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EVALUATION OF THE HEAVY METAL POLLUTION INDEX OF GROUNDWATER IN EFFUTU MUNICIPALITY, GHANA

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EVALUATION OF THE HEAVY METAL POLLUTION INDEX OF GROUNDWATER IN EFFUTU MUNICIPALITY, GHANA.

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DECLARATION

CANDIDATES DECLARATION

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

Signature: ……………………..…………………

Date: ………………………………………...……

SUPERVISOR'S DECLARATION

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

Supervisor's Name: DR. ARKOFUL SAM

Signature: ……………………..…………………

Date: ………………………………………...……

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DEDICATION

First and foremost, I dedicate this thesis to the Almighty God for having paved a way for my academic pursuits. Finally, to my parents, Mr. Maxwell Ekow Quansah and Mrs. Theresa Efua Quansah and to my Siblings.

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ABSTRACT

An assessment of the quality of groundwater in the Effutu Municipality was carried out at six sampling sites in some selected communities in the Effutu Municipality. Samples were collected from November 2020 to May 2021. Analysed various physicochemical parameters including Electrical conductivity, Temperature, pH, Chemical Oxygen Demand (COD). Heavy metals analysed are Cobalt, Zinc, Cadmium, Lead and Iron. Concentrations of the five (5) heavy metals: Cobalt, Zinc, Cadmium, Lead and Iron were determined using Flame Atomic Absorption Spectrophotometer using an air-acetylene oxidizing flame and used to evaluate the heavy metal pollution index (HPI) using two barreled approaches. In the first instance heavy metals that were not detected by the instrument were assigned zero concentration. In the second instance, these heavy metals were assigned the limit of detection from the instrument as if they were present to that extent. The result of the study revealed that, the mean values of the pH and COD of the groundwater at the sampling sites were within the GEPA and WHO permissible limit. However, the Electrical Conductivity exceeds the GEPA and WHO permissible limit at some of the selected groundwater sampling sites. The two HPI computations for not detected (ND) for metals not detected and for the limit of detection of the instrument for metals not detected for the dry season were 0.887 and 0.880 and for the raining season were 0.832 and 0.832. The two approaches used in the computation of HPI for the groundwater based on the mean concentrations of the selected heavy metals and the limit of detection from the instrument gave similar results. The near sameness of these values indicates that both approaches could be used to calculate the HPI. There was a significant correlation ($P<0.01$) between the two HPI's. The study clearly indicates that, the selected groundwater sites in the Effutu Municipality monitored to be free from the selected heavy metals and can therefore be used for human consumption.

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CHAPTER ONE

INTRODUCTION

1.0 Overview

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

1.1 Background to the Study

The importance to balance the dependence of groundwater utilization against the increasing global pollution threats from urbanization and agricultural activities facilitated this research work. Groundwater exploitation for water supply needs of many rural communities in Africa has been on the increase in the last decade, Ghana is of no exception. Groundwater continues to play an important role in the socioeconomic development of the country. Water management being the major developmental challenge as the effect of human activities has resulted in the dwindling of freshwater resources, increased pollution load, health and transportation problems and reduced ecosystem resilience which pose significant threat to sustainable development (Roodsbroeck et al. 2006).

The measurement of the levels of heavy metals in ground water enables scientist to predict the quality of the ground water. The levels of these parameters in water must fall within an acceptable reference range prescribed by World Health Organization (WHO) to indicate good water quality. In Ghana, potable water parameters must comply with the Ghana Standard Authority (GSA) permissible values which are adopted from the World Health Organizations (WHO) Guidelines for Drinking Water Quality (Danso-Boateng & Frimpong,2013). Groundwater serves

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as a drinking water for majority of people living in Winneba. The groundwater component of the water cycle maintains soil moisture, stream flow and wetlands, as well as being the source of drinking water, agricultural and industrial supplies. Groundwater is relatively more reliable during drought, especially because of its large storage, wide spread occurrence and protection from evapotranspiration and these good qualities make its development relatively inexpensive.

Drinking water that is provided by rivers, lakes and streams for most communities had become polluted because of increasing discharge of untreated industrial waste, run off from agriculture fields which contain residues of pesticides and fertilizers as well as increasing human population and activities. Through human activities like illegal mining, most rivers in Ghana have varied pollutants which have resulted in poor water quality. Hussain et al(2013) reported in their studies that physico-chemical characteristics of water quality are deteriorating day by day owing to anthropogenic activities.

1.2 Statement of the Problem

Winneba is the capital city of Effutu Municipality. According to the 2014 Ghana Statistical Service (GSS) report on population and housing census, the city is inhabited by 68,592 people from all walks of life. The presence of the Winneba campus of the University of Education, Winneba (UEW) in the city attracts large population of students to stay and study in Winneba. Other facilities that attract people to increase the population of the town include, the Winneba Nursing Training College, three (3) Senior High Schools, beaches, lagoons and hospitals. The town is a major tourist site because of its rich hunting festival called Aboakyir and its nice beaches. As the population of the town is increased, there are lots of vehicles and also mechanical shops around. These vehicles use fuel which contains heavy metals and

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also the heavy metals seep into the groundwater by indiscriminate disposal of effluents from these mechanical shops.

One of the cardinal principles of Ghana water policy formulated in June 2007 states that people without prejudice have the right to safe and adequate supply of water to meet their fundamental human needs. The importance of this principle accounts for why it is enunciated in the Millennium Development Goals (MDGs), Ghana Poverty Reduction Strategy (GPRS), and the "Africa water Vision" of the New Partnership for Africa's Development (NEPAD). Unfortunately, reports from certain areas in Ghana indicate that people do not consume safe water (Ghana Water and Sanitation Sector Performance Report. 2010).

Comparatively, landfills in Effutu Municipality are mostly in the form of uncontrolled dumps, where solid waste is filled up with little or no regard to the environment. Solid wastes deposited in landfills decompose and could pollute underlying groundwater through the infiltration of leachates. Since most of the surface waters are polluted by the anthropogenic activities of humans, majority of these people rely on groundwater by drilling boreholes and hand dug wells for their sustenance. Winneba is one of such urban areas that still has some deficit with respect to water coverage and so rely solely on hand dug wells and boreholes. The present study is carried out to evaluate the Heavy Metal Pollution index of some selected heavy metals and some selected physicochemical parameters of groundwater quality and its suitability for domestic purposes in the Effutu Municipality. The Report (2010) from Ghana Water and Sanitation Sector Performance, remarked that the quality of water resource in Ghana is fairly good but they experience pollution at varied levels with water bodies close to mining areas experiencing the highest.

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1.3 Purpose of the Research

The purpose of this study is to evaluate the heavy metal pollution index of groundwater in Winneba Municipality.

1.4 Objectives of the Study

The objectives of this study were to:

- Assess some selected physicochemical parameters in ground water.
- Assess the concentration of some selected heavy metals in the ground water.
- Evaluate the difference in concentration of some selected heavy metals at two different seasons.
- Use heavy metal pollution index (HPI) to determine the suitability level of the ground water for drinking.

1.5 Research Hypotheses

The following research hypotheses are formulated for testing at $p \leq 0.05$ statistically significant level;

Null Hypothesis: H_O: There is no statistically significant difference between the means of HPI for the dry season and the raining season (using not detected (ND) for metals not detected and the limit of detection of the instrument for metals not detected)

$HPI_A = HPI_B = HPI_1 = HPI_2$

Alternate Hypothesis: H_A: There is a statistically significant difference between the means of HPI for the dry season and the raining season (using not detected(ND) for metals not detected and the limit of detection of the instrument for metals not detected)

$HPI_A \neq HPI_B \neq HPI_1 \neq HPI_2$

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1.6 Justification of the Research

Water is an important need of mankind and so the quality of water used by mankind should be given much attention so as to improve the lives of many who use it. Because of the rapid population growth in Winneba Municipality, it is imperative that the investigation of the levels of pollution of the ground water in Winneba Municipality should be carried out regularly. The aim of the study is to provide reliable information for decision and policy makers in Ghana to design measures to address the numerous water quality issues that present potential effects on human health.

1.7 Significance of the Study

The outcome of the study will provide credible and useful information for policy makers to develop proper policies towards the development of water resources in Ghana. The research will inform the Effutu Municipal Assembly about the quality of water some people use and assist in the provision of potable water in the Effutu Municipality.

1.8 Limitations of the Study

There are several metals and components of water, but this study is limited to some selected metals due to cost and scarcity of materials.

1.9 Delimitation of the Study

Though there are several sources of groundwater in Ghana and the Central Region, this study is focused on groundwater sources from some selected areas in Effutu Municipality in the Central Region of Ghana.

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1.10 Operational Definition of Terms

AAS	Atomic Absorption Spectrophotometer
GEPA	Ghana Environmental Protection Agency
WHO	World Health Organization
ATSDR	Agency for Toxic Substance and Disease Registry
USEPA	United State Environmental Protection Agency
APHA	American Public Health Association
EPA	Environmental Protection Agency
GPRS	Ghana Poverty Reduction Strategy
MDGs	Millennium Development Goals
NEPAD	New Partnership for African's Development
CNS	Central Nervous System
GSS	Ghana Statistical Service

1.11 Organisation of the Study

This research report is presented in five chapters. The first chapter deals with the background to the study, statement of the problem, the purpose of the study, research objectives. It further spells out the significance of the study, delimitation, limitations, operational definition of terms and organization of the study. The chapter two reviewed relevant literature to the study while chapter three deals with the methodology. This comprises the research design, population, sample and sampling techniques, and instrumentation. It also discusses the reliability and validity of the instruments, data collection procedure, method of data analyses. Chapter four, deals with results and discussions of findings. Lastly, the summary, conclusions to the main findings and recommendations constituted the fifth chapter.

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CHAPTER TWO

LITERATURE REVIEW

2.0 Overview

This chapter deals with the relevant literature which has been reviewed from journals, internet, graphics and articles. These include,

- Groundwater availability
- Water quality
- Need for quality water supply
- Anthropogenic impacts on water quality
- Physical indicators of water quality
    - Temperature
- Chemical indicators of water quality
    - Conductivity
    - Chemical Oxygen Demand(COD)
    - Methods to measure COD
    - Determination of pH in groundwater
- Heavy metals determination
    - Lead
    - Exposure routes of Lead to the environment
    - Health effects of Lead
    - Cadmium
    - Exposure routes of Cadmium to the environment
    - Health effects of Cadmium
    - Iron

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- Exposure routes of Iron to the environment
- Health effects of Iron
- Zinc
- Exposure routes of Zinc to the environment
- Health effects of Zinc
- Cobalt
- Exposure routes of Cobalt to the environment
- Health effects of Cobalt

2.1 Groundwater Availability

Groundwater is the water found underground in the cracks and spaces in soil, sand and rocks. Groundwater comes from surface water percolating through overlying soils and it resides in the pore spaces between particles of soil and other geologic materials. Formations that have all the pore spaces saturated with water are called aquifers. The surface of the aquifer is called the water table. Aquifers are usually made of gravel, sand, sandstone, or fractured rock, like limestone. These materials have large connected spaces that allow water to flow through. The amount of ground water and the speed at which groundwater flows depends on the size of the spaces in the soil or rock and how well the spaces are connected (Akpan & Bassey.2020)

With sufficient water infiltration, soil contaminants such as heavy metals can leach to underlying groundwater. Unconfined aquifers are especially vulnerable to various contaminants and sediment loads including microscopic bacteria, viruses and protozoa (Nouri *et al*.2006)

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2.2 Water Quality

Water quality indicates the chemical, physical and biological characteristics of the water with reference to the use of water for particular purposes for example, drinking etc. Water quality assessment requires the analyses of the physical, chemical and biological nature with respect to the natural quality, human effects and intended uses which can affect human health and the ecosystem. Safe drinking water is the name given to water which is free from contamination by fecal matter and disease causing organisms. Examples include boreholes, treated pipe water, protected streams and rainwater (WHO. 2001).

The WHO (2002) guidelines for drinking water quality (GDWQ) promote the protection of public health by advocating for the development of locally relevant standards and regulations (health based targets), adoption of preventive risk management approaches covering catchment to consumer (water safety plans) and independent surveillance to ensure that water safety plans are being implemented and effective and that national standards are being met. This suggests that the concentration of heavy metals of safe drinking water should not cause any undesirable condition or illness.

Water is classified as safe for human consumption when it has been treated from its natural sources to comply with certain standards. Mishra et al (2010) stated that water which has high concentrations of ions from salts and metals as well as high microbial counts are not potable. Water of such is not considered as portable and is not safe for human consumption. Safe drinking water is needed by man to ensure good health, proper sanitation and national development.

Water is treated with respect to its intended use. The treatment of water is often directed to the need for human consumption, industrial use and its use in the

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environment. The contaminants that may be present in untreated water include microorganisms such as viruses and bacteria, inorganic contaminants such as salts and metals, organic contaminants from industrial processes and petroleum use, contaminants from pesticides and herbicides and radioactive contaminants. There is established water quality standards to provide the ability to regulate substances that potentially affect human health, environment and aesthetic qualities of water. The WHO(2008) guideline for Drinking Water Standards, United States Specification for Drinking Water and European Union Specification for Drinking Water are among the recognized water quality standards.

Water quality according to Diersing (2009) as cited in Tiako(2015) refers to the chemical, physical, biological and radiological characteristics of water. It depicts the analysis of water with respect to human consumption. In Ghana, the standards of physicochemical and microbial parameters as ascribed by Ghana Standard Authority (2009) reiterates that water permissible guidelines used to monitor the quality of water are in conformity with the WHO guidelines for water quality. Ghana Standard Authority (GSA) is the regulating body ensuring that water companies comply with these standards. Twumasi et al(2016), stated that safe water resources largely depend on physical, chemical and biological characteristics.

Binnie *et al* (2002) explained that potable water is improved water which is wholesome to drink and at the same time satisfies all the water quality indicators. This indicates that potable water is safe to use and does not pose any health risk when consumed. According to WHO (2011) physical, chemical and biological parameters of drinking water must satisfy either WHO or national standards and in this case the GSA approved standard is needed.

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2.3 Need for Quality Water Supply

Clean and safe water is as important as clean air. Both are necessary to ensure the survival of mankind. According to WHO (2006), water quality guidelines, potable water usage in our communities can reduce the incidence of water related diseases as well as any risk associated with using unsafe water. It also stated that potable water and good sanitation are necessary for proper economic growth and poverty reduction.

Third World Academy of Sciences Report (2002) stated that, unsafe water kills more than cancer, accidents or AIDS. It is vital to ensure that water humans drink become free from pathogens and toxic chemical substances that can threaten public health. This suggests that drinking and using safe water for domestic purposes improves peoples' health and reduces the risk of death caused by unsafe water.

According to Hughes and Koplan (2005), water which is not safe poses global health threat. They explained that unsafe water places people at the risk of diarrhea, host of water related diseases and possible intoxication by chemicals. The safe way for healthy living and ensuring good sanitation is to use improved water resources.

