH_4^+). Toxicity of ammonia (non-ionic) is mostly determined rather than the ionic ammonium (El-Greisy et al., 2016). Ammonium may contribute to total toxic effect of non-ionic ammonia in the aquatic biota (Liu et al., 2014).

High level of ammonium concentration was observed in surface water as 0.607± 0.071 mg/l with well water recording the second highest mean value of 0.312±0.013 mg/l. The mean values recorded for borehole and tap water were 0.0003±0.007 mg/l and 0.001±0.00 mg/l. Changes in mean concentrations of ammonium in borehole and tap water recorded compared to surface and well water concentrations low level of applications by the farmers near the water point sources. The concentration levels of ammonia and ammonium present in all the water samples were within than (WHO, 2017) permissible limit of drinking water.

Table 4.7: Ammonium ion concentration from the study samples

	NH_4^+			
	BH	**SW**	**TP**	**WL**
Valid	16	4	46	7
Mean	0.107	0.265	0.033	0.033
Std. Deviation	0.101	0.300	0.088	0.067
Minimum	0.000	0.000	0.000	0.000
Maximum	0.310	0.690	0.380	0.180

4.5 Correlation analysis of physicochemical parameters for tap water

From (Table 4.8), chemical parameters correlations (r) were determined to vary from very weak negative correlation (-0.303) to positive moderate correlation (0.617) and from positive moderate to perfect correlation (0.617 to 1.00) (Table 4.8). The very weak negative correlation was observed between pH, nitrate and nitrite (r = -0.396) and (r = -0.303) respectively. Sulphate - ammonium correlation was observed to be very weak positive with correlation value of (r = 0.300). Nitrite and nitrate show moderately positive correlation (r = 0.617) whiles (NH_3-NH_4) parameter were perfectly correlated (r = 1.00). Chloride ion did not show any correlation with the observed parameters. However, relationship was statistically significant between the correlated parameters studied from tap water.

Table 4.8 Shows correlation for nutrient physical and physical parameters for tap water

Parameter	NO_3^-	NO_2^-	NH_4^+	SO_4^2	NH_3^-	Cl^-	F^-	pH
NO_3^-	—							
NO_2^-	-0.454	—						
NH_4^+	-0.437	0.983***	—					
SO_4^{2-}	0.398	0.098	0.058	—				
NH_3	-0.437	0.983***	1.000***	0.058	—			
Cl^-	-0.224	0.726	0.608	0.459	0.608	—		
F^-	-0.072	0.440	0.587	-0.259	0.587	-0.253	—	
pH	0.057	-0.174	-0.151	0.695	-0.151	-0.045	-0.136	—

* $p < .05$, ** $p < .01$, *** $p < .001$

4.5.1 Correlation of physicochemical parameters for borehole

Pearson's correlation matrix was performed to determine the relationship between the chemical parameters studied. Moderately negative correlation between pH-NO_2^- was (r = -0.665). Correlation was significant between pH-NO_2^- (Table 4.9). Fluoride ion showed moderate positive correlation to ionic ammonium (NH_4^+), SO_4^{2-} and NH_3. The observed correlations are presented in (Table 4.9). However, correlation was statistically significant among the observed parameters. A "very strong positive correlation" to "a perfect positive" correlation was found to exist which ranged from 0.736 to 1.00. Nitrate parameter shown a very strong connection with NH_4^+, SO_4^{2-} and NH_3 parameters while the perfect correlation was between NH_3 and NH_4. Relationship established between the study parameters were statistically significant. Nitrite and chloride did not exhibit any relationship with the other parameters from the study samples.

Table 4.9 Pearson's Correlations matrix for borehole water

Variable	NO_3^-	NO_2^-	NH_4^+	SO_4^{2-}	NH_3	Cl^-	F^-	pH
NO_3^-	—							
NO_2^-	-0.120	—						
NH_4^+	0.736 **	-0.083	—					
SO_4^{2-}	0.739 **	-0.111	0.964 ***	—				
NH_3	0.736 **	-0.083	1.000 ***	0.964 ***	—			
Cl^-	-0.235	-0.167	-0.186	-0.200	-0.186	—		
F^-	0.215	0.014	0.535 *	0.540 *	0.535 *	-0.066	—	
pH	-0.028	-0.665 **	0.203	0.173	0.203	0.372	0.153	—

4.5.2 Correlation between nutrient parameters of well water

Pearson's correlation coefficient **r** was used to investigate the relationship among the physical parameters studied for well water. Fluoride, chloride and pH shows a positive moderate correlation ranging from (0.587 to 0.695) to NH_4^+, NH_3, NH_4+ and SO_4^{2-} parameters respectively. Ammonia and ammonium exhibit a very strong positive correlation to nitrite (r = 0.983) whiles a perfect positive correlation between ammonia and ammonium was achieved (Table 4.10). However, correlation was observed to be statistically significant between NH_4^+ -NO_2^-, NH_3 - NO_2^- and NH_3 - NH_4^+ whiles no correlation was observed among the remaining parameters.

Table 4.10: Shows Pearson's Correlations matrix for well water

Variable	NO_3^-	NO_2^-	NH_4^+	SO_4^{2-}	NH_3	Cl^-	F^-	pH
NO_3^-	—							
NO_2^-	-0.454	—						
NH_4^+	-0.437	0.983***	—					
SO_4^{2-}	0.398	0.098	0.058	—				
NH_3	-0.437	0.983***	1.000***	0.058	—			
Cl^-	-0.224	0.726	0.608	0.459	0.608	—		
F^-	-0.072	0.440	0.587	-0.259	0.587	-0.253	—	
pH	0.057	-0.174	-0.151	0.695	-0.151	-0.045	-0.136	—

* p < .05, ** p < .01, *** p < .001

4.5.3 Correlation between Nutrient levels of surface water

Pearson's correlational analysis between nutrient-nutrients parameters of surface water is presented in (Table: 4.12). Pearson's correlation observed to range from moderately negatively weak correlation to very strong positive correlation. Chloride ion showed a very strong positive correlation to NH_3, at (r =0.920), NH_4^+ at (r = 0.810) and SO_4^{2-} (r = 0.720) respectively. From (Table 4.12), a very strong to a perfect correlation was observed between parameters such as sulphates, ammonia and ammonium variables. Nitrate – nitrite parameters show similar trends (Table 4.12). These relationships might be influenced by various external factors such as environmental factors and sources of contamination. Pearson's correlation coefficient was observed to be statistically significant between (NH_3 and SO_4^{2-}) and (NH_3 - NH_4^+). pH - NO_2^- relationship was observed to be very strong negative correlation but no statistically difference was studied.

Table 4.11: Pearson's Correlations coefficient matrix nutrients

Variable	NO_2^-	F^-	Cl^-	pH	NH_4^+	SO_4^{2-}	NH_3	NO_3^-
NO_2^-	—							
F^-	-0.081	—						
Cl^-	0.008	0.061	—					
pH	-0.823	-0.420	0.254	—				
NH_4^+	0.012	-0.333	0.810	0.427	—			
SO_4^{2-}	0.120	-0.327	0.720	0.330	0.994 **	—		
NH_3	0.012	-0.333	0.920	0.427	1.000 ***	0.994 **	—	
NO_3^-	0.840	-0.395	-0.444	-0.657	0.288	-0.201	-0.288	—

* $p < .05$, ** $p < .01$, *** $p < .001$

4.5.4 Microbiological loads of the water samples

The bacteriological data determined from the sampled studied were computed prior to SPSS version 21 using analysis of variance. The quantitative microbiological analysis of sixteen (16) boreholes, seven well water (7), forty-six (46) tap water and four (4) surface water samples were analysed for both faecal and total coliforms.

Faecal Coliforms

Water sampled from the selected areas were found to contain faecal coliform bacteria. The average mean concentration recorded from the borehole water in the study areas was 14.44 ± 12.42 CFU/100 ml with a range of 0.00 – 200 CFU/ 100 ml for faecal coliforms. Surface water samples recorded a total mean concentration of 15.50 ± 8.03 CFU/100 ml with a range of 0.00 – 38.00 CFU/100 ml. Tap water faecal coliform mean concentration was recorded as 15.59 ± 5.65 CFU/100 ml (Figure 4.5), Well water from the sample site recorded the highest average mean of 26.86±21.55 CFU/100 ml and 0.00-153 CFU/100 ml. However, faecal coliforms concentrations from the study samples were all above WHO (2017) allowable limits of 0CFU/100 ml for drinking water. However, the lowest concentration was observed for borehole water samples was 14.44 ± 12.42 CFU/100 ml. This current study average mean concentration for faecal coliforms agrees well with Mohamud et al., (2022) and Amanning - Kwarteng (2016) studies on microbial analysis of drinking, from Kibi – Ghana.