When drinking water supply scheme is unable to meet the required standards of water quality to people in their area, it brings challenge to fulfill the millennium development goals MDGs (target 7c) of ensuring affordable and sustainable access to drinking water supply (United Nations, 2005). This means that water quality is critical to public health. According to Haylamicheal and Moges (2012), the provision of improved and adequate water which meets water quality standards improves human health and increases individual productivity. Diarrhea and cholera outbreak can be consequences of using contaminated water.

Many natural sources of water have become contaminated because of human activities such as industrialization and bad agriculture practices. Water bodies once

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pure has now become contaminated with varied pollutants which have increased both the microbiological and physicochemical contents. Water quality standards become relevant in treating contaminated water and serve as guidelines for water quality. WHO (2011), stated that water quality standards have the objective to reduce the spread of diseases people contract from using water. Water considered to be safe should be pleasant to drink, which implies that it must be wholesome and palatable in all respects.

The provision of adequate and safe water for drinking and human use is essential for human physiology and existence (Nwosu & Ogueke.2004). Water resources which contain substances detrimental to health, objectionable taste, colour and odour are unfit for immediate consumption unless subjected to some sort of treatment (Oketola *et al.* 2006). Water treated for consumption must satisfy one or two standards that conform to WHO drinking water guidelines values. Ensuring that people obtain adequate and quality supply of water for consumption is vital for sustainable development (Khalil & Ouarda. 2009).

Clean drinking water provision is a way of creating opportunity for the poor to progress economically (UNEP/WHO.2004). The improved health, time saved in searching for good water as well as averted health cost undoubtedly become good indicators for eradicating poverty. In addition, a significant relationship has been established between the supply of quality drinking water and improved sanitation, health and economic benefits (Peter.2010).

The principal factor encouraging improved supply of water is to overcome plague of killing diseases that afflict developing countries as well as improving productivity. When people fall sick they waste a tenth of their productive time which disrupts education and development. This implies that there can be substantial

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improvement in people's lives through the provision of potable water. The level of pollution of raw water can influence the quality of the treated water (Adejuwon & Mbuk.2011).

2.4 Anthropogenic Impacts on Water Quality

With the onset of industrialization and increasing population, the range of demand for water has increased with respect to greater demand for high quality water. Water is considered as the most suitable medium to clean, disperse, transport and dispose of wastes (domestic and industrial wastes, mine drainage waters, irrigation returns, etc.). These activities have undesirable, effects on the natural environment. Also, uncontrolled land use, urbanization, deforestation, accidental release of chemical substances and discharge of untreated wastes or leaching of noxious liquids from solid waste deposits have impacted negatively on the quality of water resources (UNESCO.2003).

2.5 Physical Indicators of Water Quality

2.5.1 Temperature

Water temperature is a major controlling factor for aquatic life. It controls the rate of metabolic activities, reproductive activities and therefore the life cycles. If temperatures increase, decrease or fluctuate too widely, metabolic activities may speed up, slow down, malfunction, or stop altogether. There are many factors that can influence the temperature. Water temperatures can fluctuate seasonally, daily, and even hourly, especially in smaller sized streams. Spring discharges and overhanging canopy of stream vegetation provides shade and helps buffer the effects of temperature changes. Water temperature is also influenced by the quantity and velocity of stream flow and the temperature of effluents dumped into the water. When people dump heated effluents into waterways, the effluents raise the temperature of

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the water. Temperature affects the concentration of dissolved oxygen in water bodies. Oxygen is more easily dissolved in cold water (Missouri Department of Natural Resource.2012).

2.6 Chemical Indicators of Water Quality

2.6.1 Conductivity

Conductivity is the measure of water's capability to pass an electric current. It provides useful indicator of the mineralization and the pollution status of any water source (Jain *et al*.2005). It depends on dissolved ions present in a solution. The ability of water to pass an electric current is directly related to the concentration of inorganic dissolved solids. Organic compounds do not conduct electrical current very well and therefore have a low conductivity when in water. Conductivity is also affected by temperature and the warmer the water, the higher the conductivity. For this reason, conductivity is reported as conductivity at 25 degrees Celsius. Conductivity in streams and rivers is affected primarily by the geology of the area through which the water flows. Discharges to streams can change the conductivity depending on their make-up. Conductivity is measured in micro siemens per centimeter (µS/cm). Natural background conductivity found in many fresh waters range from 10.0 – 300.0 µS/cm. Health effect associated with EC in drinking water can occur at levels as low as 370 µS/cm. However, water sources with electrical conductivity levels' exceeding 1400 µS/cm generally are regarded as polluted (Fatoki & Muyima.2003).

2.6.2 Chemical oxygen demand (COD)

COD is referred to as a measure of the oxygen equivalent of the organic matter in a water sample that is susceptible to oxidation by a strong chemical oxidant. The COD value indicates the mass of oxygen consumed per liter of solution and expressed

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in milligrams per liter (mg/L). The higher the chemical oxygen demand, the higher the amount of pollution in the water sample. However, COD is considered as one of the important quality control parameters of an effluent in wastewater treatment facility (Alam.2015).

Under such strong oxidizing conditions, the complete oxidation of organic compounds produces carbon dioxide (CO_2) and water (H_2O). The COD for any organic compound can be theoretically calculated from writing a balanced equation (Boyles.1997).

2.6.2 Methods to measure COD

The dichromate method is the American Public Health Association (1998) standard method for determining COD with the use of potassium dichromate which is adapted by the GSA. The amount of dichromate is determined by direct titration using Ferrous Ammonium Sulfate (FAS) as the titrant and ferroin (1, 10 phenanthroline ferrous sulfate) as the indicator, (Boyles.1997). During the course of the titration, the titrant (Fe^{2+}) reacts instantly with hexavalent chromium (Cr^{6+}) to form trivalent chromium (Cr^{3+}) and ferric ion (Fe^{3+}) which is shown below:

$$3Fe^{2+} + Cr^{6+} \rightarrow 3Fe^{3+} + Cr^{3+} \qquad (2.1)$$

The final hexavalent chromium level is then subtracted from the initial level to determine the amount of hexavalent chromium reduced during the digestion. This difference is used to calculate the COD by following equation

$$\text{COD,mg/L} = \frac{(A - B) \times N \times 8000}{\text{mL sample}} \qquad (2.2)$$

Where, A is the mL FAS required for the titration of the blank, B is the mL FAS required for the titration of the sample, N is the normality of FAS.

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2.6.3 Determination of pH in groundwater

The pH value of water is the measure of the relative amount of free hydrogen and hydroxyl ions in the water. The WHO guidelines set the pH in the range of 6.5-8.5 (WHO.2008). Human activities like industrial operations and toxic waste disposal have effect on the pH of water sources. A change in the pH of water can have consequences on aquatic life which are extremely sensitive to changes in water temperature and composition.

The pH of natural water can provide important information about many chemical and biological processes and indirect correlations to a number of different impairments. The pH is the measurement of the acid/base activity in solution, specifically it is the negative logarithm of the activity/concentration of hydrogen ions.

$$pH = -\log[H^+] \qquad (2.3)$$

The pH scale runs from 0 to 14. A pH value of 7 is neutral; a pH less than 7 is acidic and greater than 7 represents base saturation or alkalinity. Pure water free of dissolved gases would naturally become ionized as;

$$H_2O \rightleftharpoons H^+ + OH^- \qquad (2.4)$$

The actual number of water molecules that would ionize is relatively very small with the amount of hydrogen ions $[H^+]$ being equal to the amount hydroxide ions $[OH^-]$. At room temperature the concentration of $[H^+]$ in pure water would be 1×10^{-7} moles per liter. A pH of 7 is neutral because the $-\log(1 X 10^{-7})$ is 7 by definition.

In unpolluted water, the pH is governed by the exchange of carbon dioxide with the atmosphere. Carbon dioxide is soluble in water and the amount of CO_2 that would dissolve in the water would be a function of temperature and the concentration of CO_2 in the air. As the gaseous CO_2 becomes aqueous, the CO_2 would be converted into H_2CO_3 which would acidify the water to a pH of about 6. If any alkaline earth

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metals such as sodium are present, the carbonates and bicarbonate formed from the solublisation of CO_2 would interact with sodium increasing the alkalinity, shifting the pH up over 7. Lower values in pH are indicative of high acidity, which can be caused by the deposition of acid forming substances in precipitation. A high organic content would tend to decrease the pH because of the carbonate chemistry. As microorganisms break down organic material, the by product would be CO_2 that dissolve and equilibrate with the water forming carbonic acid (H_2CO_3). Other organic acids such as humic and fulvic acids can also result from organic decomposition.

In addition to organic acids and the carbonate chemistry, the acidity of natural waters could also be controlled by mineral acids produced by hydrolysis of salts of metals such as aluminum and iron. Most metals will become more soluble in water as the pH decreases. For example, sulphur in the atmosphere from the burning of coal creates acid rain. The acid rain dissolves metals such as copper, lead, zinc and cadmium as the rain runs off of manmade structures and into bodies of water. The excesses of dissolved metals in solution negatively affect the health of the aquatic organisms.

The alkalinity of natural waters is determined by the soil and bedrock through which it passes. This is usually an indication of the number of carbonates and bicarbonates that shift the equilibrium producing [OH^-]. Other contributors to an alkaline pH include boron, phosphorous, nitrogen containing compounds and potassium.

Changes in pH can be indicative of an industrial pollutant, photosynthesis or the respiration of algae that is feeding on a contaminant. Most ecosystems are sensitive to changes in pH and the monitoring of pH has been incorporated into the environmental laws of most industrialized countries. pH is typically monitored for

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assessments of aquatic ecosystem, recreational waters, irrigation sources and discharges, livestock drinking water sources, industrial discharges, intakes, and storm water run-off (Schwarzenbach, Gschwend, & Imboden.2003).

2.7 Heavy Metals Determination

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

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

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

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water. This technology is environmental friendly and potentially cost effective (Tangahu, *et al*.2011).

2.7.1 Lead

Lead has a symbol Pb, an atomic number 82, atomic weight 207.19, and a specific gravity of 11.34. It is a bluish or silvery-grey metal with a melting point of 327.5°C and a boiling point at atmospheric pressure of 1740°C. It has four naturally occurring isotopes with atomic weights 208, 206, 207 and 204 (in decreasing order of abundance). Lead is number two on the ATSDR's "Top 20 List" of toxic and hazardous substances. Lead exists in many forms in the natural sources throughout the world and is now one of the most widely and evenly distributed trace metals. Most of the lead in the environment is in the inorganic form and exists in several oxidized states (Jackson *et al*.2005).

2.7.1.1 Exposure routes of lead to the environment

The sources of lead entering the environment are atmospheric lead (primarily from automobile emissions), paint chips, used ammunition, fertilizers, pesticides and lead-acid batteries or other industrial products. The transport and distribution of lead from major emission sources, both fixed and mobile are mainly through air. Lead in the air has come from a variety of sources. Leaded gasoline is the major source of dispersing lead into the human environment. When leaded gasoline is burned, it emits small particles of lead into the air, where they remain for extended periods of time. The lead particles eventually fall out into soil and dust, creating a large amount of lead to continue to poison generations unless covered or removed (Landmeyer et al.2003).

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The dispersive nature of leaded gasoline and its long-term effects, the ease with which lead enters the body after it is emitted by motor vehicles, and the vulnerability of at-risk urban populations, especially children, combine to make elimination of leaded gasoline (Redmon et al.2020).The manufacture of paint containing high concentrations of lead for interior and exterior residential surfaces, toys, and furniture was banned in 1978 by the Consumer Product Safety Commission. Although lead-containing paint was banned for residential use in the United States in 1978, residential paint on older buildings is the most frequent source of lead exposure in young children. Aside from lead paints, lead is emitted into the air from industrial emissions. These industrial sources included smelters, refineries, incinerators, power plants, manufacturing operations, recycling efforts, and hundreds of other sources. Some old homes may have lead water pipes, which can then contaminate drinking water (Redmon et al.2020).

Lead in the environment binds strongly to particles, such as soil, sediment and sewage sludge. Because of the low solubility of most of its salts, lead tends to precipitate out of complex solutions. It does not bio-accumulate in most organisms, but can accumulate in biota feeding primarily on particles, e.g. mussels and worms. These organisms often possess special metal binding proteins that remove the metals from general distribution in the organism; in humans, lead may accumulate in the bones. Lead is a dangerous element, it is harmful even in small amounts. Lead enters the human body in many ways. It can be inhaled in dust from lead paints, or waste gases from leaded gasoline (Jamali & Mirshak.2007; Tembe et al.2007)

2.7.1.2 Health effects of lead

High concentrations of lead in the body can cause death or permanent damage to the central nervous system, the brain, and kidneys. This damage commonly results

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in behavior and learning problems (such as hyperactivity), memory and concentration problems, high blood pressure, hearing problems, headaches, slowed growth, reproductive problems in men and women, digestive problems, muscle and joint pain. Lead is considered the number one health threat to children, and the effects of lead poisoning can last a lifetime. Lead poisoning stunt a child's growth, damage the nervous system, and cause learning disabilities. Children are susceptible to lead because developing skeletal systems require high calcium levels. Lead that is stored in bone is not harmful, but if high levels of calcium are ingested later, the lead in the bone may be replaced by calcium and mobilized. Once free in the system, lead may cause nephrotoxicity, neurotoxicity and hypertension (Moriguchi et al.2003).

According to (Moriguchi et al.2003), strong relationship between contaminated drinking water with heavy metals and chronic diseases such as renal failure, liver cirrhosis, hair loss, and chronic anemia was identified in their study. These diseases were apparently related to contaminant drinking water with heavy metals such as Pb, Cd, Cu, Mo, Ni, and Cr. Renal failure was related to contaminated drinking water with lead and cadmium, liver cirrhosis to copper and molybdenum, hair loss to nickel and chromium, and chronic anemia to copper and cadmium. Studies of these diseases suggested that abnormal incidence in specific areas was related to industrial wastes and agriculture activities that have released hazardous and toxic materials in the groundwater and thereby led to the contamination of drinking water in those areas.

2.7.2 Cadmium

Cadmium is a chemical element with the symbol Cd and atomic number 48. Cadmium is number seven on ATSDR's toxic and hazardous substances "Top 20 list," and a byproduct of the mining and smelting of lead and zinc. It is found in very low

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concentration in most rocks, as well as in coal and petroleum and often in combination with zinc. Geologic deposits of cadmium can serve as sources to groundwater and surface water, especially when in contact with soft, acidic waters. There is no evidence indicating its essentiality to humans (Hogan.2010).

2.7.2.1 Exposure routes of cadmium to the environment

Cadmium is introduced into the environment from paints and pigments, and plastic stabilizers, mining and smelting operations and industrial operations, including electroplating, reprocessing cadmium scrap, and incineration of cadmium containing plastics. It is used in nickel-cadmium batteries, PVC plastics, and paint pigments. Cadmium can be found in soils because insecticides, fungicides, sludge, and commercial fertilizers that contain cadmium are used in agriculture. Cadmium emissions are also from fossil fuel use and cigarettes. It may enter drinking water as a result of corrosion of galvanized pipe. Cadmium dispersed in the environment can persist in soils and sediments for decades (Bhattacharya.2020).