Total Coliforms

The mean concentration of total coliforms bacteria recorded from the borehole water samples was 76.84 ± 22.12 CFU/100 ml with a range of 0.00- 343 CFU/100 ml. The total coliform observed mean for well water was 95.85 ± 41.05 CFU/100 ml. These concentrations obtained from borehole and well water samples (Figure 4.3) were found to be lower compared to (Mohamud, et al., 2022) studies from Daraweyne and Dabaraqas, Somaliland. The values were 8.8×10^3 cfu/100 ml for boreholes and 2.8×10^3 cfu/100 ml well water. However, this current study was higher than recommended WHO (2017) 0 cfu/100 ml. The mean value recorded from (Figure 4.5) of the total coliforms for borehole water samples was greater than WHO (2017) permissible limit of total coliform in drinking water 0 cfu/100 ml. Tap water samples average means concentration from the studies was determined to be 63.56 ± 10.88 CFU/100 ml. Total coliforms average concentration observed from surface water was 50.00 ± 32.93 CFU/100 ml.

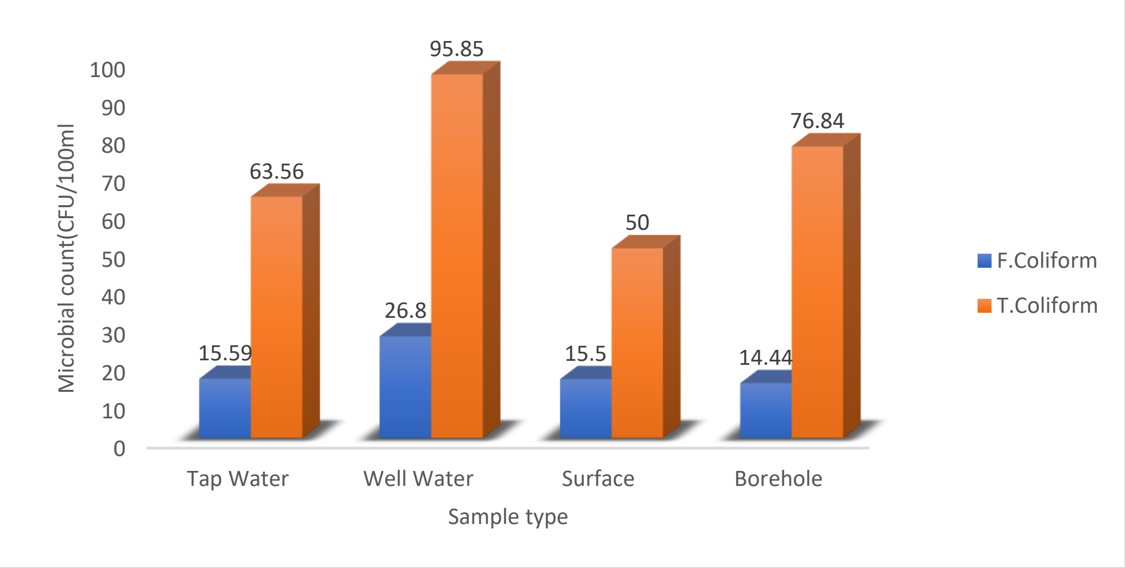

Figure 4.5: Levels of microbial loads from the water samples

4.5.5 Descriptive statistics of heavy metals

In this study, Jeffrey's Amazing Statistical Program (JASP) version 0.18.3 tool was used to analyse the heavy metals concentrations. The heavy metals analysed were Pb, As, Zn, Cu, and Cr in the 73 water samples that were collected from ten different communities during the studies. These include Esaase, Manhyia, Aboabo Tetekaaso, New Teteramu, Ahwerewa, Essouwin, Korko, Abodease, Mpatuamu and Manso Nkwanta in the Amansie West district in the Ashanti region of Ghana. In appendix A, descriptive statistics for the concentrations of potentially harmful elements in dust from seven distinct land uses are shown along with background values based on the global average shale value.

4.5.6 Mean concentrations arsenic from the study samples

Results from arsenic (As) metals detected above from the water samples were higher than WHO (2017) acceptable limits of 10 µg/L for drinking water. The mean concentration values recorded for arsenic were 12.348 µg/l for tap water, 12.313 µg/l for borehole, 29.250 µg/l for surface water and for 18.143 µg/l well water (Figure 4.6). Water samples study was observed to be lower than the average mean concentration of metal arsenic reported by Abdelhalima et al., (2022) as 37.47mg/l but observed to be higher than Regina et al, (2020) studies for both dry 3.21 µg/L and wet 3.66 µg/L seasons. It was also observed from the analysis that among the water samples studied, the highest average mean concentration value was observed from surface water 29.250 µg/l whiles the lowest average mean concentration was also recorded to be 12.313 µg/l for tap water. Arsenic in water ranged from 0.0 µg/L to 87 µg/L for tap water, 0.0 µg/L to 80 µg/L for borehole, 0.00 µg/L to 74 µg/L for well water and 0.00 µg/L to 61.0 µg/L respectively. The result findings agree well with (Charity et al., 2024) who's findings for arsenic ranged from 169.14 ± 2.18 µ g/L in the (Datano township) a study conducted at Amansie West District, Ghana.

The high level of arsenic concentration in groundwater was due to the presence of arsenopyrites and pyrites in the rock (geology) and effect of galamsey activities within the study areas. Water contaminated by heavy metal arsenic may have the potential to cause damage to organs in human body such as heart, liver, eye and nerves system (Das et al., 2012).

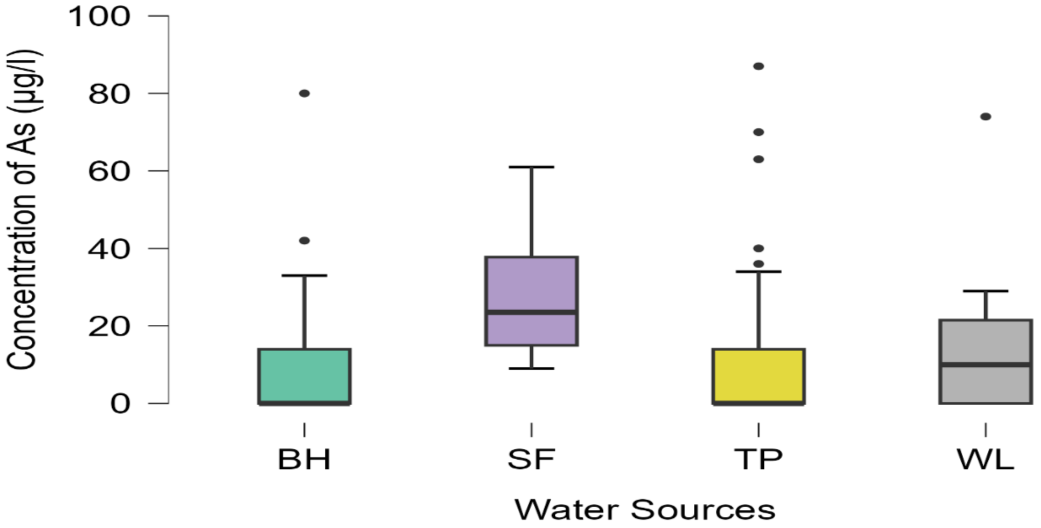

Figure 4.6. Metal concentrations of the water samples

4.5.6 Chromium metal concentrations from study samples

Chromium metal analyzed from the study samples were in order 47.66 µg/l, 61.37 µg/l, 247.7 µg/l and 343.30 µg/l for tap water, borehole water, well water and surface water respectively. The highest average mean concentration value for chromium metals were observed in surface water (Figure 4.7) whiles the lowest mean was obtained to be 47.66 µg/L for tap water. Well and borehole water also recorded a mean value of 247.7µg/L and 61.37 µg/L respectively. The mean values for chromium heavy metals ranged from 47.7 to 343.30µg/L. The mean concentrations of chromium metal recorded from the study samples were all found to be above the WHO (2017) permissible limit chromium for drinking water 50 µg/l. Well and borehole concentrations were also observed to be lower than that of EPA limit of (100 µg/l). Tap water average mean value was less than (WHO, 2017) background values for drinking water.