2.7.2.2 Health effects of cadmium

Cadmium and its compounds are highly toxic and exposure to this metal is known to cause cancer and targets the body's cardiovascular, renal, gastrointestinal, neurological, reproductive, and respiratory systems. It is generally present in the environment at low levels, however, human activities have greatly increased levels in environmental media relevant to population exposure (Nies.2003).

.A summary on Cadmium and its effect on health by Bhattacharya(2020) revealed that cadmium once absorbed, is efficiently retained in the human body, in which it accumulates throughout life. It is primarily toxic to the kidney, especially to the proximal tubular cells, the main site of accumulation. It can also cause bone demineralization, either through direct bone damage or indirectly as a result of renal

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dysfunction. In the industry, cadmium is hazardous both by inhalation and ingestion and can cause acute and chronic intoxications. Excessive exposures to airborne cadmium may impair lung function and increase the risk of lung cancer.

2.7.3 Iron

Iron is a chemical element with symbol Fe and an atomic number 26, atomic mass of 55.845amu and a melting point of 1538^{0}C. In contrast to zinc, iron are the abundant elements on earth and is a biologically essential component for every living organism. The most common iron-containing ore is haematite, but iron is found widely distributed in other minerals such as magnetite and taconite.

2.7.3.1 Exposure routes of iron to the environment

The production and use of iron compounds as catalysts, pigments, drugs, as well as their use in agriculture, nutrition, metallurgy, and leather tanning may result in their release to the environment through various waste streams. The mining and processing of iron ores also may result in the release of iron compounds to the environment. The iron and steel industries are also likely sources of emissions of iron compounds to the environment. Occupational exposure to iron compounds may occur through inhalation and dermal contact with these compounds at workplaces where iron compounds are produced or used (Munter et al.2005).

2.7.3.2 Health effects of iron

Toxicity occurring with acute iron overdose results from a combination of the corrosive effects on the gastrointestinal mucosa and the metabolic and hemodynamic effects caused by the presence of excessive elemental iron. Inhalation of ferric salts as dusts & mists is irritating to the respiratory tract. Ferric salts are regarded as skin irritants. Early symptoms of acute iron toxicity include diarrhea, sometimes containing blood; fever; nausea, severe; stomach pain or cramping, sharp; vomiting,

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severe, sometimes containing blood. Late symptoms of acute iron toxicity include bluish-colored lips, fingernails, palms of hands; drowsiness; pale, clammy skin; seizures; unusual tiredness or weakness; weak and fast heartbeat. Pulmonary siderosis results from inhalation of iron dust or fumes (Merrill et al.2012).

The corrosive effect of iron results in stomach and intestinal erosions and ulceration (i.e., hemorrhagic gastritis and enteritis with blood loss). However, there is a lack of correlation between the severity of intestinal damage and death. Large chronic doses of iron may so interfere with assimilation of phosphorus as to cause severe rickets in infants (Isewede et al.2020).

2.7.4 Zinc

Zinc is a chemical element with a symbol Zn and atomic number 30, atomic mass of 65.39u and a melting point of 420^{0}C. Zinc has a low-melting metal of Group 12 of the periodic table. It is essential to life and is one of the most widely used metals. Zinc is of considerable commercial importance. A little more abundant than copper, zinc makes up an average of 65 grams of every ton of earth's crust. The chief zinc mineral is the sulfide sphalerite (zinc blende), which together with it oxidation products smithsonite and hemimorphite constitute nearly all of the world's zinc ore.

2.7.4.1 Exposure routes of zinc to the environment

Zinc is an essential trace element, necessary for plants, animals, and microorganisms.. It is typically the second most abundant transition metal in organisms after iron and it is the only metal which appears in all enzyme classes. Some zinc is released into the environment by natural processes, but most come from human activities like mining, steel production, coal burning, and burning of waste. It attaches to soil, sediments, and dust particles in the air. Rain and snow remove zinc

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dust particles from the air. Depending on the type of soil, some zinc compounds can move into the groundwater and into lakes, streams, and rivers. Most of the zinc in soil stays bound to soil particles and does not dissolve in water (Batayneh.2012). It builds up in fish and other organisms, but it does not build up in plants. Ingesting small amounts present in your food and water. Humans are exposed to zinc through drinking contaminated water or a beverage that has been stored in metal containers or flows through pipes that have been coated with zinc to resist rust; eating too many dietary supplements that contain zinc; and working in any of the following jobs: construction, painting, automobile mechanics, mining, smelting, and welding; manufacture of brass, bronze, or other zinc-containing alloys; manufacture of galvanized metals; and manufacture of machine parts, rubber, paint, linoleum, oilcloths, batteries, some kind of glass, ceramics, and dyes (Noulas et al.2018).

2.7.4.2 Health effects of zinc

Zinc is a trace element that is necessary for a healthy immune system. A lack of zinc can make a person more susceptible to disease and illness. It is responsible for a number of functions in the human body, and it helps stimulate the activity of at least 100 different enzymes. Zinc is an essential element in our diet. Too little zinc can cause problems, but too much zinc is also harmful. Harmful effects generally begin at levels 10-15 times higher than the amount needed for good health. Large doses taken by mouth even for a short time can cause stomach cramps, nausea, and vomiting. Inhaling large amounts of zinc (as dusts or fumes) can cause a specific short-term disease called metal fume fever. Acute exposure to zinc oxide can result in coughing, substernal pain, upper respiratory tract irritation, rales, chills, fever, nausea, and vomiting. Zinc chloride fume is an irritant of the eyes, skin, mucous membranes, and lungs in humans (Singh et al.2012) . The signs and symptoms of acute exposure to

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zinc chloride fume include conjunctivitis, irritation of the nose and throat, hoarseness, cough, dyspnea, wheezing, rales, rhonchi, chest tightness and/or pain, nausea, vomiting, epigastric pain, listlessness, lightheadedness, and a metallic taste in the mouth.

Excessive concentrations of zinc taken on a long-term basis can cause anemia and decrease the levels of good cholesterol. Chronic exposure to zinc oxide by skin contact may result in popular-pustular skin eruptions in the axilla, inner thigh, inner arm, scrotum and pubic areas. Excessive absorption of zinc suppresses copper and iron absorption (Oyem et al.2015). The U.S. Food and Drug Administration (FDA) has stated that zinc damages nerve receptors in the nose, which can cause anosmia (loss of sense of smell).

2.7.5 Cobalt

Cobalt is a chemical element with the symbol Co and atomic number 27, atomic weight of 59 and a melting point of 1,495^{0}C. Like Nickel, Cobalt is found in the Earth's crust only in chemically combined form, save for small deposits found in alloys of natural meteoric iron. The free element, produced by reductive smelting, is a hard, lustrous, silver-gray metal.

2.7.5.1 Exposure routes of cobalt to the environment

Cobalt is found naturally throughout the environment. The general population may be exposed to cobalt in the air, drinking water, and food. Higher-than-normal exposure levels for cobalt can occur in the air and water near industrial areas, particularly near hard metal industrial sites (Park et al.2013).

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2.7.5.2 Health effects of cobalt

The short-term effects of cobalt inhalation include respiratory effects such as a significant decrease in ventilatory function, congestion, edema, and hemorrhage of the lung. Acute animal tests in rats have shown cobalt to have extreme toxicity from inhalation exposure.Long-term effects of cobalt inhalation include respiratory irritation, wheezing, asthma, pneumonia, and fibrosis. Cardiac effects, congestion of the liver, kidneys, and conjunctiva, and immunological effects that include cobalt sensitization are also potential effects from chronic exposure. Studies have reported respiratory, cardiovascular, and CNS effects, decreased body weight, necrosis of the thymus, and effects on the blood, liver, and kidneys from inhalation exposure to cobalt (Choi et al.2005).

2.8 Chapter Summary

Lot of studies abound in the literature on heavy metal pollution of water sources. Such works include those of Boateng,Opoku and Akoto (2019), Gyamfi, Appiah-Adjei and Adjei (2019) and Asare-Donkor and Adimado (2020). These authors concluded that there was the need to monitor water quality on a regular basis. This is because, the increase in concentration of heavy metals in groundwater will increase the threat to human health. Also, several methods exist in literature on the development and application of pollution index methods for water quality assessment. Some of these include the work of Appiah-Opong, et al (2021) and Doyi, et al (2018).

In this present study, use is made of the weighted arithmetic average of the concentrations of five (5) heavy metals; lead ,cadmium, iron, zinc and cobalt as the basis of a heavy metal pollution index (HPI) adopting two approaches based on the instrument's limit of detection and the generated data.

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CHAPTER THREE

MATERIALS AND METHODS

3.0 Overview

This chapter deals with the materials and methods used in the collecting and analyzing of data. These include,

- Study area
- Effutu municipal map
- Pre-sampling preparations
- Sampling
- Procedure
    - Geographical Information System (GIS) Approach
- Data collection procedure
    - Water samples
    - Acidification of water samples
    - Digestion of water samples for metal determination
- Metals (Atomic Absorption Spectrometry – Direct Aspiration)
    - Lead
    - Iron
    - Cadmium
    - Zinc
    - Cobalt
- Chemical oxygen demand (COD) determination
- Physicochemical analysis
    - Determination of pH

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    - Determination of conductivity
- Heavy metal pollution index
    - Indexing approach

3.1 Study Area

The target areas were some selected communities in Winneba, Effutu Municipality. The Effutu Municipality is situated between latitudes 5^{O} 28’ and 5^{O} 18’ north and longitudes 0^{O} 25’ and 0^{O} 40’west on the eastern part of the Central Region of Ghana (Fig.1). It is bordered to the north by the Agona Municipal, on the northeast by the West Akim Municipal, to the south by the Gulf of Guinea, and to the west by the Gomoa District. The Municipality covers an area of about 417.3 km^2. Winneba is the administrative capital of the Effutu Municipal with a population of about 70,592. The Municipality is generally low lying with granite rocks and isolated hills. The two major rivers; Ayensu and Gyahadze drain the Municipality and enter the sea at Worabeba and Opram respectively (GSS.2014).

The Municipality lies within the dry-equatorial climatic zone characterized by low rainfall and long dry season of five months. The vegetation is that of the coastal savannah grassland which is suitable for vegetable cultivation or dry season irrigation farming. The soils in the Municipality are largely clayey with high salinity hence its suitability for salt production and pottery/roofing tiles production. The famous Aboakyer Festival of the people of the Municipality derived its existence from the annual sacrifices made to the Penkye Otu deity. Figure 1 is the map of the study area with the sampling points indicated accordingly.

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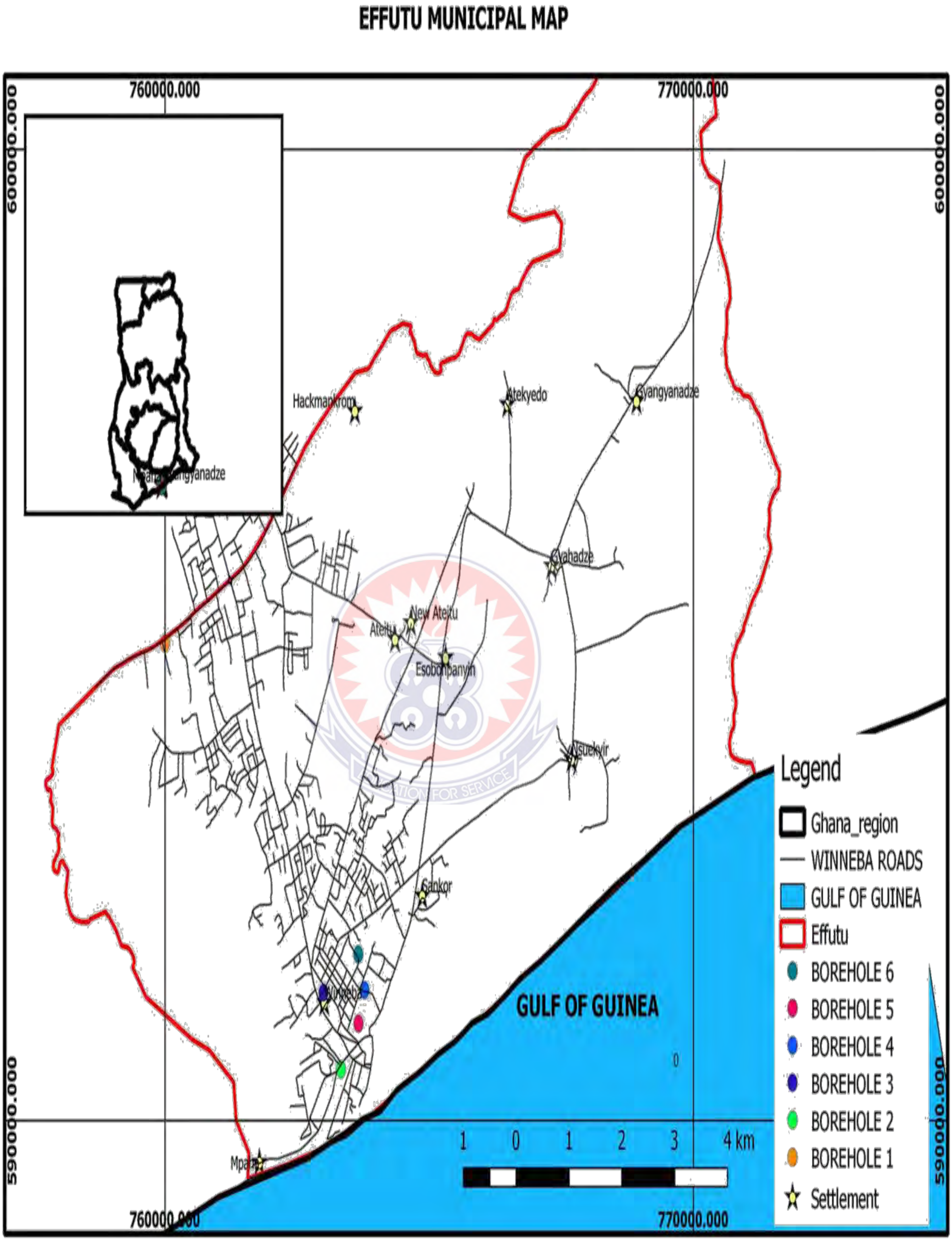

Figure 3.1: Map of the Study Area

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Figure 3.2: A Hand-Dug Well with Fissured Concrete Lining.

Figure 3.3: A Polluted Stream close to a Hand-Dug Well.

Figure 3.4: Pit Latrine close to a Hand-Dug Well.

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3.2 Pre-Sampling Preparations

Two sample bottles of volume 500ml each were thoroughly rinsed with distilled water. Upon reaching the sampling site, each bottle was rinsed with water from the respective sampling sites thrice before the actual sample collection was done. Van Dorn water sampler, the pH meter, conductivity meter and 10% HNO_3 for use at the sampling site were acquired from the water research institute, Accra. Ice block was also made available in a thermos flask for storing the samples.