However, the study's findings were higher than as reported by Naveedullah, *et al.*, (2013) from Siling watershed for both Summer and winter as 44.71 µg/l and 30.50 µg/l respectively. The mean values obtained from the analysis agrees well with Akoto et al., (2014). Water contaminated with chromium metal could be a major source of health problem if used for agricultural like irrigation and household activities such as bathing and drinking purposes. Direct exposure to hexavalent chromium through ingestion in food, breathing or through water may results in skin irritation; induce respiratory cancer and high blood pressure (Puri et al., 2019). Health risk related to chromium are likely to develop in the study area.

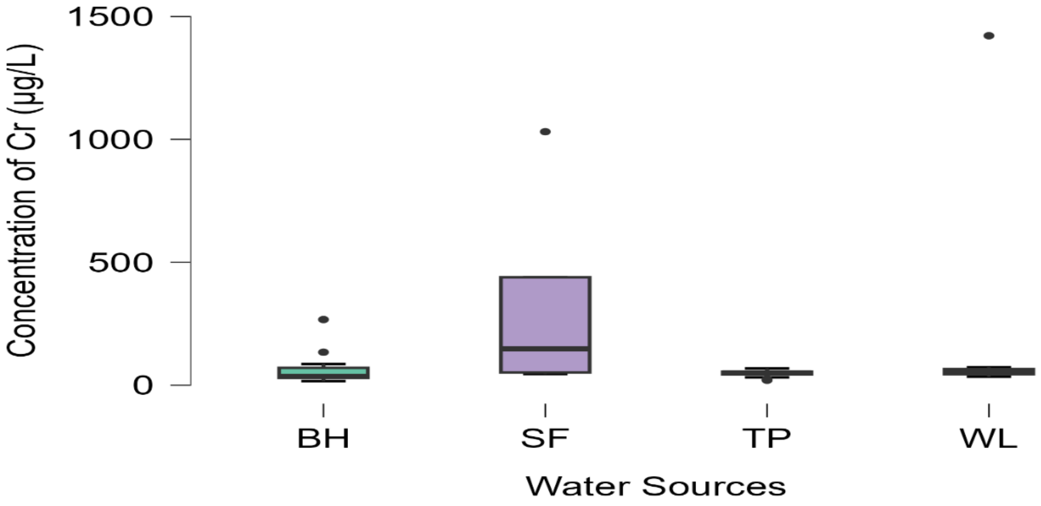

Figure 4.7 Metal concentrations of the water samples

4.5.7 Mean concentration of lead metal from the water samples

The results of water samples analyzed for heavy metal lead (Pb) showes a higher mean concentration for tap water as 457.50 µg/l. The well and borehole water showed relatively higher concentrations during the study as 352.29 µg/l and 303.80 µg/l respectively whiles the surface water recorded the lowest average mean concentration of 276.65 µg/l. Results obtained from the water sample studies had a mean value higher than reported by (Asamoah et al., 2016) as 65 µg/l, (Reginal et al., 2021) as 47.67 µg/l, (Charity et al., 2024) as 15.6 µg/l Amansie west, Ghana and 10.1µg/l by (Maryam et al.,

2021) Isfahan, Iran from (Figure 4.8). The results were also found to be higher than (WHO ,2017) maximum allowable limit (MAL) of (10) µg/l and (EPA, 2023) 15 µg/l of lead in drinking water. High level of lead in drinking water may cause health issues to human like, hormonal disease, cardiac, human carcinogenic, malformed nerve connections and induce blood illnesses (Brown et al., 2012).

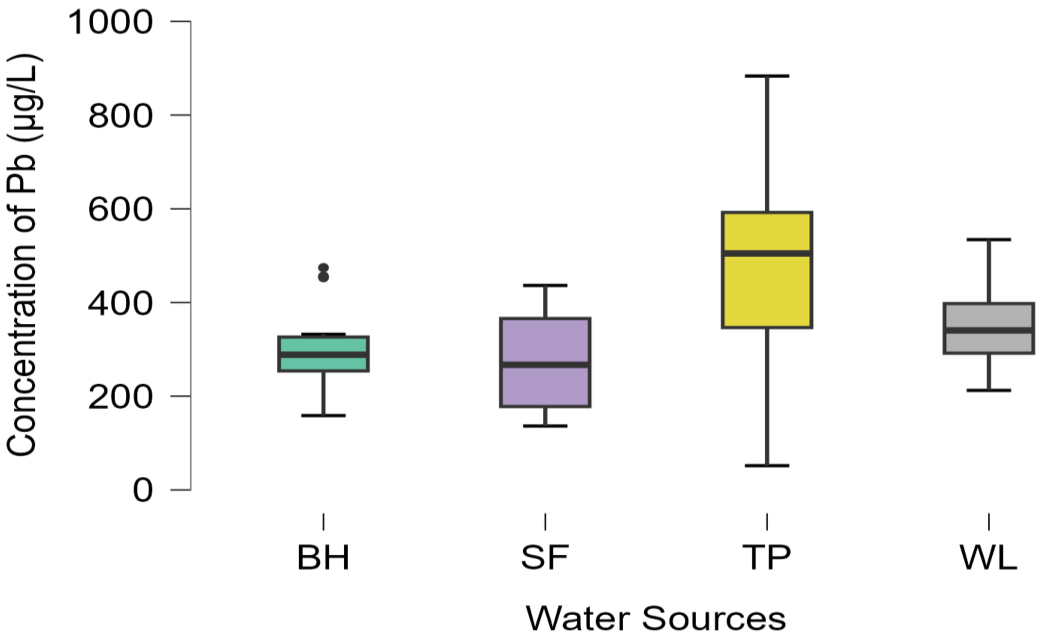

Figure 4.8: Lead metal concentrations of the water samples.

4.5.8 Concentration of zinc metal from the study samples

The level of zinc content (concentration) measured from the study samples well, tap water, borehole and surface water varies from 13.0 to 51.0, µg/l, 0.00 to 93.0 µg/l, 0.0 to 43.0µg/l and 14.0 to 33.00 µg/l respectively with their mean concentrations of 30.57, 19.47, 16.50 and 22.50 µg/l. The highest level of Zn content was recorded in well water as 30.57 µg/l (Figure 4.9) whiles the lowest mean concentrations was observed in borehole water 16.50 µg/l (Figure 4.9). The second highest mean value was studied in surface water to be 22.50 µg/l (Figure 4.9) as compared to the other water samples studied. The zinc means concentrations observed from all the water samples analysed were all lower than observed in Asamoah et al., (2016) 79.0 µg/l, but higher than as reported by (Abdullah et al., 2024) who's findings was recorded as 8.1 µg/l from El-Farafra Oasis, Egypt. Zinc concentration recorded from the study samples were all lower than the maximum allowable limits (MAL) of (3000) µg/l (WHO, 2017).

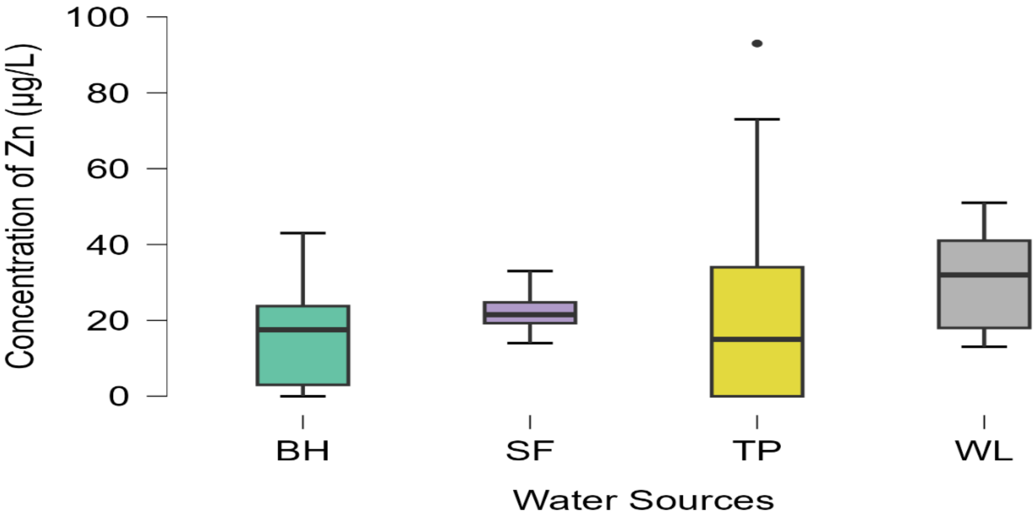

Figure: 4.9: Zinc metal concentrations of the water samples.

4.5.9 Concentration of copper metals from the study samples

Copper metal concentration determined from the samples ranged from 0.0 to 268 µg/l for tap water, 0.0 µg/l to 28.00 µg/l for well water, 1.00 to 112 µg/l for borehole and 4.00 to 16 µg/l for surface water. The lowest average mean concentration of copper metal was recorded in surface water as 7.00 µg/l (Figure 4.10) whiles the highest average mean concentration value was observed to be 73.1 µg/l in borehole water according to (Figure 4.10). Tap water and well water recorded an average mean of 13.14 µg/l and 4.571 µg/l. The amount of copper content detected from all the study sample were all within the permissible limit of drinking 2000 µg/l set up by (WHO, 2017).

The study findings for copper concentrations were also lower than as recorded by Akoto et al., (2014) who's finding ranged 3 to 308 µg/l. It was also observed to be lower than Amaning-Kwarteng, (2016) report on copper concentration for borehole 62 µg/l and 69 µg/l for hand-dug wells as well as Asamoah et al., (2014) with a mean concentration of 139 µg/l for surface water from the Amansie West, Ghana. Though, copper is considered as an essential element to plant as well as human. Red blood cell creation, maintenance of nervous as well as human immune system are as a result of copper functioning. However, excessive consumption of copper element may cause low crop productivity according to Wagh et al., (2018)

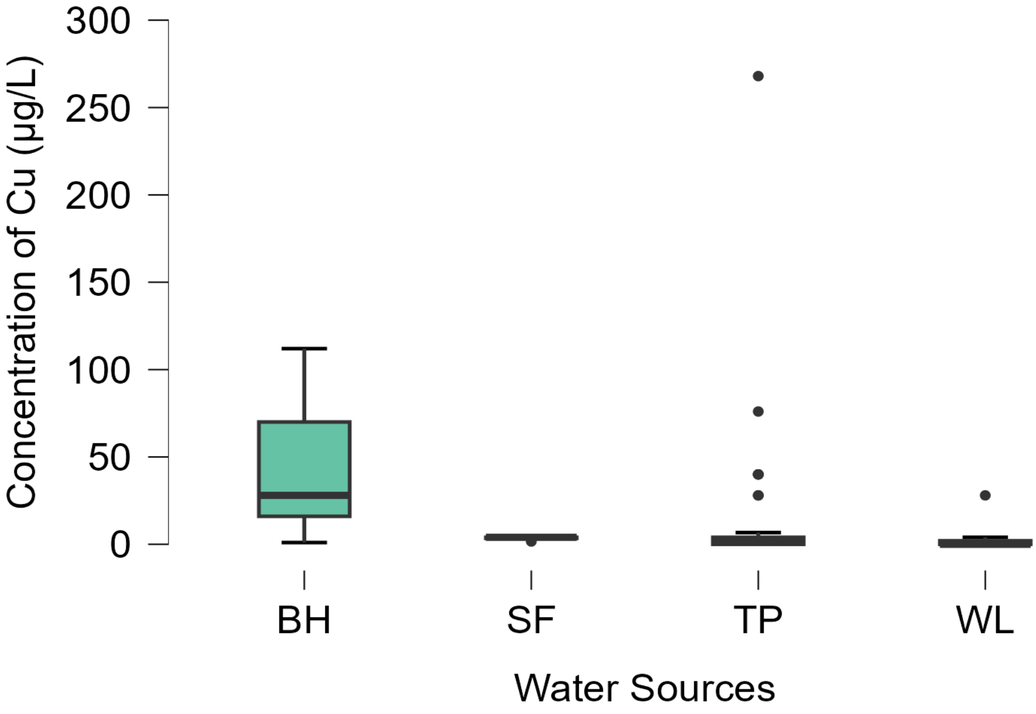

Figure 4.10: Copper metal concentrations of the study samples

4.5.10 Cadmium concentration

Cadmium concentrations detected from the water samples were all below the WHO (2017) maximum permissible limit of 3 µg/l for drinking water. Analysis obtained from the studies shows that, none of the study samples tested positive to cadmium metals from the water samples collected. This result indicates that, cadmium has no effects of causing any health problem to the water resource and may cause no harm to humans and aquatic organisms as well when consumed. However, water contaminated with high level of cadmium metal has the potential of causing cancer. and long -term exposure to very low concentration can results to health consequence on human renal, skeleton and lung functions Wu et al. (2016). High level of cadmium can also produce a variety of medical issues such as kidney disease, muscle pain, vomiting and liver damage (Alam et al., 2012).

4.6 Correlational Analysis of parameters

Pearson correlational analysis was employed to investigate the associations between the concentration of heavy metals components and other studied parameters from the water samples (Adusei-Mensah et al., 2019). According to the findings, Arsenic (As) exhibited very weak negative correlations with lead ($r = -0.28$), chromium ($r = -0.39$) and copper ($r = -0.13$) whiles a very weak positive correlation was observed between As- zinc ($r = 0.34$), EC - Pb ($r = 0.43$) and pH-TDS ($r = 0.38$). Strong positive correlation was observed between TDS – EC ($r =0.64$) meaning that their activities are likely to emanate from the same source. However, correlation was observed to be statistically significance at $p < 0.03$ for As-Zn and As- Cr ($p < 0.008$) but no observable significance was made among the other parameters studied. The ‘’weak’’ positive or negative correlations means that, an increase in one parameter concentration does not have any effect of the other parameter.

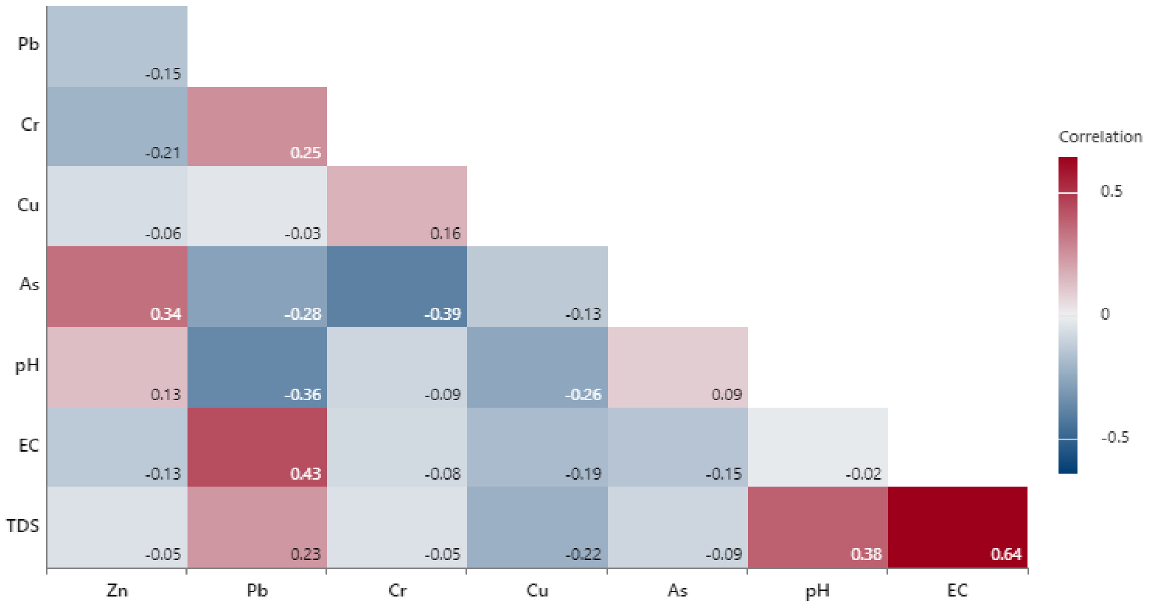

Figure 4.11: Pearson's correlations of the parameters for tap water

4.6.1 Relationship between heavy metals and physical parameters

Pearson's correlation was observed to varied from a "very weak negative correlation" to a "very strong positive correlation" whiles no correlation was also established among other parameters (Figure 4.12). The negative weak correlations to very strong negative correlation was also observed which ranged between -0.34 to -0.83 which was observed between Cu-As (r = -0.34) and (r = -0.83) in pH-Cr. This change concentration of one component does not affect the other parameter and their activities are not influence by the other. Positive moderate correlations to very strong positive was also observed. From (Figure 4.12), Pb shows a positive moderate to TDS and pH as (r = 0.48) and (r =0.58) respectively whiles pH-Zn shows similar results.