3.3 Sampling

Seventy-two(72) samples were collected from six(6) sites in six communities in Winneba Municipality which includes: Ansaful, UEW South, Flamengo , Oyibi , Kwendrum, Otuana. Thirty six(36) samples were collected during the dry season and thirty six(36) samples were also collected during the wet season.

3.4 Procedure

3.4.1 Geographical information system (GIS) approach

Locations of the sampling point were picked by a Garmin e-Trex hand-held Global Positioning System (GPS) receiver and the coordinates were recorded. The special distribution of the sampled point is presented in Table 3.1.

Table 3.1: GPS Coordinates of Sampling Point Location

Sampling Sites	Latitude(^{0}N)	Longitude(^{0}E)
BH 1 (UEW South)	$7^0$60″57	$5^0$95″91
BH 2 (Oyibi)	$7^0$63″32	$5^0$90″52
BH 3 (Otuana)	$7^0$63″83	$5^0$91″31
BH 4 (Kwendrum)	$7^0$63″77	$5^0$91″34
BH 5 (Ansaful)	$7^0$63″77	$5^0$91″34
BH 6 (Flamengo)	$7^0$63″65	$5^0$91″71

BH- Borehole

Source: Field data, 2021

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3.5 Data Collection Procedure

3.5.1 Water sampling

Ground water samples were collected at various locations with a researcher designed drawing sampler and transferred into 500mL each of polyethylene containers. Drops of 1-2 mL concentrated HNO_3 were added to one set of the samples for metal analysis. The other set of samples for physicochemical parameters analysis were not acidified.

Conductivity, pH and temperature were determined with the portable Eijkeljamp 18.21 Multiparameter Analyser after calibration on the field.

3.5.2 Acidification of water samples

Acidification of the water samples were done just after the pH determination. About 2.0 mL concentrated HNO_3 was added to 300 mL of the samples, to preserve the water samples and to keep the metal ions in solution. The samples were covered tightly, stored in cold box (4°C) and transported to the laboratory for further treatment and analysis with strict adherence to the sampling protocol as described by Gale and Robins (1989) and analyzed independently using the Standard Methods (1998).

3.5.3 Digestion of water samples for metal determination

Each sample was thoroughly mixed by shaking and 100 mL of the sample was transferred into a conical flask. About 5.0 mL concentrated HNO_3 and a few boiling chips were added together(APHA.1999). The mixture was then heated until the volume reduced to about 15 mL. Complete digestion was indicated by a light coloured solution. The content of the conical flask was filtered with Whatman No 42 filter paper. The filtrate was transferred into 100 mL volumetric flask and the volume finally adjusted to 100 mL with distilled water and stored at 4^0C, ready for AAS analysis (APHA.1999).

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3. 6 Metals (Atomic Absorption Spectrometry)

3.6.1 Lead

The sample was preserved in the field with nitric acid. The sample aliquot was then digested with nitric acid. The solution was aspirated and the absorbance measured spectrometrically at a wavelength of 217.0nm with the aid of a Flame Atomic Absorption Spectrophotometer and compared to identically-prepared standard (0.25ppm, 1ppm and 2.00ppm) solutions, using the air-acetylene oxidizing flame and detection limit of the instrument is 0.010mg/l.

3.6.2 Iron

A sample solution was aspirated into a flame and atomized using Flame Atomic Absorption Spectrophotometer made of 50 mm burner (Agilent Technologies 900). A light beam was directed through the flame into a monochromator and onto a detector that measured the amount of light absorbed by the element in the flame. The sample was acidified to a pH less than 2 with Nitric acid (HNO_3). The characteristic wavelength for iron determination was 248.3 nm and this procedure was used to determine Total Iron (APHA.1998), by comparing with identically prepared standard iron solution (0.5ppm, 1.0ppm and 2.0ppm) using the air-acetylene oxidizing flame and detection limit of the instrument is 0.010mg/l.

3.6.3 Cadmium

The sample was preserved in the field with nitric acid. The sample aliquot was then digested with nitric acid. The solution was aspirated and the absorbance measured spectrometrically at a wavelength of 228.0 nm with the aid of a Flame Atomic Absorption Spectrophotometer(Agilent Technologies 900) and compared to identically-prepared standards (0.5ppm, 1.0ppm and 5.00ppm) solutions, using the air-acetylene oxidizing flame and detection limit of the instrument is 0.003 mg/l.

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3.6.4 Zinc

The sample was preserved in the field with nitric acid. The sample aliquot was then digested with nitric acid. The solution was aspirated and the absorbance measured spectrometrically at a wavelength of 213.9 nm with the aid of a Flame Atomic Absorption Spectrophotometer(Agilent Technologies 900) and compared to identically-prepared standards (1.0ppm, 2.0ppm and 5.0ppm) solutions, using the air-acetylene oxidizing flame and detection limit of the instrument is 0.005 mg/l.

3.6.5 Cobalt

The sample was preserved in the field with nitric acid. The sample aliquot was then digested with nitric acid. The solution was aspirated and the absorbance measured spectrometrically at a wavelength of 240.7 nm with the aid of a Flame Atomic Absorption Spectrophotometer(Agilent Technologies 900) and compared to identically-prepared standard (0.25ppm, 1.00ppm and 2.00ppm) solutions, using the air-acetylene oxidizing flame and detection limit of the instrument is 0.010 mg/L.

3.7 Chemical Oxygen Demand (COD) Determination

Eight culture tubes were set up in a tube holder. A blank and a control solution was prepared. A blank solution was prepared with 5ml of distilled water whiles the control solution was prepared with 2.5 ml of distilled water plus 2.5ml of control solution. Five (5) ml of each sample was fixed in the culture tubes. Three (3) ml of potassium dichromate was added to each sample, including the blank and control. Seven (7) ml of sulphuric acid was added to each of the samples including the blank and the control. The culture tubes were corked and the solution digested to a temperature of 150^{0}C for 2 hours. After the digestion, the samples including the control and blank were cooled for 15minutes and were titrated against ferrous ammonium sulphate, using ferrion as indicator.

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3.8 Physicochemical Analysis

3.8.1 Determination of pH

The pH of the water was measured with the aid of Eijkeljamp 18.21 Multiparameter pH meter which gave a direct value of pH. The pH meter was calibrated by using standard pH buffer solutions of pH 4.0, 7.0 and 10.0.

Procedure: About 150 ml groundwater sample was measured using a measuring cylinder and transferred into a clean glass beaker. The electrode of the pH meter was inserted into it and the button selector of the pH meter turned to read the pH. The displayed pH value was recorded and the process repeated three times for all other water samples.

3.8.2 Determination of conductivity

The Conductivity of water samples were determined by using Eijkeljamp 18.21 Multiparameter conductivity meter. Calibration of the instrument was done by using standard sodium chloride solution of 1413µS/cm. The conductivity meter was set to operation mode for measurement.

Procedure: About 150 ml of groundwater sample was measured and transferred into a clean 250 ml glass beaker and the conductivity meter electrode was then put into the water. The displayed value was read and recorded after five (5) minutes in µS/cm. This procedure was repeated three times for the other water samples.

3.9 Heavy Metal Pollution Index

For the calculation of heavy metal pollution index, eleven important parameters were chosen. Concentrations of five heavy metals: Lead (Pb), Cadmium (Cd), Iron (Fe), Zinc (Zn) and Cobalt (Co) were determined and used to evaluate the heavy metal pollution index (HPI) adopting two different approaches. In the first instance heavy metals that were not detected by the instrument were assigned zero concentration. In the second instance, these heavy metals were assigned the limit of detection of the instrument as if they were present to that extent.

3.9.1 Indexing approach

The HPI, represents the total quality of water with respect to heavy metals. The proposed HPI was developed by assigning a rating or weightage (Wi) for each selected parameter. The rating system is an arbitrarily value between zero and one, reflecting the relative importance of individual quality considerations, and can be defined as inversely proportional to the recommended standard (Si) for each parameter (Mohan et al.1996).The highest tolerant value for drinking water (Si) refers to the maximum allowable concentration in drinking water in absence of any alternate water source. The desirable maximum value (Ii) indicates the standard limits for the same parameters in drinking water.

The HPI model (Mohan *et al*.1996) is given by;

$$HPI = \frac{\sum_{i=1}^{n} w_i Q_i}{\sum_{i=1}^{n} w_i} \quad \ldots\ldots 1$$

Where Qi is the sub-index of the ith parameter, Wi is the unit weightage of the ith parameter and n is the number of parameters considered.

The unit weight, Wi, is calculated by;

$$Wi = \frac{K}{S_i} \quad \ldots\ldots 2$$

The proportionality constant, K is calculated by,

$$K = \frac{1}{\sum_{i=1}^{n} \frac{1}{S_i}} \quad \ldots\ldots 3$$

Where

$$\sum_{i=1}^{n} \frac{1}{S_i} = \frac{1}{s_1} + \frac{1}{s_2} + \frac{1}{s_3} \ldots + \frac{1}{s_i} \quad \ldots\ldots 4$$

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Where S_1, S_2, S_3, etc. represent standards for different heavy metals in water such as Co, Zn, Cd, Pb, Fe as in the study.

The sub-index (Qi) of the parameter is calculated by;

$$Q_i = \sum_{i=1}^{n} \frac{|M_i - I_i|}{S_i - I_i} \times 100 \ldots\ldots 5$$

Where Mi is the monitored value of heavy metal of ith parameter, Ii is the ideal value of the ith parameter and Si is the standard value of the ith parameter in ppb. The quantity [Mi – Ii] indicates numerical difference of the two values, ignoring the algebraic sign; that is the absolute value. Generally, the critical pollution index of HPI value for drinking water is 100 (Prasad & Bose.2001). In computing the HPI, Prasad & Bose (2001) considered unit weightage (Wi) as a value inversely proportional to the maximum admissible concentration (MAC) of the corresponding parameter as proposed by Siegel(2002). This approach is being applied in this current study.

CHAPTER FOUR

RESULTS AND DISCUSSION

4.0 Overview

This chapter deals with the mean values of all the various parameters which were computed from the raw data obtained from the field. For the purpose of discussion, the results were compared with the control group as well as the WHO guideline values where applicable. Some descriptive and inferential statistics were made and added to the Tables for discussion.

4.1 Physicochemical Parameters for the Dry Season

4.1.1 pH

The pH of water provides information about the solubility, biological availability and chemical processes within water bodies, and indicates the relative acidic or basic nature of water. All the samples analysed showed values of pH within the drinking water guideline values of 6.5-8.5(WHO.2006) as shown in Figure 4.1. At high pH water taste can be sour also result in soapy taste. Directly, very low or high pH values can burn mucous membranes of the intestinal mucosa (Fatoki & Muyima.2003). Acceptable pH range for palatable water is therefore set from 6.0-9.0 (Ghana EPA. 1997). The pH of water samples recorded values ranging from 6.78-7.41 with a mean value of 7.15±0.09. The lowest pH values was recorded at BH (5) and BH (6) recorded the highest mean value. The pH values of the groundwater recorded were slightly acidic and also slightly alkaline at some places hence the results were considered good enough for domestic purposes. Mitharwal *et al* (2009) indicated that pH of water is an essential indicator for determining water quality and gives information on various types of geochemical equilibrium that occurs in water. This is represented in Figure 4.1

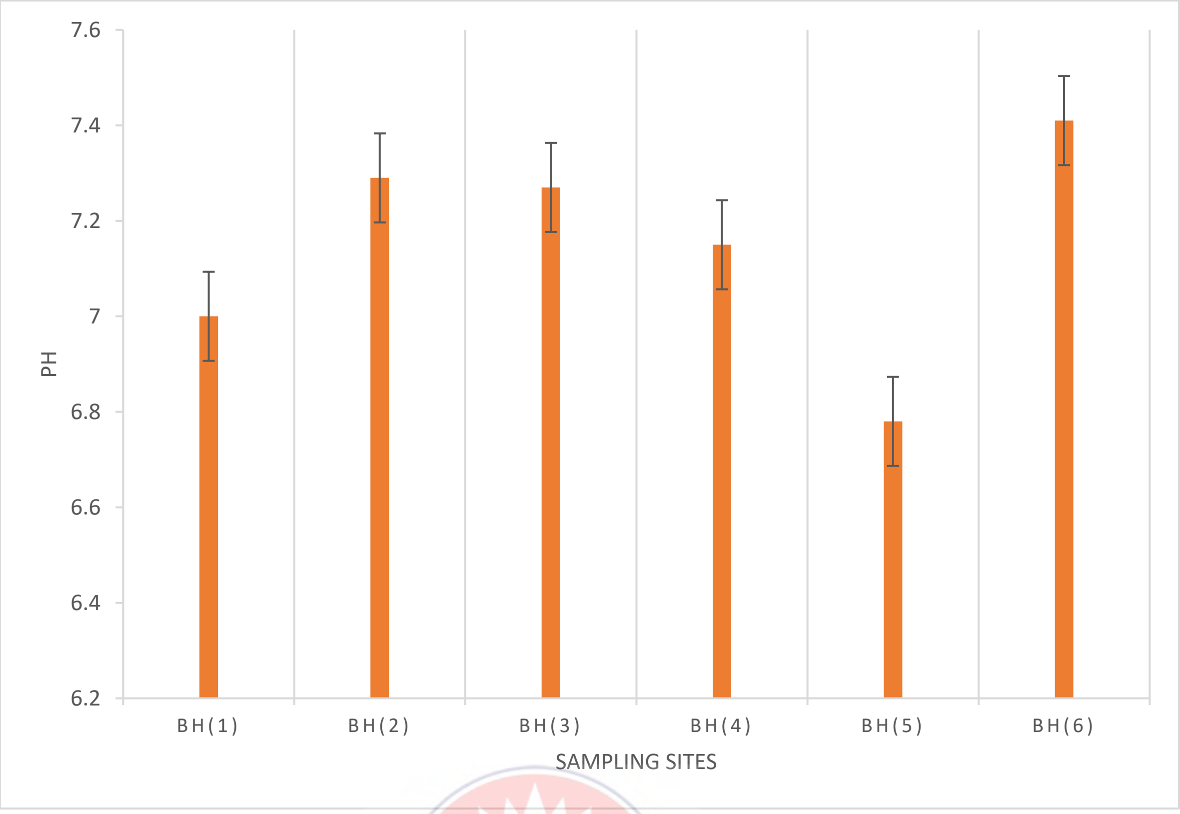

Figure 4.1: Mean pH values of groundwater in Effutu Municipality during the Dry Season.