Very strong positive correlation between EC-Zn at (r = 0.71) and Cu-Pb (r = 0.80) was established. This means that EC and Zn may come from the same source as well as that of Cu-Pb. However, EC-Zn and As- pH did not show any sign of relationship among them (Figure 4.12) However, Pearson's correlation was observed to be statistically significant ($p < 0.03$) between Cu-Pb (Figure: 4.12). The very strong positive correlation indicates that, a rise in Cu metal concentrations will influence lead metal concentration positively.

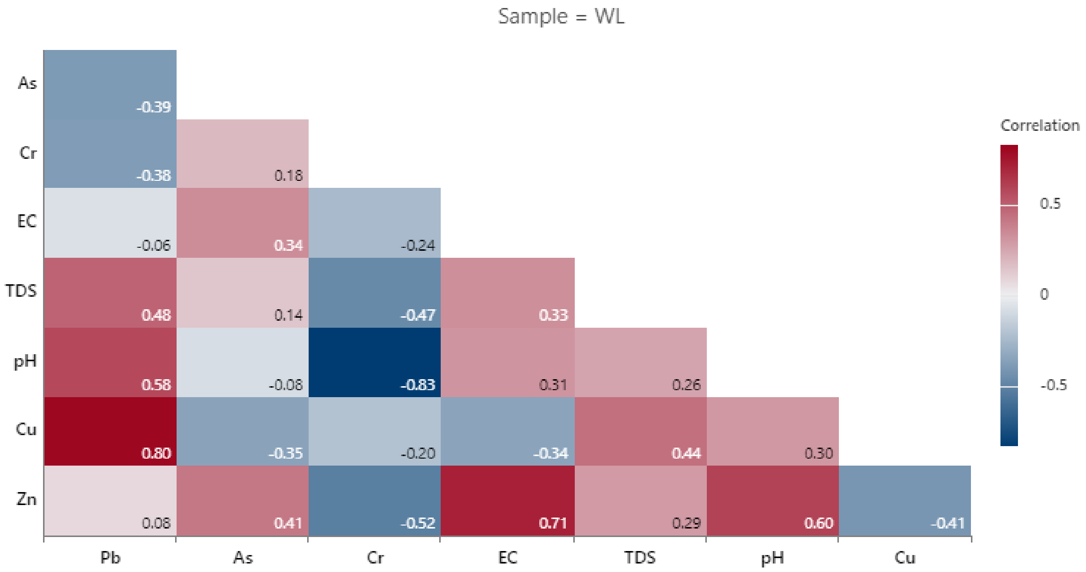

Figure 4.12: Pearson's correlations of the parameters for well water

4.6.2 Pearson's correlation analysis for borehole water

Among the parameters studied (Figure 4.13), copper (Cu) and zinc (Zn) showed a moderately weak positive correlation with lead (Pb) at r = 0.46 and 0.48 respectively (Figure 4.13). As, and Pb also shows similar trend to pH. No correlation was observed between As -EC, As-TDS, Cu-TDS and As-Cr. However, no statistical difference was established between the study parameters. This observation revealed that, a change in concentration of any of the observed parameters will not have any direct association (connection) with the other parameters.

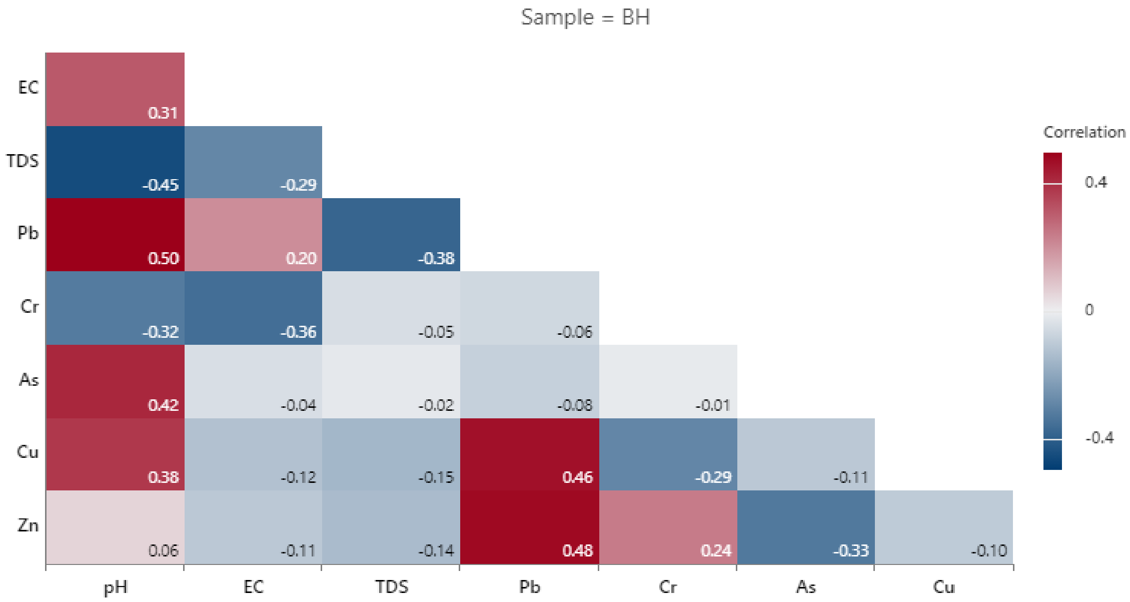

Figure 4.13: Pearson's correlations of the parameters for borehole water

4.6.3 Pearson's Correlation analysis for surface water

Pearson's correlation analysis was assessed to establish any relationship between the metals and other physical parameters studied. From (Figure 4.14), correlation ranged from positive moderate correlation to very strong positive correlation and negative weak correlation to strong negative correlation. EC and Zn shows moderate positive correlation to Pb as EC-Pb (r = 0.56) and Zn-Pb as (r = 0.60). This means that their activities are likely to come from the same source. As-TDS shows similar relationship as in the case of Zn-Pb as As-TDS (r = 0.60). Zn and pH show a very strong positive with EC, suggesting that an increase in Zn and pH concentrations can also causes a rise in electrical conductivity (Figure 4.14). From (Figure 4.14), it can also be observed that pH-Zn shows a very strong positive (r = 0.87), indicating that their activities may come from similar sources. EC, TDS, Cu and Zn exhibits strong negative correlation to Cr and As (Figure 4.14) whiles very strong negative correlation between Cu-Zn was observed (r = -0.93).

This shows that EC, TDS, Cu, Zn, Cr and As activities may originate from different sources. No statistically differences were observed among studied parameters.