4.1.2 Temperature

Temperature is an important biological factor which plays an important role in the metabolic activities of living things (Murhekar, 2011). The mean temperature of samples ranged between 26.7°C and 26.8°C and a mean of 26.78 ± 0.02°C (Figure 4.2). The mean temperature values received for the entire study were within the WHO permissible values that is between 22 ℃ and 29 ℃ for drinking water(Addo. 2011), hence there were no threats to human and aquatic life. The variations in the temperature of water samples recorded could be because of depth of the water, season of sampling, groundwater influx, air circulation and the weather conditions that triumphed during the period of sampling and investigations (Peirce et al. 1998). This is represented in Figure 4.2

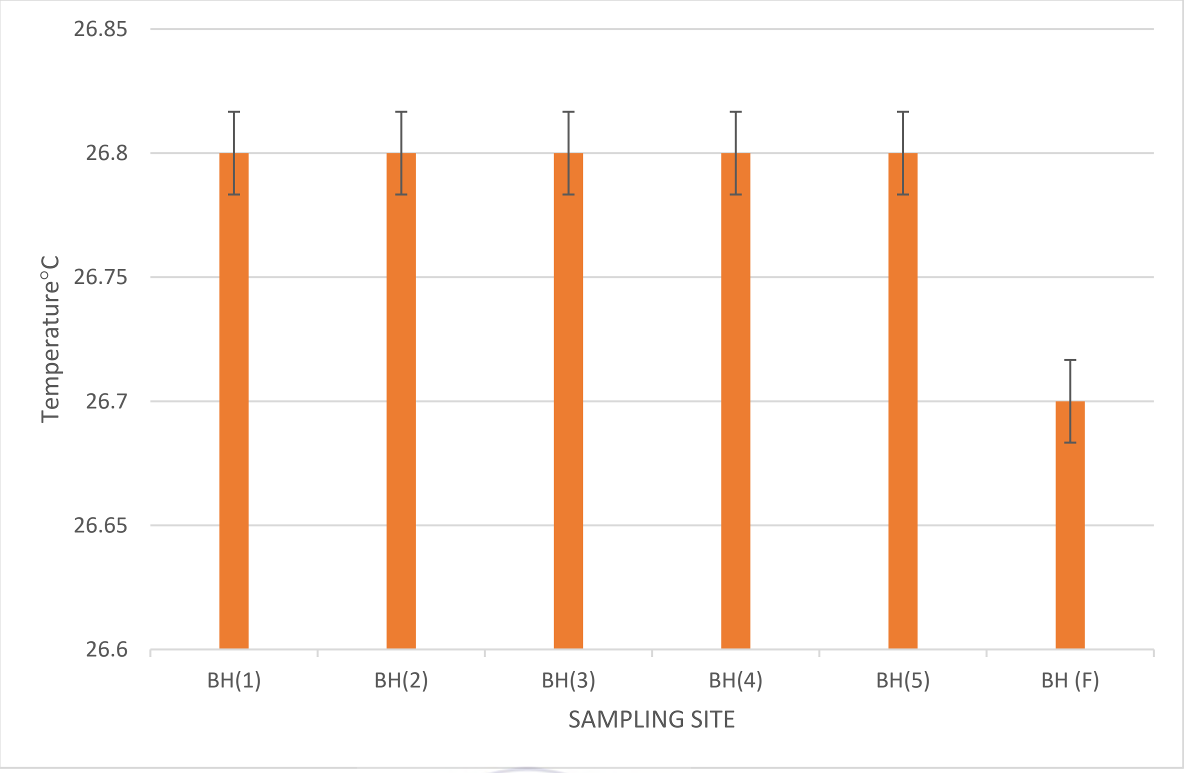

Figure 4.2: Mean Temperature values of groundwater in Effutu municipality during the dry season.

4.1.3 Electrical conductivity

Electrical conductivity is related to the mass of total dissolved solids and other ions in a water body and gives information about the level of mineralization of the water under study (Gyamfi, et al.2012). The average E.C value ranges at a minimum of 740 µS/cm at BH (1) to a maximum of 5500 µS/cm at BH(5). One community registered average conductivity values that were below the WHO (2006) permissible limit of 1400 µS/cm for drinking water whiles five (5) communities registered average conductivity values above the WHO (2006) permissible limit of 1400 µS/cm for drinking water. Mean value recorded is 2326.5±670.83 which falls above the WHO (2006) standard of 1000 µS/cm. The average conductivity values recorded at the five (5) sample sites were generally high compared with GEPA standard of 1500 µS/cm whilst one site was generally low compared with GEPA standards of 1500 µS/cm. Electrical conductivity is mainly caused by dissolved inorganic salts such as sodium and sulphate salts. Higher levels of TDS concentration can impart salty or bitter taste to water thereby making it undesirable for consumption. Water with high salty concentration causes excessive scaling in distribution pipes, heaters, and boilers (Gray.2008).

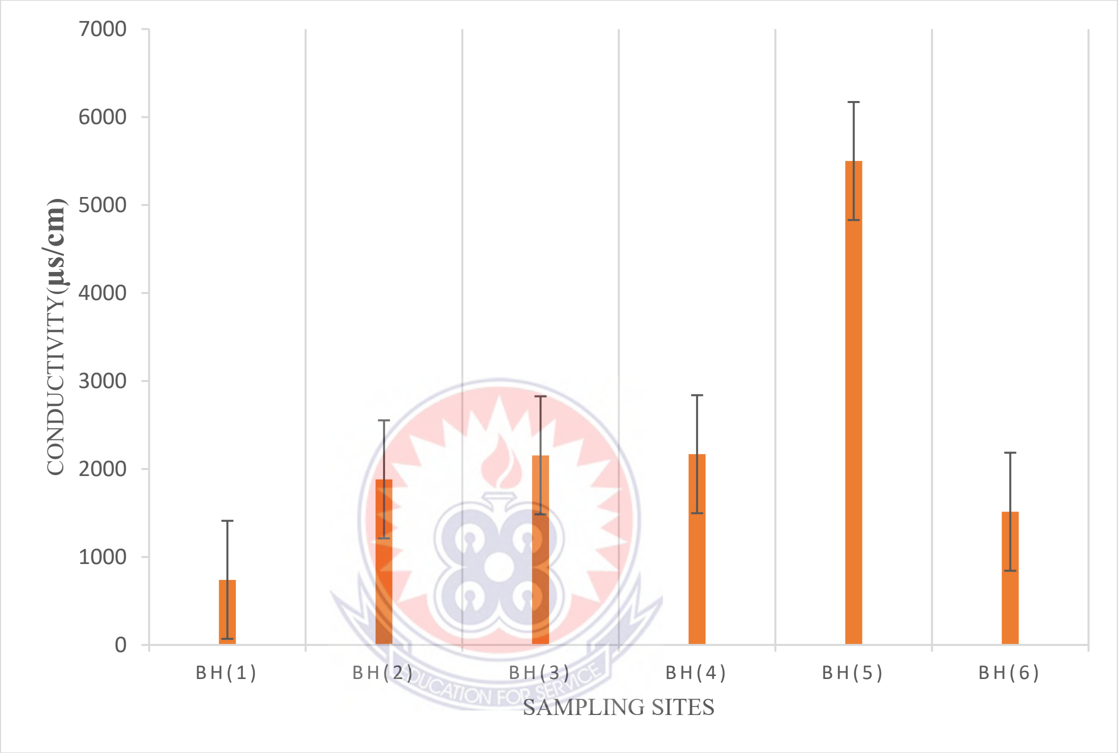

Figure 4.3: Mean Conductivity Values of Groundwater in Effutu Municipality during the Dry Season.

4.1.4 Chemical oxygen demand (COD)

The chemical oxygen demand (COD) is a measure of water and wastewater quality. The COD is the amount of oxygen consumed to chemically oxidize organic water contaminants to inorganic end products. Higher COD levels mean a greater amount of oxidizable organic material in the sample, which would reduce dissolved oxygen (DO) levels. A reduction in DO can lead to anaerobic conditions, which is deleterious to higher aquatic life forms. The mean COD values gave a range of 8.00mg/L as its lowest value at BH (6) to 46.4mg/L being its highest value at BH(5). The average value was 27.47 ± 5.13mg/L. The mean COD values obtained from all the sampling sites were below the standard of 250mg/L, as represented in Figure 4.4.

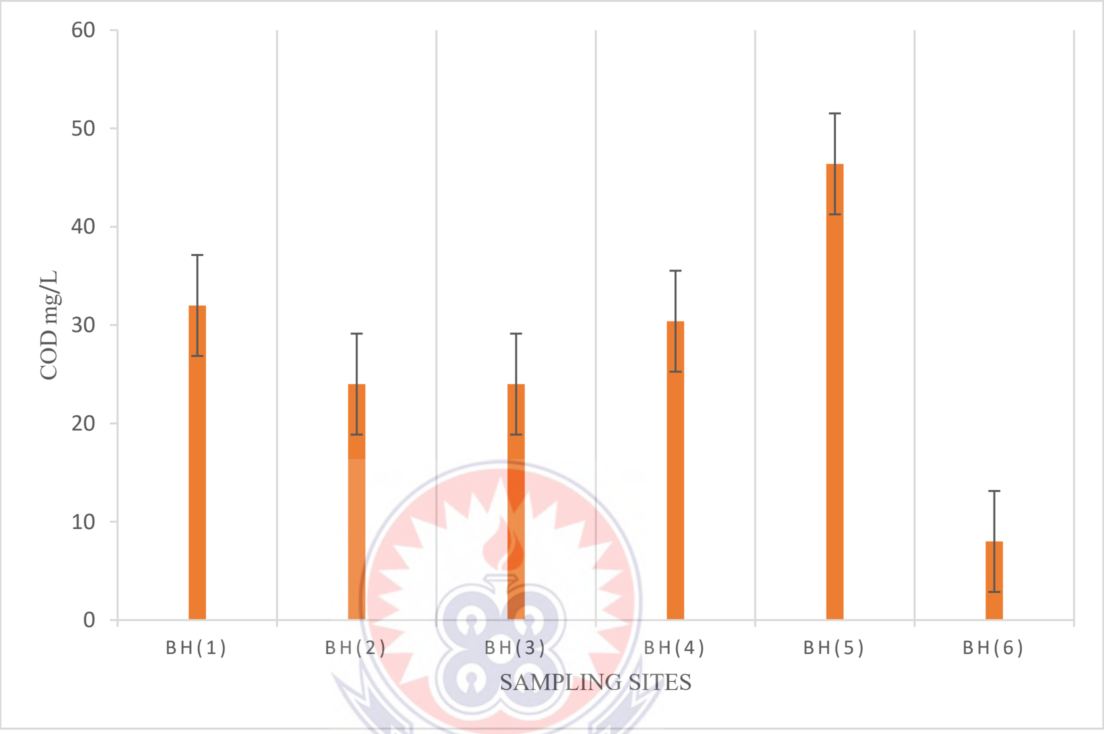

Figure 4.4: Mean COD Values of Groundwater in Effutu Municipality during the Dry Season.

Table consisting of the standards used for the Heavy Metal Pollution Index (HPI) computation

Table 4.1: Standards used for the HPI Computation

	W	S	1	MAC
Co	*0.001	10	10	1000
Zn	*0.0002	2000	3000	5000
Cd	*0.3	3	3	3
Pb	*0.7	10	10	1.5
Fe	*0.005	300	200	200

Maximum Admissible Concentration (MAC) adapted from Siegel (2002) and WHO (2002)

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W is Weightage (1/MAC)

S is Standard permissible in µg/L

I is Highest permissible in µg/L

MAC is Maximum admissible concentration in µg/L

$W_i = \frac{1}{MAC}$

$*Co_{wi} = \frac{1}{1000} = 0.001$

$*Zn_{wi} = \frac{1}{5000} = 0.0002$

$*Cd_{wi} = \frac{1}{3} = 0.3$

$*Pb\ _{wi} = \frac{1}{1.5} = 0.7$

$*Fe_{wi} = \frac{1}{200} = 0.005$

Table 4.2 is for Heavy Metal Pollution index (HPI) computation for borehole BH (1) during the dry season.

Table 4.2: HPI Computation for Borehole BH (1) with not detected (ND) for Metals not detected.

Heavy Metal	Mean Value µg/L	Standard Permissible Value	Highest Desirable Value	Unit Weightage $(W_i)_1$	Sub – Index $(Q_i)_1$	$(W_i \times Q_i)_1$
Co	ND	10	10	0.001	nd	nd
Zn	7	2000	3000	0.0002	*299.3	0.0599
Cd	ND	3	3	0.3	nd	nd
Pb	ND	10	10	0.70	nd	nd
Fe	65	300	200	0.005	*135	0.675
				$\Sigma_{w_i}(1)$ =1.0062		$* \ \Sigma_{Wi \times Qi}(1)$ = 0.7349

nd = not-defined

$* \ \Sigma_{w_i}(1)$= 0.001+0.0002+0.3+0.70+0.005 = 1.0062

$* \ \Sigma_{Wi \times Qi}(1)$= 0.0559 + 0.675= 0.7349

$$Q_i = \sum_{i=1}^{1} \frac{|M_i - I_i|}{S_i - I_i} \times 100$$

$$*Zn_{Qi} = \sum_{i=1}^{1} \frac{|7-3000|}{2000-3000} \times 100$$

Zn_{Qi} = 299.3

$$*Fe_{Qi} = \sum_{i=1}^{1} \frac{|65-200|}{300-200} \times 100$$

Fe_{Qi} = 135

$$*HPI_1 = \sum_{i=1}^{n} \frac{|W_i \times Q_i|}{W_i}$$

$$HPI_1 = \sum_{i=1}^{n} \frac{0.7349}{1.0062}$$

HPI_1 = 0.730

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Table 4.3 is for Heavy Metal Pollution index (HPI) computation for borehole BH (1) during the dry season.

Table 4.3: HPI Computation for Borehole BH (1) with the limit of detection of the Instrument for Metals not detected.

Heavy Metal	Mean Value µg/L	Standard Permissible Value	Highest Desirable Value	Unit Weightage $(W_i)_1$	Sub – Index $(Q_i)_1$	$(W_i \times Q_i)_1$
Co	10	10	10	0.001	0	0
Zn	7	2000	3000	0.0002	*299.3	0.0599
Cd	3	3	3	0.3	0	0
Pb	10	10	10	0.70	0	0
Fe	65	300	200	0.005	*135	0.675
				$\Sigma_{w_i}(1)$ = 1.0062		$* \ \Sigma_{W_i \times Q_i}(1)$ = 0.7349

$* \ \Sigma_{w_i}(1) = 0.001 + 0.0002 + 0.3 + 0.70 + 0.005 = 1.0062$

$* \ \Sigma_{W_i \times Q_i}(1) = 0.0559 + 0.675 = 0.7349$

$$*Q_i = \sum_{i=1}^{1} \frac{|M_i - I_i|}{S_i - I_i} \times 100$$

$$*Zn_{Q_i} = \sum_{i=1}^{1} \frac{|7-3000|}{2000-3000} \times 100$$

$Zn_{Q_i} = 299.3$

$$*Fe_{Q_i} = \sum_{i=1}^{1} \frac{|65-200|}{300-200} \times 100$$

$Fe_{Q_i} = 135$

$$*HPI_1 = \sum_{i=1}^{n} \frac{|W_i \times Q_i|}{W_i}$$

$$HPI_1 = \sum_{i=1}^{n} \frac{0.7349}{1.0062}$$

$$HPI_1 = 0.730$$

Table 4.4 is for Heavy Metal Pollution index (HPI) computation for borehole BH (2) during the dry season.

Table 4.4: HPI Computation for Borehole BH (2) with not detected (ND)for Metals not detected.

Heavy Metal	Mean Value µg/L	Standard Permissible Value	Highest Desirable Value	Unit Weightage $(W_i)_2$	Sub – Index $(Q_i)_2$	$(W_i \times Q_i)_2$
Co	ND	10	10	0.001	nd	nd
Zn	7	2000	3000	0.0002	299.3	0.0599
Cd	ND	3	3	0.3	nd	nd
Pb	ND	10	10	0.70	nd	nd
Fe	25	300	200	0.005	175	0.875
				$* \Sigma_{(Wi)2}$ =1.0062		$* \Sigma_{(Wi \times Qi)2}$ = 0.9349

nd = not-defined

$* \Sigma_{(Wi)2}$= 0.001+0.0002+0.3+0.70+0.005 = 1.0062

$* \Sigma_{(Wi \times Qi)2}$= 0.0559 + 0.875= 0.9349

$$Q_i = \sum_{i=1}^{1} \frac{|M_i - I_i|}{S_i - I_i} \times 100$$

$$Zn_{Qi} = \sum_{i=1}^{1} \frac{|7-3000|}{2000-3000} \times 100$$

Zn_{Qi} = 299.3

$$Fe_{Qi} = \sum_{i=1}^{1} \frac{|25-200|}{300-200} \times 100$$

Fe_{Qi} = 175

$$HPI_2 = \sum_{i=1}^{n} \frac{|W_i \times Q_i|}{W_i}$$

$$HPI_2 = \sum_{i=1}^{n} \frac{0.9349}{1.0062}$$

HPI_2 = 0.929

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Table 4.5 is for Heavy Metal Pollution index (HPI) computation for borehole BH (2) during the dry season.

Table 4.5: HPI Computation for Borehole BH (2) with the Limit of detection of the Instrument for Metals not detected.

Heavy Metal	Mean Value µg/L	Standard Permissible Value	Highest Desirable Value	Unit weightage $(W_i)_2$	Sub – Index $(Q_i)_2$	$(W_i \times Q_i)_2$
Co	10	10	10	0.001	0	0
Zn	7	2000	300	0.0002	*299.3	0.0599
Cd	3	3	3	0.3	0	0
Pb	10	10	10	0.70	0	0
Fe	25	300	200	0.005	*175	0.875
				$* \Sigma_{(Wi)2}$ = 1.0062		$* \Sigma_{(Wi \times Qi)2}$ = 0.9349

$* \Sigma_{(Wi)2}$= 0.001+0.0002+0.3+0.70+0.005 = 1.0062

$* \Sigma_{(Wi \times Qi)2}$= 0.0559 + 0.875= 0.9349

$$Q_i = \sum_{i=1}^{1} \frac{|M_i - I_i|}{S_i - I_i} \times 100$$

$$*Zn_{Qi} = \sum_{i=1}^{1} \frac{|7-3000|}{2000-3000} \times 100$$

$Zn_{Qi} = 299.3$

$$*Fe_{Qi} = \sum_{i=1}^{1} \frac{|25-200|}{300-200} \times 100$$

$Fe_{Qi} = 175$

$$*HPI_2 = \sum_{i=1}^{n} \frac{|W_i \times Q_i|}{W_i}$$

$$HPI_2 = \sum_{i=1}^{n} \frac{0.9349}{1.0062}$$

$HPI_2 = 0.929$

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Table 4.6 is for Heavy Metal Pollution index (HPI) computation for borehole BH (3) during the dry season.

Table 4.6: HPI Computation for Borehole (BH) 3 with not detected (ND)for Metals not detected.

Heavy Metal	Mean Value µg/L	Standard Permissible Value	Highest Desirable Value	Unit Weightage $(W_i)_3$	Sub – Index $(Q_i)_3$	$(W_i \times Q_i)_3$
Co	ND	10	10	0.001	nd	nd
Zn	5	2000	3000	0.0002	*299.5	0.0599
Cd	ND	3	3	0.3	nd	nd
Pb	ND	10	10	0.70	nd	nd
Fe	11	300	200	0.005	*189	0.945
				$*\ \Sigma_{(Wi)3}$ = 1.0062		$*\ \Sigma_{(Wi \times Qi)3}$ = 1.0049

nd = not-defined

$*\ \Sigma_{(Wi)3} = 0.001+0.0002+0.3+0.70+0.005 = 1.0062$

$*\ \Sigma_{(Wi \times Qi)3} = 0.0559 + 0.945 = 1.0049$

$$Q_i = \sum_{i=1}^{1} \frac{|M_i - I_i|}{S_i - I_i} \times 100$$

$$*Zn_{Qi} = \sum_{i=1}^{1} \frac{|5-3000|}{2000-3000} \times 100$$

$Zn_{Qi} = 299.5$

$$*Fe_{Qi} = \sum_{i=1}^{1} \frac{|11-200|}{300-200} \times 100$$

$Fe_{Qi} = 189$

$$*HPI_3 = \sum_{i=1}^{n} \frac{|W_i \times Q_i|}{W_i}$$

$$HPI_3 = \sum_{i=1}^{n} \frac{1.0049}{1.0062}$$

$HPI_3 = 0.999$

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Table 4.7 is for Heavy Metal Pollution index (HPI) computation for borehole BH (3) during the dry season.

Table 4.7: HPI Computation for Borehole (BH) 3 with the Limit of detection of the Instrument for Metals not detected.

Heavy Metal	Mean Value µg/L	Standard Permissible Value	Highest Desirable Value	Unit Weightage $(W_i)_3$	Sub - Index $(Q_i)_3$	$(W_i \times Q_i)_3$
Co	10	10	10	0.001	0	0
Zn	5	2000	300	0.0002	*299.5	0.0599
Cd	3	3	3	0.3	0	0
Pb	10	10	10	0.70	0	0
Fe	11	300	200	0.005	*189	0.945
				$* \Sigma_{(Wi)3}$ = 1.0062		$* \Sigma_{(Wi \times Qi)3}$ = 1.0049

$* \Sigma_{(Wi)3} = 0.001+0.0002+0.3+0.70+0.005 = 1.0062$

$* \Sigma_{(Wi \times Qi)3} = 0.0559 + 0.945 = 1.0049$

$$Q_i = \sum_{i=1}^{1} \frac{|M_i - I_i|}{S_i - I_i} \times 100$$

$$*Zn_{Qi} = \sum_{i=1}^{1} \frac{|5-3000|}{2000-3000} \times 100$$

$Zn_{Qi} = 299.5$

$$*Fe_{Qi} = \sum_{i=1}^{1} \frac{|11-200|}{300-200} \times 100$$

$Fe_{Qi} = 189$

$$*HPI_3 = \sum_{i=1}^{n} \frac{|W_i \times Q_i|}{W_i}$$

$$HPI_3 = \sum_{i=1}^{n} \frac{1.0049}{1.0062}$$

$HPI_3 = 0.999$

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Table 4.8 is for Heavy Metal Pollution index (HPI) computation for borehole BH (4) during the dry season.

Table 4.8: HPI Computation for Borehole (BH) 4 with not detected (ND)for Metals not detected.

Heavy Metal	Mean Value µg/L	Standard Permissible Value	Highest Desirable Value	Unit Weightage $(W_i)_4$	Sub – Index $(Q_i)_4$	$(W_i \times Q_i)_4$
Co	ND	10	10	0.001	nd	nd
Zn	8	2000	3000	0.0002	*299.2	0.05984
Cd	ND	3	3	0.3	nd	nd
Pb	ND	10	10	0.70	nd	nd
Fe	14	300	200	0.005	*186	0.93
				$* \Sigma_{(Wi)4}$ = 1.0062		$* \Sigma_{(Wi \times Qi)4}$ = 0.9898

nd = not-defined

$* \Sigma_{(Wi)4}$= 0.001+0.0002+0.3+0.70+0.005 = 1.0062

$* \Sigma_{(Wi \times Qi)4}$= 0.05984 + 0.93= 0.9898

$$Q_i = \sum_{i=1}^{1} \frac{|M_i - I_i|}{S_i - I_i} \times 100$$

$$*Zn_{Qi} = \sum_{i=1}^{1} \frac{|8-3000|}{2000-3000} \times 100$$

$$Zn_{Qi} = 299.2$$

$$*Fe_{Qi} = \sum_{i=1}^{1} \frac{|14-200|}{300-200} \times 100$$

$$Fe_{Qi} = 186$$

$$*HPI_4 = \sum_{i=1}^{n} \frac{|W_i \times Q_i|}{W_i}$$

$$HPI_4 = \sum_{i=1}^{n} \frac{0.9898}{1.0062}$$

$$HPI_4 = 0.984$$

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Table 4.9 is for Heavy Metal Pollution index (HPI) computation for borehole BH (4) during the dry season.

Table 4.9: HPI Computation for Borehole BH (4) with the Limit of detection of the Instrument for Metals not detected.

Heavy Metal	Mean Value µg/L	Standard Permissible Value	Highest Desirable Value	Unit Weightage $(W_i)_4$	Sub – Index $(Q_i)_4$	$(W_i \times Q_i)_4$
Co	10	10	10	0.001	0	0
Zn	8	2000	300	0.0002	*299.2	0.05984
Cd	3	3	3	0.3	0	0
Pb	10	10	10	0.70	0	0
Fe	14	300	200	0.005	*186	0.93
				$* \Sigma_{(Wi)4}$ = 1.0062		$* \Sigma_{(Wi \times Qi)4}$ = 0.9898

$* \Sigma_{(Wi)4}$= 0.001+0.0002+0.3+0.70+0.005 = 1.0062

$* \Sigma_{(Wi \times Qi)4}$= 0.05984 + 0.93= 0.9898

$$Q_i = \sum_{i=1}^{1} \frac{|M_i - I_i|}{S_i - I_i} \times 100$$

$$*Zn_{Qi} = \sum_{i=1}^{1} \frac{|8-3000|}{2000-3000} \times 100$$

Zn_{Qi} = 299.2

$$*Fe_{Qi} = \sum_{i=1}^{1} \frac{|14-200|}{300-200} \times 100$$

Fe_{Qi} = 186

$$*HPI_4 = \sum_{i=1}^{n} \frac{|W_i \times Q_i|}{W_i}$$

$$HPI_4 = \sum_{i=1}^{n} \frac{0.9898}{1.0062}$$

HPI_4 = 0.984

Table 11 is for Heavy Metal Pollution index (HPI) Computation for Borehole BH (5) during the Dry Season.

Table 4.10: HPI Computation for Borehole BH (5) with not detected (ND)for Metals not detected.

Heavy Metal	Mean Value µg/L	Standard Permissible Value	Highest Desirable Value	Unit Weightage $(W_i)_5$	Sub - Index $(Q_i)_5$	$(W_i \times Q_i)_5$
Co	ND	10	10	0.001	nd	nd
Zn	142	2000	3000	0.0002	285.8	0.05716
Cd	ND	3	3	0.3	nd	nd
Pb	ND	10	10	0.70	nd	nd
Fe	78	300	200	0.005	122	0.61
				$* \Sigma_{(Wi)5}$ = 1.006		$* \Sigma_{(Wi \times Qi)5}$ = 0.6672

nd = not-defined

$* \Sigma_{(Wi)5}$= 0.001+0.0002+0.3+0.70+0.005 = 1.0062

$* \Sigma_{(Wi \times Qi)5}$ =0.05716 + 0.61= 0.6672

$$Q_i = \sum_{i=1}^{1} \frac{|M_i - I_i|}{S_i - I_i} \times 100$$

$$*Zn_{Qi} = \sum_{i=1}^{1} \frac{|142-3000|}{2000-3000} \times 100$$

Zn_{Qi} = 285.8

$$*Fe_{Qi} = \sum_{i=1}^{1} \frac{|78-200|}{300-200} \times 100$$

Fe_{Qi} = 122

$$*HPI_A = \sum_{i=1}^{n} \frac{|W_i \times Q_i|}{W_i}$$

$$HPI_A = \sum_{i=1}^{n} \frac{0.6672}{1.0062}$$

HPI_A = 0.663

Table 4.11 is for Heavy Metal Pollution index (HPI) computation for borehole BH (5) during the dry season.

Table 4.11: HPI Computation for Borehole BH (5) with the Limit of detection of the Instrument for Metals not detected.

Heavy Metal	Mean Value µg/L	Standard Permissible Value	Highest Desirable Value	Unit Weightage $(W_i)_5$	Sub - Index $(Q_i)_5$	$(W_i \times Q_i)_5$
Co	10	10	10	0.001	0	0
Zn	142	2000	3000	0.0002	*285.8	0.05716
Cd	3	3	3	0.3	0	0
Pb	10	10	10	0.70	0	0
Fe	78	300	200	0.005	*122	0.61
				$* \Sigma_{(Wi)5}$ = 1.0062		$* \Sigma_{(Wi \times Qi)5}$ = 0.6672

$* \Sigma_{(Wi)5} = 0.001+0.0002+0.3+0.70+0.005 = 1.0062$

$* \Sigma_{(Wi \times Qi)5} = 0.05716 + 0.61 = 0.6672$

$$Q_i = \sum_{i=1}^{1} \frac{|M_i - I_i|}{S_i - I_i} \times 100$$

$$*Zn_{Qi} = \sum_{i=1}^{1} \frac{|142-3000|}{2000-3000} \times 100$$

$Zn_{Qi} = 285.8$

$$*Fe_{Qi} = \sum_{i=1}^{1} \frac{|78-200|}{300-200} \times 100$$

$Fe_{Qi} = 122$

$$*HPI_5 = \sum_{i=1}^{n} \frac{|W_i \times Q_i|}{W_i}$$

$$HPI_5 = \sum_{i=1}^{n} \frac{0.6672}{1.0062}$$

$HPI_5 = 0.663$

Table 4.12 is for Heavy Metal Pollution index (HPI) computation for borehole BH (6) during the dry season.

Table 4.12: HPI Computation for Borehole BH (6) with not detected (ND) for Metals not detected.

Heavy Metal	Mean Value µg/L	Standard Permissible Value	Highest Desirable Value	Unit Weightage $(W_i)_6$	Sub – Index $(Q_i)_6$	$(W_i \times Q_i)_6$
Co	ND	10	10	0.001	nd	nd
Zn	ND	2000	3000	0.0002	*300	0.06
Cd	ND	3	3	0.3	nd	nd
Pb	ND	10	10	0.70	nd	nd
Fe	7	300	200	0.005	*193	0.965
				$* \Sigma_{(Wi)6}$ = 1.0062		$* \Sigma_{(Wi \times Qi)6}$ = 1.025

nd = not-defined

$* \Sigma_{(Wi)6}$= 0.001+0.0002+0.3+0.70+0.005 = 1.0062

$* \Sigma_{(Wi \times Qi)6}$= 0.06 + 0.965= 1.025

$$Q_i = \sum_{i=1}^{1} \frac{|M_i - I_i|}{S_i - I_i} \times 100$$

$$*Zn_{Qi} = \sum_{i=1}^{1} \frac{|0-3000|}{2000-3000} \times 100$$

Zn_{Qi} = 300

$$*Fe_{Qi} = \sum_{i=1}^{1} \frac{|7-200|}{300-200} \times 100$$

Fe_{Qi} = 193

$$*HPI_6 = \sum_{i=1}^{n} \frac{|W_i \times Q_i|}{W_i}$$

$$HPI_6 = \sum_{i=1}^{n} \frac{1.025}{1.0062}$$

HPI_6 = 1.019

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Table 4.13 is for Heavy Metal Pollution index (HPI) computation for borehole BH (6) during the dry season.