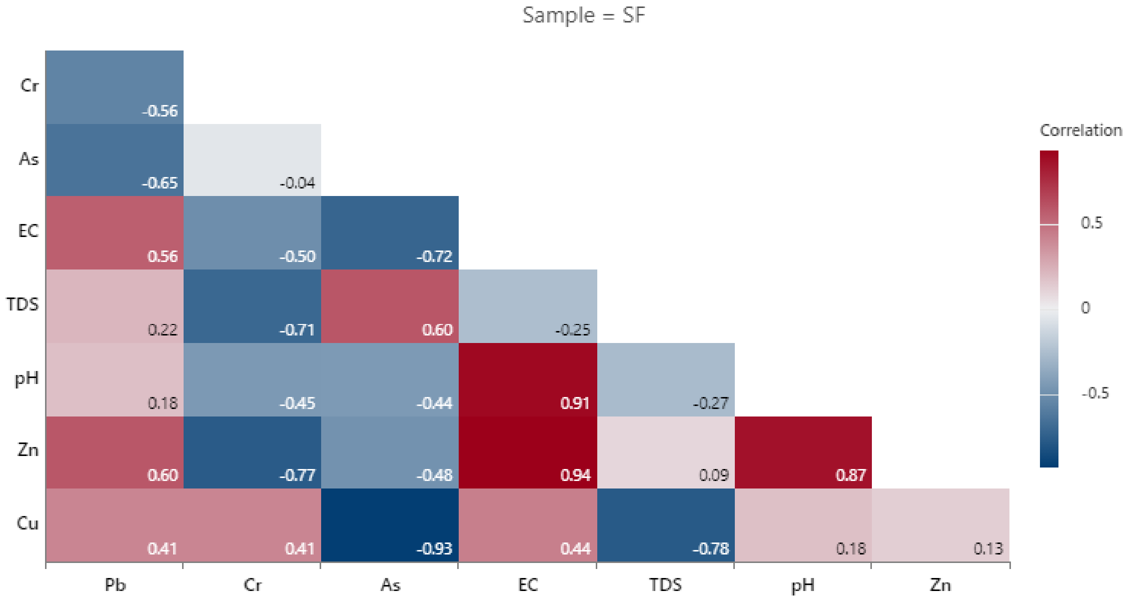

Figure 4.14: Pearson's Correlation analysis of surface water parameters

4.7 Heavy Metal Pollution Index (HPI)

Assessment of water contamination status were determined using the heavy metal pollution index. The average mean concentration of the studied elements was used to estimate the combined effect of each of the trace element and the overall water quality (Reza & Sing, 2010) as well as the suitability of the water for human consumption (Rizwan et al., 2011).

The overall average mean (HPI) results obtained from the study area for the various water samples were 243, 2694, 3265 and 2074 for borehole, well, tap and surface water respectively. The heavy metals pollution index (HPI) tool also revealed that, all the four different sampling source(s) is contaminated with some of the studied heavy metal especially lead which shows higher (HPI) values fall within the category of high heavy metal pollution as suggested by Sobhanardakania et al., (2016) in all the sampling water. The study also reveals HPI levels for individual trace element (lead metal) which was found to be higher than 100 in all the study samples. Tap water from the study area recorded the highest Heavy Metal Pollution Index (HPI) value as 3251 follows by well 2617.7, surface water 1965.8 and borehole 215.9. The high level of HPI for lead could be due to the use of copper pipe with lead solder (solder made or installed before the 1986s that contained high lead levels) and lead pipes materials, rampant artisanal and small -scale mining and industrial mining activities that may deals with soil containing lead products or materials such as batteries (World Health Organization, WHO (2010). Lead service line (pipe that runs from the water main to the home's that may contain lead), excessive use of leaded gasoline by the mining company as well as small scale miners, recent demolished of old buildings that may contain lead – based paint from the study area by the mining company. The high level of HPI in this current research agrees with the findings of Boateng et al., (2015) in Ejisu-Juaben Municipality in the Ashanti Region of Ghana, but disagrees with Eldaw et al., (2020), Kamal (2016), Mirza et al., (2020) and Maskooni et al., (2020) whose findings from North Kurdufan State, India, Bangladesh and southwest Iran respectively on underground water recorded HPI value of less than 100. The high level of lead metal within the study area can result to weight loss, fatigue, vomiting and seizures in children and adults may experience high blood pressure, joint and muscle pain, difficulty in memory or concentration and cause harm to reproductive health.

4.7.1 Principal Component Analyses (PCA) for metals

The principal component analysis for metal concentrations was performed to minimized the dimensionality of the dataset and identify underlying patterns among the water parameters studied (Charity et al., 2024). After the analysis of PCA revealed critical insights into the extent and pattern of contamination of heavy metals. For borehole water studied within the area, Amansie West District- Ghana, only one principal component was extracted at eigenvalue greater than 1. PC1 primarily captures the influence of Lead, Zinc and Copper, indicating that they are the major drivers of variations both surface and groundwater quality (Table 4.13). High scores on PC1 suggest that significant contamination by the various metals, especially Lead and Zinc. Principal component analysis (PC1) was able to explain 34.6% of variability. This means that heavy metal Lead, Zinc and Copper may come from the same possible sources. High lead of these metals pose severe health risk to the individuals within the study environment (Adusei-Mensah et al., 2019).

Table 4.12: Component Loadings of metal elements for borehole

Variables	PC1	Uniqueness
Pb	0.854	0.271
Zn	0.686	0.530
Cu	0.542	0.706
As	-0.484	0.766
Cr		0.997

Note. Applied rotation method is varimax.

Component Characteristics

	Unrotated solution			Rotated solution		
	Eigenvalue	Proportion var.	Cumulative	SumSq. Loadings	Proportion var.	Cumulative
Component 1	1.730	0.346	0.346	1.730	0.346	0.346

4.7.2 Principal Component Analysis for Tap Water

Principal components analysis (PCA) for tap water was extracted to indicate the possible sources of tap water contamination. At an eigenvalue greater than 1 (Table 4.14), metals such as chromium and lead was found to originate from the same sources whiles arsenic and zinc metals may be released from anthropogenic activities like mining, atmospheric deposition, domestic and municipal sewage waste (Boateng et al., 2019). The PC1 was able to explain only 37.3% of the total variance. High chromium and lead levels in the study samples from the study area could be attributed to industrial activities that has taken over in recent years due to the ongoing mining activities.

Table 4.13: Component Loadings of metal elements for tap water

Variables	PC1	Uniqueness
As	**-0.780**	**0.391**
Cr	**0.714**	**0.490**
Zn	**-0.593**	**0.648**
Pb	**0.568**	**0.677**
Cu		**0.927**

Note. **Applied rotation method is varimax.**

Component Characteristics

	Unrotated solution			Rotated solution		
	Eigenvalue	Proportion var.	Cumulative	SumSq. Loadings	Proportion var.	Cumulative
Component 1	**1.866**	**0.373**	**0.373**	**1.866**	**0.373**	**0.373**

4.7.3 Principal Component Analysis for Well Water

Well water samples analyzed for PCA had a strong positive loading copper (0.900) and lead (0.875) and negative loading on arsenic (-0.669) accounting for about 45.2% of the total variance. This positive and negative loading values was obtained at an eigenvalue greater than 1. The strong positive loading between copper and lead indicate that their activities may come from common sources whiles the negative loading value for arsenic suggest that its activities may emerge from different source (Afitiri, 2019).

4.7.4 Principal Component Analysis for Surface Water

Table: 4.14. Component Loadings metal element for well water

Variables	PC1	Uniqueness
Cu	0.900	0.190
Pb	0.875	0.234
As	-0.669	0.552
Cr		0.852
Zn		0.910

Note. Applied rotation method is varimax.

Component Characteristics

	Unrotated solution			Rotated solution		
	Eigenvalue	Proportion var.	Cumulative	SumSq. Loadings	Proportion var.	Cumulative
Component 1	2.261	0.452	0.452	2.261	0.452	0.452

Heavy metal elements, Lead, arsenic and zinc dominated in PC1 from (Table 4.17), suggesting that their influenced are the major contributing factors surface and groundwater contamination (Charity et al., 2024). The positive coefficient component loading factors recorded from surface water PCA were (0.774), (0.646) and (0.547) for Zn, As and Pb respectively. Chromium metal only shows negative correlation coefficient component loading factor from surface water. This value revealed that chromium metal released into surface water bodies may be due to the ongoing wedeling activities within the study area. However, only 39.7% was explained by PC1.

Table 4.15: Component Loadings factors for surface water

Variables	PC1	Uniqueness
Cr	-0.785	0.384
Zn	0.774	0.401
As	0.646	0.582
Pb	0.547	0.701
Cu		0.950

Note. Applied rotation method is varimax.