Table 4.13: HPI Computation for Borehole BH (6) with the limit of detection of the Instrument for Metals not detected.

Heavy Metal	Mean Value µg/L	Standard Permissible Value	Highest Desirable Value	Unit Weightage $(W_i)_6$	Sub – Index $(Q_i)_6$	$(W_i \times Q_i)_6$
Co	10	10	10	0.001	0	0
Zn	2000	2000	3000	0.0002	*100	0.02
Cd	3	3	3	0.3	0	0
Pb	3	10	10	0.70	0	0
Fe	7	300	200	0.005	*193	0.965
				$* \Sigma_{(Wi)6}$ = 1.0062		$* \Sigma_{(Wi \times Qi)6}$ = 0.985

$* \Sigma_{(Wi)6}$= 0.001+0.0002+0.3+0.70+0.005 = 1.0062

$* \Sigma_{(Wi \times Qi)6}$= 0.02 + 0.965= 0.985

$$Q_i = \sum_{i=1}^{1} \frac{|M_i - I_i|}{S_i - I_i} \times 100$$

$$*Zn_{Qi} = \sum_{i=1}^{1} \frac{|2000-3000|}{2000-3000} \times 100$$

Zn_{Qi} = 0.02

$$*Fe_{Qi} = \sum_{i=1}^{1} \frac{|7-200|}{300-200} \times 100$$

Fe_{Qi} = 193

$$*HPI_6 = \sum_{i=1}^{n} \frac{|W_i \times Q_i|}{W_i}$$

$$HPI_6 = \sum_{i=1}^{n} \frac{0.985}{1.0062}$$

HPI_6 = 0.979

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Descriptive summary statistics table for heavy metals during the dry season

Table 4.14: Descriptive Summary Statistics for Heavy Metals during the Dry Season

Parameter	Units	Min	Max	Mean	Median	Stdev	Mac^a
Temp	^{0}C	26.7	26.8	26.78	26.8	0.041	
pH		6.78	7.41	7.15	7.21	0.228	6.5-8.5
E.C	µS/cm	740	5500	2326.5	2018.5	1643.19	1400
COD	mg/L	8	46.4	26.466	27.4	12.57	250
Co	µg/l	<0.010	<0.010	<0.010	<0.010	<0.010	1000
Zn	µg/l	5	142	28	7	55.37	5000
Cd	µg/l	<0.003	<0.003	<0.003	<0.003	<0.003	3
Pb	µg/l	<0.010	<0.010	<0.010	<0.010	<0.010	1.5
Fe	µg/l	7	78	33.33	19.5	30.44	200

Source: Laboratory data, 2021

Correlation matrix between the parameters during the dry season

Table 4.15: Correlation Matrix between the Parameters during the Dry Season

	pH	Temp	E.C	COD	Zn	Fe	HPI_A	HPI_B
pH	1	-0.557	-0.655	-0.950**	-0.802	-0.919**	.0920**	0.897*
Temp		1	0.242	0.758	0.212	0.424	-0.424	-0.330
E.C			1	0.681	0.946**	0.494	-0.497	-0.491
COD				1	0.748	0.811	-0.812*	-0.761
Zn					1	0.725	-0.728	-0.734
Fe						1	-1.000**	-0.995**
HPI_A							1	0.995**
HPI_B								1

Source: Laboratory data, 2021

*. Correlation is significant at the 0.05 level (2-tailed).

**. Correlation is significant at the 0.01 level (2-tailed).

Table 4.16: HPI of Groundwater at each Sampling point during the Dry Season (mean HPI_A = 0.887 and HPI_B = 0.880)

Sampling Point	HPI_A	HPI_B	HPI Classification
1	0.730	0.730	LOW
2	0.929	0.929	LOW
3	0.999	0.999	LOW
4	0.984	0.984	LOW
5	0.663	0.663	LOW
6	1.019	0.979	LOW

Source: Laboratory data, 2021

Table 4.17: HPI Classification Table

HPI	QUALITY OF WATER
0-25	Very good
26-50	Good
51-75	Poor
Above 75	Very poor (unsuitable for drinking)

(Majhi & Biswal, 2016)

The HPI was calculated by taking the mean concentration value of the selected metals determined using the two equations discussed in the indexing approach. The standards used for the computation of the HPI are given in Table 2 with unit weightage (Wi), standard permissible values (Si), highest permissible values (Ii) and maximum admissible concentration (MAC) are presented for the groundwater under study. Two approaches have been used to calculate the HPI values. In the first instance, heavy metals that were not detected by the instrument is assigned zero concentration. In the second instance, these heavy metals were assigned the limit of detection of the instrument as if they were present to that extent. The two HPI computations for not detected (ND) for metals not detected and for the limit of detection of the instrument for metals not detected for the groundwater were calculated to be 0.887 and 0.880 respectively. The near sameness of these values

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indicates that both approaches could be used to calculate the HPI. This assertion is buttressed by strong positive significant correlation ($P<0.01$) between the two HPI. The mean HPI were below the critical value of 100. The HPI of each sampling point was also calculated separately (Table 4.16). This enabled comparison of quality of water at each ground water sampling point with respect to the determined heavy metals. The HPI of the groundwater was below the critical index value of 100. In fact all the HPI could be classified as low because it is lower than 25 and the quality of water has been very good.

The correlation analysis of parameters using the Statistical Package for the Social Sciences (SPSS 16.0 package) is presented in Table 4.15. Correlation at 99% level of confidence ($P<0.01$) demonstrated significant correlation between Zn and E.C. Which corresponds to the increase in the concentration of Zn as E.C increases.

Furthermore, there was a strong positive significant correlation between pH and HPI, the pH also correlated negatively with all metals. The pH of a solution is dependent on hydrogen ion concentration. Therefore, the negative correlation between pH and all metals analysed in this work is remarkable and consistent with the redox potential of the metals relative to hydrogen.

4.2 Physicochemical Parameters for the Rainy Season

4.2.1 pH

The pH of water provides information about the solubility, biological availability and chemical processes within water bodies, and indicates the relative acidic or basic nature of water.All the samples analysed produced values of pH lying within the drinking water guideline values of 6.5-8.5(WHO.2006) with the exception of one sampling point BH(6), with pH of 8.6 as shown in Figure 4.5 below. At high pH, water taste can be sour with soapy feeling. Directly, very low or high pH values can burn mucous membranes of the intestinal mucosa (Fatoki & Muyima,2003). Acceptable pH range for palatable water is therefore set from 6.0-9.0 (Ghana EPA. 1997) . The pH of water samples recorded values ranging from 6.52-7.46 with a mean value of 7.08±0.15. The lowest pH value was recorded at BH (5) and BH (6) recorded the highest mean value. The pH values of the groundwater recorded were slightly alkaline, hence the results were considered good enough for domestic purposes. Mitharwal *et al* (2009) indicated that pH of water is an essential indicator to determine water quality and gives information on various types of geochemical equilibrium that occurs in water. This is represented in Figure 4.5

Figure 4.5: Mean pH Values of Groundwater in Effutu Municipality during the Rainy Season.

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4.2.2 Temperature

Temperature is an important biological factor which plays an important role in the metabolic activities of living things (Murhekar, 2011). The mean temperature ranged between 24.4℃ and 25.5℃ and a mean of 24.88 ± 0.17℃ (Figure 4.6). The mean temperature values received for the entire study were within the WHO permissible values that is between 22 ℃ and 29 ℃ for drinking water (Addo, Darko, Gordon, & Nyarko, 2011), hence there were no threats to human and aquatic life. The variations in the temperature of water samples recorded could be because of depth of the water, season of sampling, groundwater influx, air circulation and the weather conditions that prevailed during the period of sampling and investigations (Peirce et al.1998). This is represented in Figure 4.6

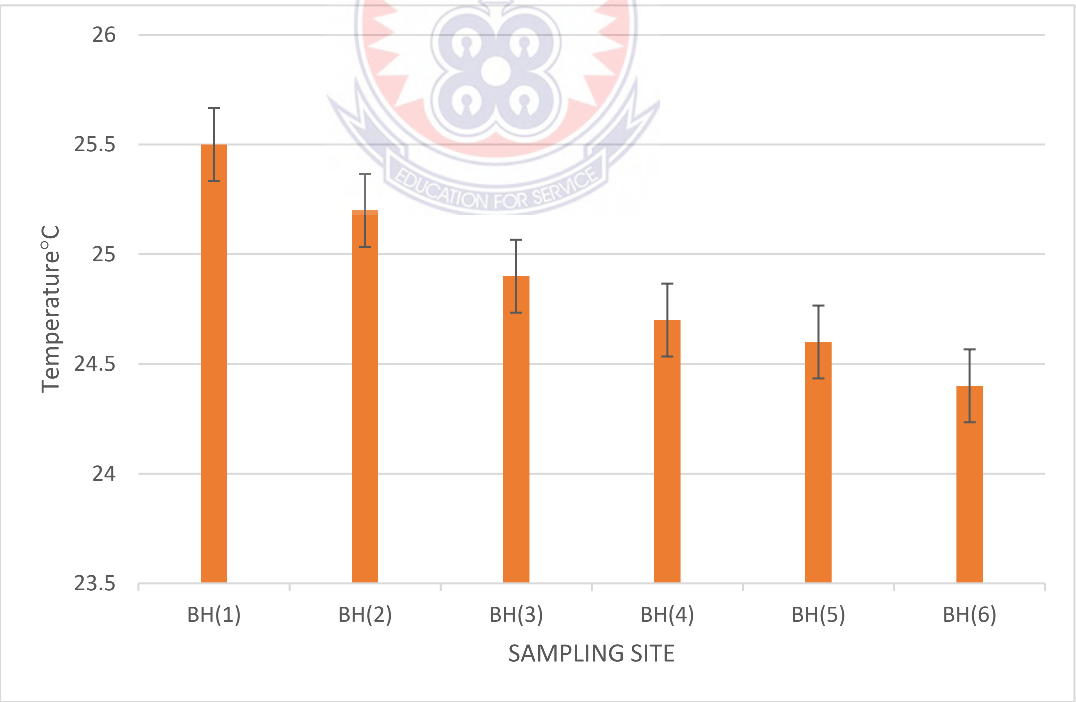

Figure 4.6: Mean Temperature Values of Groundwater in Effutu Municipality during the Rainy Season.

4.2.3 Electrical conductivity

Electrical conductivity is related to the mass of total dissolved solids and other ions in a water body and gives information about the level of mineralization of the water under study (Gyamfi, et al.2012). The average E.C value ranges at a minimum of 887 µS/cm at BH(1) to a maximum of 7380 µS/cm at BH(5). Two communities registered average conductivity values that were below the WHO (2006) permissible limit of 1000 µS/cm for drinking water whiles four (4) communities registered average conductivity values above the WHO(2006) permissible limit of 1000 µS/cm for drinking water. Mean value recorded is 2865.17±972.95µS/cm which fall above the WHO(2006) standard of 1000 µS/cm. The average conductivity values recorded at five(5) sample sites were generally high compared with GEPA standard of 1500 µS/cm whilst two sites were generally low compared with GEPA standards of 1500 µS/cm as can be seen in fig 4.7. Electrical conductivity is mainly caused by dissolved inorganic salts such as sodium and sulphate salts. Higher levels of TDS concentration can impart salty or bitter taste to water thereby making it undesirable for consumption. Water with high salty concentration causes excessive scaling in distribution pipes, heaters, and boilers (Gray.2008).

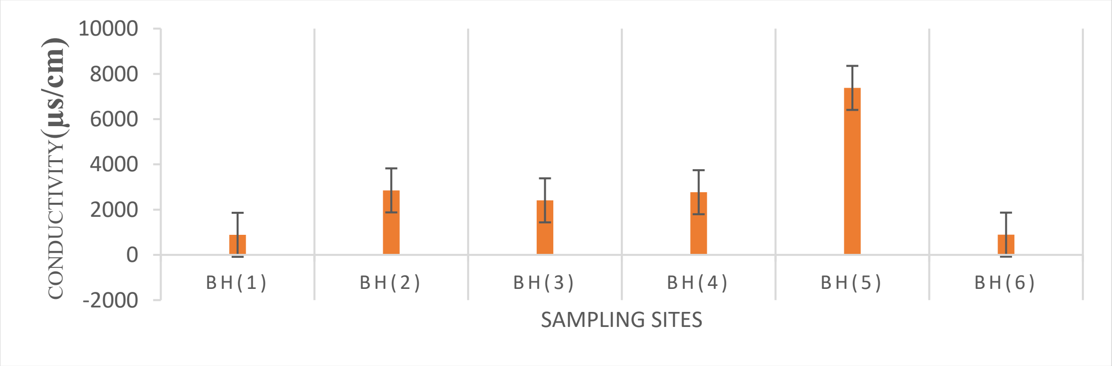

Figure 4.7: Mean Conductivity Values of Groundwater in Effutu Municipality during the Rainy Season.

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4.2.4 Chemical oxygen demand (COD)

The chemical oxygen demand (COD) is a measure of water and wastewater quality. The COD is the amount of oxygen consumed to chemically oxidize organic water contaminants to inorganic end products. Higher COD levels mean a greater amount of oxidizable organic material in the sample, which will reduce dissolved oxygen (DO) levels. A reduction in DO can lead to anaerobic conditions, which is deleterious to higher aquatic life forms. The mean COD values gave a range of 17.6 mg/L as its lowest value at BH(6) to 41.6 mg/L being its' highest value at BH(5). The average value was 31.73 ± 3.61. The mean COD values obtained from all the sampling sites were below the standard of 250 mg/L, as represented in Figure 4.8.