Component Characteristics

	Unrotated solution			Rotated solution		
	Eigenvalue	**Proportion var.**	**Cumulative**	**SumSq. Loadings**	**Proportion var.**	**Cumulative**
Component 1	1.983	0.397	0.397	1.983	0.397	0.397

4.8 Health Risk Assessment

4.8.1 Hazard Index (HI) and Hazard quotient (HQ)

Non- carcinogenic risk assessment was determined from the various sample water studied. Hazard quotient was estimated by dividing their reference dose values (RfD) of the study elements by their average daily intake. The hazard index (HI) values recorded from As, Cu, Cr, Pb and Zn heavy metal was used for assessment of total health risk (Sultana et al., 2017). These values were estimated for the different age groups (adults and children). The average risk means of Hazard index (HI) calculated each heavy metal was summed up and expressed as the hazard index (HI) according to Khalili et al., (2019).

Hazard index (HI) values recorded from groundwater (borehole and tap water) consumed by adult and children were all less than 1 (Figure 4.15). The result indicates that, adult and children exposure to borehole and tap water had insignificant non-carcinogenic health risk to human health as the values recorded from the study samples were all below

WHO hazard index threshold of 1 (Nyantakyi et al., 2024). The Hazard index (HI) values from the entire research region demonstrate that, the water resources have a non-carcinogenic risk related to the water intake.

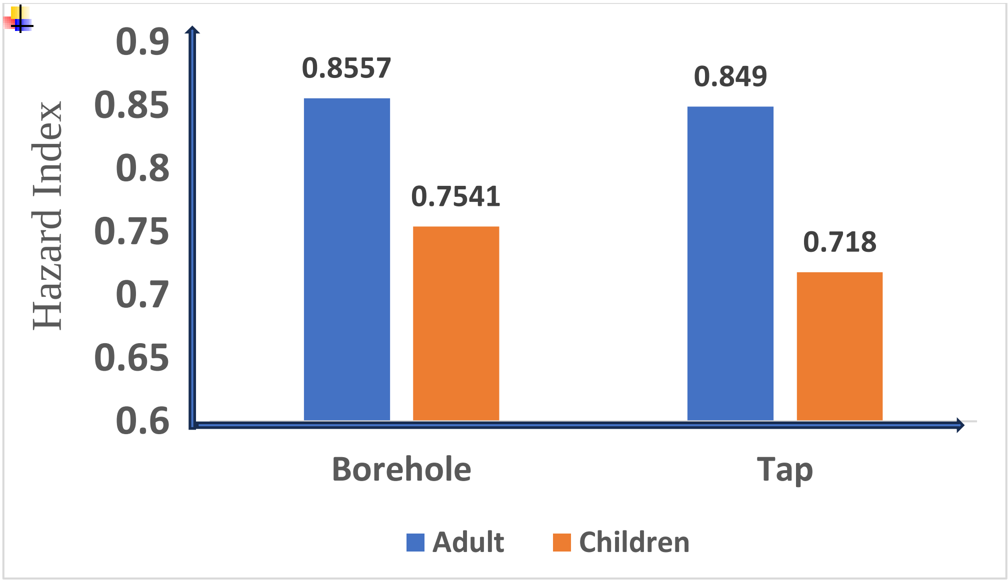

Figure 4.15: Human health risk for non-carcinogenic

4.8.2 Carcinogenic risk assessment of heavy metals

This current research studies the carcinogenic risk assessment for chromium, lead and arsenic metals. Cancer risk for Cr, Pb and As from groundwater (tap and boreholes) water samples. Prolong exposure to these heavy metals have the potential to induce cancer related diseases to the individual (Zakir et al., 2020). The average chronic daily intake from (Eq.11) were used to estimate the total exposure of the indigens using the heavy metals Cr, Pb and As for carcinogens (Khalili, et al., 2019).

The cancer risk assessed from tap for adult and children for heavy metal As, and chromium were all observed to be greater than the cancer risk value of $1.0x10^{-4}$ suggesting that children and adult will develop cancer risk diseases (Myers et al., 2023). Lead cancer risk value estimated for lead metal from tap was within cancer risk threshold $1.0x10^{-4}$.

However, persistent high level of lead concentration in drinking water can result to of health-related issues. This study findings are consistent with previous studies conducted by (Tay et al., 2019).

Table 4. 16 Cancer risk assessment for tap water

Element	As	Cr	Pb	WHO (2017)
Adults	3.6×10^{-2}	4.8×10^{-2}	3×10^{-4}	1×10^{-4}
Children	4.4×10^{-2}	4.6×10^{-2}	7×10^{-4}	1×10^{-4}

Heavy metals such as As, Cr and Pb associated with cancer risk diseases according to Nyantakyi et al., (2019) was evaluated from consumption of borehole water (Table 4.19). Children show higher level of cancer risk than adult for arsenic exposure and lead. This could be due ongoing organ development in children than adult (Adusei-Mensah et al., 2019). High level of chromium exposure to was observed in adult than children and this could be attributed to the ongoing wedeling of metals by the adult within the area.

This means that, the heavy metals As, Cr and Pb study may have the potential to pose cancer risk related diseases to human.

Table 4.17: Cancer risk assessment for borehole water

Element	As	Cr	Pb	WHO (2017)
Adults	3.9×10^{-2}	1×10^{-3}	3×10^{-6}	1×10^{-4}
Children	4.9×10^{-2}	7×10^{-4}	4.6×10^{-3}	1×10^{-4}

4.9 Canadian Council of Minister of Environment Water Quality Index

To estimate the water quality from the study area, CCME-WQI was used. pH, EC, NO_3, NO_2^- NH_3, NH_4, SO_4^{2-}, F^-, Cl^-, TDS, Turbidity and heavy metals analyzed were computed in the CCME WQI equations. The overall CCME - WQI values determined from the water sampling sources (well water, surface water, borehole and tap water) from the selected study area are showed in (Table 4.19). The table showed that the total number of samples (variables) studied were eleven (11) and the overall total numbers of the test involved were 44.

The number of failed parameters (variables) from all the four sampling water sources, well water, surface water, borehole and tap water which does not meeting the standard limits (objectives) were, 2 for well water (EC and Turbidity), 2 for surface water (turbidity and ammonium), 1 for borehole (EC) and tap water samples recorded 2 of the parameters (EC and ammonia) are the main parameters responsible for the effect of the quality of the water. Tap water samples recorded the maximum failed variable for EC (551) and borehole water recording the minimum failure variable for EC.

The water samples sources which exceeded the turbidity limit during the study were well and surface water (20.9) and (116) respectively. However, ammonia and ammonium parameters were also exceeded their objective values in tap water and borehole (19.9) and 46.6 respectively. This could be due to the use of excessive agro - chemicals by the farmer within the study area that maybe seps into the leakage pipes that is connected from the main water source to household. The total number of unsuccessful (failed) test that deviated from their standard (objective) limits were seven out of the total 44 tests being assessed from all the four water sampling type. In all the water sampling sources, the highest nse value was observed in surface water (0.51) with a corresponding excursion value of (22.53). This indicates clearly that; turbidity and ammonium are the main contributors' factors to surface water contamination as compared to the other physicochemical parameters.

The calculated values for F1, F2 and F3 in all the sampling water sources were, 18.18, 15.91 and 7.344 for well water for F1, F2 and F3 respectively. Surface water F1, F2 and F3 values was observed to be 18.18, 15.91and 33.68 in that order whiles borehole and tap water F1, F2 and F3 values was calculated to be (9.09, 15.91 and 0. 6098) boreholes and (18.18, 15.91 and 0.851) for tap water respectively. The determination of the CCME WQI in the water quality assessment showed that, the water samples collected from the selected study areas were between the index range of CCME WQI (0 – 100). The CCME WQI recorded for well water was (85.42) and considered good according to CCME WQI. Surface water showed a fair rank with CCME WQI of (68.07) from (Table: 4.8.1). This fair nature of the surface water is usually protected but sometimes threatened from the desirable level due to the small- and large-scale mining as well as the application of excessive fertilizers used by the farmers. Whiles borehole and tap water showed CCME WQI of 89.41 and 86.04 were classified as good (Table: 4.20) respectively.

Table 4.18: Water quality status from the study area

SAMPLE TYPE	CCME-WQI RANGE	VALUE OBTAINED	INTERPRETATIONS
Well	80 - 94	85.42	Good
Surface	60 - 79	68.07	Fair
Borehole	80 - 94	89.41	Good
Tap	80 - 94	86.04	Good

CHAPTER FIVE

SUMMARY OF FINDINGS, RECOMMENDATIONS, AND CONCLUSION

5.1 Findings from chemical parameters

To compare the results with the World Health Organization's (WHO, 2017) and Ghana Water Company Limited's (GWCL) recommended values for drinking water, the physical characteristics of each water sample were evaluated using a number of metrics. A variety of physical characteristics are used to determine the quality of water. In all four of the water resources under investigation, electrical conductivity (EC) in borehole water samples was found to be more than the WHO drinking water permitted limits of 523.80 mg/l. Except for well water, tap water and surface water which recorded a mean concentration value to be below WHO 400 mg/l limits. Total dissolved solids (TDS) recorded an average mean concentration value from three samples sources which ranged from 156.0 to 272.0 mg/l. With surface water recording the highest value 272.0 mg/l and surface water recording the least value of 97.7 mg/l.

Water clarity, measured by turbidity, was found to be higher than the WHO's (2017) recommended drinking water limit of 5 NTU for both surface and well water, but borehole and tap water had lower turbidity concentrations of 0.66 and 3.00 NTU, respectively. All physical parameters, including temperature and results, fell within the WHO water standards. Upon comparison of all the nutrient characteristics examined, it was found that none of them exceeded the corresponding drinking water regulations.

According to World Health Organization (WHO) drinking water guidelines, all of the nutrient characteristics fall within the range that Ghana Water Company Limited (GWCL) had advised. All of the sample water had pH average mean values between 6.27

and 6.80, which were found to be somewhat acidic. However, the pH 6.80 of the surface water had the highest concentration value. The amounts of nitrate and nitrite showed a statistically significant connection with pH.

Sulphate and ammonia levels were found to be greater in borehole water than in the other parameters that were examined from the borehole water. In surface water bodies, the values of ammonium and chloride ions were higher than the other parameters, however the nitrate and fluoride ions from tap water were found to be equally higher than the other chemical qualities. However, it was found that the chemical attributes SO_4^{2-}- NH_4^+, NH_3-NH_4^+, NH_3- F^-, and F^-- SO_4^{2-} all had a positive correlation that was statistically significant (Table 6). The WHO (2017) recommended limit for drinking water was found to be higher than the ammonia and ammonium values.

After analysis, it was discovered that every water sample included metals like lead, copper, zinc, and chromium except cadmium metal. Lead metal levels in drinking water were found to be greater above the WHO acceptable limit. It was shown that Pearson's correlation ranged from a very strong negative correlation, moderately positive correlation to a very strong positive correlation between Cu-Zn (r=-0.93), Pb-EC (r=0.56), Pb-Zn (r=0.60) and Zn-pH (r=0.80) from surface water. The samples of tap water that included heavy metals showed a very weak negative correlation to strong positive connection (Figure: 4.9). There was a mild positive link between lead, copper and zinc (Figure 4.9) but no correlation between As-EC, As-TDS, Cu-TDS and As-Cr for borehole water.

While there was somewhat moderately positive connection between Pb, TDS and pH, a very strong positive correlation between EC-Zn (r=0.71) and Cu-Pb (r= 0.80) was also determined from well water. Cu-As (r=-0.34) shows very weak negative correlation whiles Cr-Ph shows a very strong negative correlation (r= -0.83). However, correlation between the studied parameters identified from well water was statistically significant.

For tap water, surface water, well water and borehole water, one primary component (PC1) was extracted with an eigenvalue higher than 1.

Lead, Zinc and copper were the most prevalent heavy metals in borehole water sources, accounting for 34.6% of the total variance indicating that, their activities may produce from the same source. However, arsenic heavy metal had a coefficient value of (-0.484) which suggest that As level from the borehole may be release by different activities. The total variance explained by PC1 from tap water was 37.3% with coefficients of 0.714 for Cr metal, 0.568 for Pb metal, -0.780 for As and -0.593 for Zn metal. Cr and Pb values indicate that, their activities may come from common source such as anthropogenic activities. At an eigenvalue greater than 1, copper, lead and arsenic heavy metals was found to be dominant in well water representing 45.2% of the total variance (Table 4.2). The values obtained revealed that, copper and lead are likely to originate from similar sources whiles arsenic may come from different source.

From (Table 4.2), the component loading factors for surface water were Cr (-0.785), Zn (0.774), As (0.646) and Pb (0.547). Zn, As and Pb from the component loading factor (Table 4.6) were found to be dominant and may come from similar sources. However, chromium metal with coefficient of (-0.785) suggest that its activity may come from different point source. The total variance obtained was found to be 39.7%. Hazard index (HI) of the heavy metals study indicated a non- carcinogenic risk. The heavy metals Pb, Cr and As shows a higher chance of cancer related diseases.

5.2 Microbial Loads results.

The lowest fecal coliform count of all the bacterial subclassifications was 14.44 cfu/100 ml in borehole water, whereas the highest fecal coliform count was 26.50 cfu/100 ml in well water. Comparing the bacteriological levels of the water samples, however, revealed that every fecal coliform found in the sampling water was higher above the advised threshold for drinking water. Faecal coliforms and total coliforms displayed comparable patterns. Out of all the water resources, well water had the highest mean count of coliforms (95.85 cfu/100 ml), whereas surface water had the lowest overall count (50.0 cfu/100 ml). The World Health Organization's (WHO, 2017) recommended mean count of 0.0/100 ml for total coliforms in drinking water was not found in any of the water samples.

5.3 Conclusion

- Physicochemical quality of the water was judged safe because their concentrations were below WHO permissible limits of drinking water.
- Microbial load was above WHO permissible limit of drinking water.
- Whereas Cu and Zn concentrations were within WHO limits of drinking, Pb, Cr, and As exceeded, indicating that there could be health risk with Pb, Cr, and As when the water is consumed.
- There was no significant risk of non- carcinogenic health effect because the hazard index (HI) values were less than < 1 indicating a non - carcinogenic risks.
- Pb, Cr, and As are likely to pose cancer risk because the cancer risk index exceeded the recommended threshold value of 10^{-4}.

5.4 Recommendations

- Artisanal and small-scale gold mining activities within the area should be regulate by the District Assembly and the Environmental Protection Agency
- The District Assembly should ensure proper disposal of waste
- Residents should treat their water before using it

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APPENDICES

Descriptive Statistics

	Zn			
	Borehole	**Hand dug-well**	**Tap water**	**Surface**
Valid	16	7	46	4
Mean	16.500	30.570	19.470	22.500
Std. Deviation	13.466	12.473	21.577	11.676
Minimum	0.000	13.000	0.000	21.000
Maximum	43.000	42.000	93.000	46.000

Descriptive Statistics

	Cu			
	Borehole	**Hand dug-well**	**Tap water**	**Surface**
Valid	16	7	46	4
Mean	73.100	4.571	13.140	7.000
Std. Deviation	12.757	10.254	41.224	7.486
Minimum	52.000	0.000	0.000	1.600
Maximum	94.000	28.000	268.000	18.000

Descriptive Statistics

	Cr			
	Borehole	**Hand dug-well**	**Tap water**	**Surface**
Valid	16	7	46	4
Mean	61.37	247.70	47.66	343.30
Std. Deviation	62.966	16.096	10.279	106.435
Minimum	17.000	225.000	20.200	224.500
Maximum	267.100	273.100	68.100	432.000

Descriptive Statistics

	Pb			
	Borehole	**Hand dug-well**	**Tap water**	**Surface**
Valid	16	7	46	4
Mean	303.801	325.291	457.506	276.650
Std. Deviation	91.299	136.516	207.241	101.394
Minimum	158.600	136.300	51.700	191.700
Maximum	474.300	534.200	883.400	436.400

Descriptive Statistics

	As			
	Borehole	**Hand dug-well**	**Surface water**	**Tap water**
Valid	16	7	4	46
Mean	12.313	18.143	29.250	12.348
Std. Deviation	22.255	11.000	24.180	22.419
Minimum	0.000	0.000	9.000	0.000
Maximum	80.000	29.000	61.000	87.000