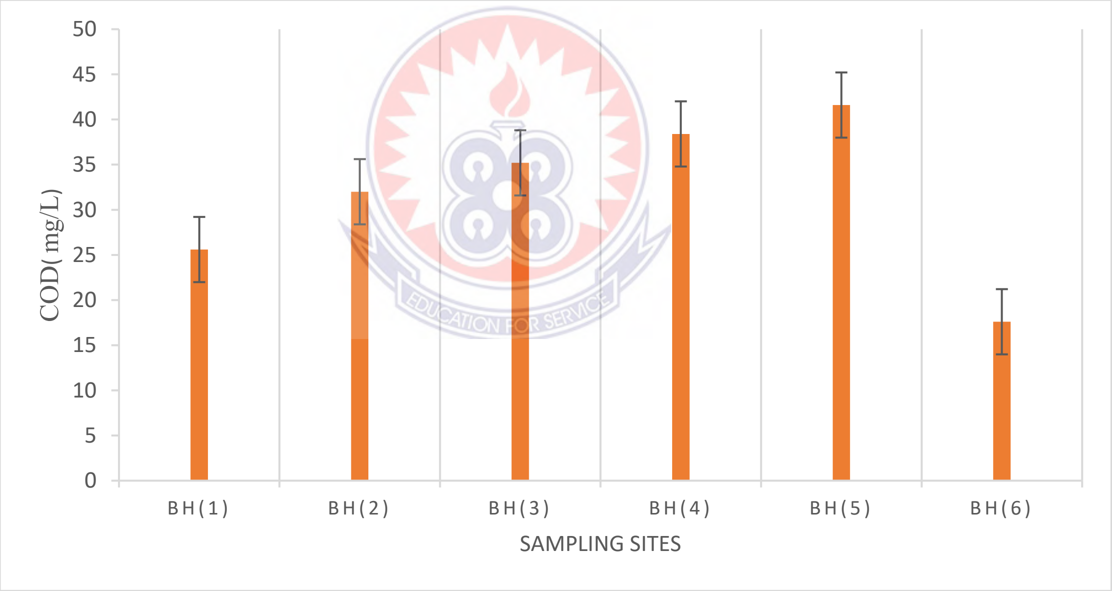

Figure 4.8: Mean COD Values of Groundwater in Effutu Municipality during the Rainy Season.

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Table 4.18 is for Heavy Metal Pollution index (HPI) computation for borehole BH (1) during the rainy season.

Table 4.18: HPI Computation for Borehole (BH) 1 with not detected (ND) for Metals not detected.

Heavy Metal	Mean Value µg/L	Standard Permissible Value	Highest Desirable Value	Unit Weightage $(W_i)_1$	Sub – Index $(Q_i)_1$	$(W_i \times Q_i)_1$
Co	ND	10	10	0.001	nd	Nd
Zn	11	2000	3000	0.0002	*298	0.0596
Cd	ND	3	3	0.3	nd	Nd
Pb	ND	10	10	0.70	nd	Nd
Fe	57	300	200	0.005	*143	0.715
				$* \Sigma_{w_i}(1)$ = 1.0062		$* \Sigma_{W_i \times Q_i}(1)$ = 0.7746

nd = not-defined

$* \Sigma_{w_i}(1) = 0.001+0.0002+0.3+0.70+0.005 = 1.0062$

$* \Sigma_{W_i \times Q_i}(1) = 0.0596 + 0.715 = 0.7746$

$$Q_i = \sum_{i=1}^{1} \frac{|M_i - I_i|}{S_i - I_i} \times 100$$

$$*Zn_{Qi} = \sum_{i=1}^{1} \frac{|11-3000|}{2000-3000} \times 100$$

$Zn_{Qi} = 298$

$$*Fe_{Qi} = \sum_{i=1}^{1} \frac{|57-200|}{300-200} \times 100$$

$Fe_{Qi} = 143$

$$HPI_1 = \sum_{i=1}^{n} \frac{|W_i \times Q_i|}{W_i}$$

$$HPI_1 = \sum_{i=1}^{n} \frac{0.7746}{1.0062}$$

$HPI_1 = 0.76$

Table 4.19 is for Heavy Metal Pollution index (HPI) computation for borehole BH (1) during the rainy season.

Table 4.19: HPI Computation for Borehole BH (1) with the Limit of Detection of the Instrument for Metals not detected.

Heavy Metal	Mean Value µg/L	Standard Permissible Value	Highest Desirable Value	Unit Weightage $(W_i)_1$	Sub – Index $(Q_i)_1$	$(W_i \times Q_i)_1$
Co	10	10	10	0.001	0	0
Zn	11	2000	3000	0.0002	*298	0.0596
Cd	3	3	3	0.3	0	0
Pb	10	10	10	0.70	0	0
Fe	57	300	200	0.005	*143	0.715
				$* \Sigma_{w_i}(1)$ = 1.0062		$* \ \Sigma_{Wi \times Qi}(1)$ = 0.7746

nd = not-defined

$* \Sigma_{w_i}(1)$= 0.001+0.0002+0.3+0.70+0.005 = 1.0062

$* \Sigma_{Wi \times Qi}(1)$= 0.0596+ 0.715= 0.7746

$$Q_i = \sum_{i=1}^{1} \frac{|M_i - I_i|}{S_i - I_i} \times 100$$

$$*Zn_{Qi} = \sum_{i=1}^{1} \frac{|11-3000|}{2000-3000} \times 100$$

Zn_{Qi}= 298

$$*Fe_{Qi} = \sum_{i=1}^{1} \frac{|57-200|}{300-200} \times 100$$

Fe_{Qi} = 143

$$HPI_1 = \sum_{i=1}^{n} \frac{|W_i \times Q_i|}{W_i}$$

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$$HPI_1 = \sum_{i=1}^{n} \frac{0.7746}{1.0062}$$

$$HPI_A = 0.760$$

Table 4.20 is for Heavy Metal Pollution index (HPI) computation for borehole BH (2) during the rainy season.

Table 4.20: HPI Computation for Borehole BH (2) with not detected (ND) for Metals not detected.

Heavy Metal	Mean Value µg/L	Standard Permissible Value	Highest Desirable Value	Unit Weightage $(W_i)_B$	Sub – Index $(Q_i)_B$	$(W_i \times Q_i)_B$
Co	ND	10	10	0.001	nd	nd
Zn	30	2000	3000	0.0002	*297	0.0594
Cd	ND	3	3	0.3	nd	nd
Pb	ND	10	10	0.70	nd	nd
Fe	10	300	200	0.005	*190	0.95
				$* \Sigma_{w_i}(A)$ = 1.0062		$* \Sigma_{Wi \times Qi}(A)$ = 1.0094

nd = not-defined

$* \Sigma_{w_i}(1) = 0.001+0.0002+0.3+0.70+0.005 = 1.0062$

$* \Sigma_{Wi \times Qi}(1) = 0.0594 + 0.95 = 1.0094$

$$Q_i = \sum_{i=1}^{1} \frac{|M_i - I_i|}{S_i - I_i} \times 100$$

$$*Zn_{Qi} = \sum_{i=1}^{1} \frac{|30-3000|}{2000-3000} \times 100$$

$$Zn_{Qi} = 297$$

$$*Fe_{Qi} = \sum_{i=1}^{1} \frac{|10-200|}{300-200} \times 100$$

$$Fe_{Qi} = 190$$

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$$\mathrm{HPI_A} = \sum_{i=1}^{n} \frac{|W_i \times Q_i|}{W_i}$$

$$\mathrm{HPI_A} = \sum_{i=1}^{n} \frac{1.0094}{1.0062}$$

$$\mathrm{HPI_A} = 1.00$$

Table 4.21 is for Heavy Metal Pollution index (HPI) computation for borehole BH (2) during the rainy season.

Table 4.21: HPI Computation for Borehole BH (2) with the Limit of Detection of the Instrument for Metals not detected.

Heavy Metal	Mean Value µg/L	Standard Permissible Value	Highest Desirable Value	Unit Weightage $(W_i)_2$	Sub – Index $(Q_i)_2$	$(W_i \times Q_i)_2$
Co	10	10	10	0.001	0	0
Zn	30	2000	300	0.0002	*297	0.0594
Cd	3	3	3	0.3	0	0
Pb	10	10	10	0.70	0	0
Fe	10	300	200	0.005	*190	0.95
				$* \Sigma_{w_i}(2)$ = 1.0062		$* \Sigma_{W_i \times Q_i}(2)$ = 1.0094

$* \Sigma_{w_i}(1) = 0.001+0.0002+0.3+0.70+0.005 = 1.0062$

$* \Sigma_{W_i \times Q_i}(1) = 0.0594 + 0.95 = 1.0094$

$$Q_i = \sum_{i=1}^{1} \frac{|M_i - I_i|}{S_i - I_i} \times 100$$

$$*\mathrm{Zn_{Qi}} = \sum_{i=1}^{1} \frac{|30-3000|}{2000-3000} \times 100$$

$\mathrm{Zn_{Qi}} = 297$

$$*\mathrm{Fe_{Qi}} = \sum_{i=1}^{1} \frac{|10-200|}{300-200} \times 100$$

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$Fe_{Qi} = 190$

$$HPI_2 = \sum_{i=1}^{n} \frac{|W_i \times Q_i|}{W_i}$$

$$HPI_2 = \sum_{i=1}^{n} \frac{1.0094}{1.0062}$$

$$HPI_2 = 1.00$$

Table 4.22 is for Heavy Metal Pollution index (HPI) computation for borehole BH (3) during the rainy season.

Table 4.22: HPI Computation for Borehole BH (3) with not detected (ND) for Metals not detected.

Heavy Metal	Mean Value µg/L	Standard Permissible Value	Highest Desirable Value	Unit Weightage $(W_i)_3$	Sub – Index $(Q_i)_3$	$(W_i \times Q_i)_3$
Co	ND	10	10	0.001	nd	nd
Zn	9	2000	3000	0.0002	*299.1	0.05982
Cd	ND	3	3	0.3	nd	nd
Pb	ND	10	10	0.70	nd	nd
Fe	3	300	200	0.005	*197	0.985
				$* \Sigma_{w_i}(3)$ = 1.0062		$* \Sigma_{Wi \times Qi}(3)$ = 1.04482

nd = not-defined

$* \Sigma_{w_i}(1) = 0.001 + 0.0002 + 0.3 + 0.70 + 0.005 = 1.0062$

$* \Sigma_{Wi \times Qi}(1) = 0.05982 + 0.985 = 1.04482$

$$Q_i = \sum_{i=1}^{1} \frac{|M_i - I_i|}{S_i - I_i} \times 100$$

$$*Zn_{Qi} = \sum_{i=1}^{1} \frac{|9 - 3000|}{2000 - 3000} \times 100$$

$Zn_{Qi} = 299.1$

$$*Fe_{Qi} = \sum_{i=1}^{1} \frac{|3-200|}{300-200} \times 100$$

$$Fe_{Qi} = 197$$

$$HPI_3 \quad = \sum_{i=1}^{n} \frac{|W_i \times Q_i|}{W_i}$$

$$HPI_3 \quad = \sum_{i=1}^{n} \frac{1.04482}{1.0062}$$

$$HPI_3 \quad = 1.04$$

Table 4.23 is for Heavy Metal Pollution index (HPI) computation for borehole BH (3) during the rainy season.

Table 4.23: HPI Computation for Borehole BH (3) with the Limit of Detection of the Instrument for Metals not detected.

Heavy Metal	Mean Value µg/L	Standard Permissible Value	Highest Desirable Value	Unit Weightage $(W_i)_3$	Sub – Index $(Q_i)_3$	$(W_i \times Q_i)_3$
Co	10	10	10	0.001	0	0
Zn	9	2000	3000	0.0002	*299.1	0.05982
Cd	3	3	3	0.3	0	0
Pb	10	10	10	0.70	0	0
Fe	3	300	200	0.005	*197	0.985
				$* \Sigma_{w_i}(3)$ $= 1.0062$		$* \ \Sigma_{Wi \times Qi}(3)$ $= 1.04482$

$* \Sigma_{w_i}(1) = 0.001+0.0002+0.3+0.70+0.005 = 1.0062$

$* \Sigma_{Wi \times Qi}(1) = 0.05982 + 0.985 = 1.04482$

$$Q_i = \sum_{i=1}^{1} \frac{|M_i - I_i|}{S_i - I_i} \times 100$$

$$*Zn_{Qi} = \sum_{i=1}^{1} \frac{|9-3000|}{2000-3000} \times 100$$

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$Zn_{Qi} = 299.1$

$$*Fe_{Qi} = \sum_{i=1}^{1} \frac{|3-200|}{300-200} \times 100$$

$Fe_{Qi} = 197$

$$HPI_3 = \sum_{i=1}^{n} \frac{|W_i \times Q_i|}{W_i}$$

$$HPI_3 = \sum_{i=1}^{n} \frac{1.04482}{1.0062}$$

$HPI_3 = 1.04$

Table 4.24 is for Heavy Metal Pollution index (HPI) computation for borehole BH (4) during the rainy season.

Table 4.24: HPI Computation for Borehole BH (4) with not detected (ND) for metals not detected.

Heavy Metal	Mean Value µg/L	Standard Permissible Value	Highest Desirable Value	Unit weightage $(W_i)_4$	Sub – Index $(Q_i)_4$	$(W_i \times Q_i)_4$
Co	ND	10	10	0.001	nd	nd
Zn	6	2000	3000	0.0002	*299.9	0.0599
Cd	ND	3	3	0.3	nd	nd
Pb	ND	10	10	0.70	nd	nd
Fe	4	300	200	0.005	196	0.98
				$*\,\Sigma_{w_i}(A)$ = 1.0062		$*\,\Sigma_{Wi \times Qi}(A)$ = 1.0399

nd = not-defined

$*\,\Sigma_{w_i}(1) = 0.001+0.0002+0.3+0.70+0.005 = 1.0062$

$*\,\Sigma_{Wi \times Qi}(1) = 0.0599 + 0.98 = 1.0399$

$$Q_i = \sum_{i=1}^{1} \frac{|M_i - I_i|}{S_i - I_i} \times 100$$

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$$*Zn_{Qi} = \sum_{i=1}^{1} \frac{|6-3000|}{2000-3000} \times 100$$

$$Zn_{Qi} = 299.9$$

$$*Fe_{Qi} = \sum_{i=1}^{1} \frac{|4-200|}{300-200} \times 100$$

$$Fe_{Qi} = 196$$

$$HPI_4 \;= \sum_{i=1}^{n} \frac{|W_i \times Q_i|}{W_i}$$

$$HPI_4 \;= \sum_{i=1}^{n} \frac{1.0399}{1.0062}$$

$$HPI_4 \;= 1.03$$

Table 4.25 is for Heavy Metal Pollution index (HPI) computation for borehole BH (4) during the rainy season.

Table 4.25: HPI Computation for Borehole BH (4) with the Limit of Detection of the Instrument for Metals not detected.

Heavy Metal	Mean Value µg/L	Standard Permissible Value	Highest Desirable Value	Unit Weightage $(W_i)_4$	Sub – Index $(Q_i)_4$	$(W_i \times Q_i)_4$
Co	10	10	10	0.001	0	0
Zn	6	2000	300	0.0002	*299.2	0.0599
Cd	3	3	3	0.3	0	0
Pb	10	10	10	0.70	0	0
Fe	4	300	200	0.005	196	0.98
				$* \Sigma_{w_i}(4)$ = 1.0062		$* \Sigma_{Wi \times Qi}(4)$ = 1.0399

$* \Sigma_{w_i}(1) = 0.001 + 0.0002 + 0.3 + 0.70 + 0.005 = 1.0062$

$* \Sigma_{Wi \times Qi}(1) = 0.0599 + 0.98 = 1.0399$

$$Q_i = \sum_{i=1}^{1} \frac{|M_i - I_i|}{S_i - I_i} \times 100$$

$$*Zn_{Qi} = \sum_{i=1}^{1} \frac{|6-3000|}{2000-3000} \times 100$$

$$Zn_{Qi} = 299.9$$

$$*Fe_{Qi} = \sum_{i=1}^{1} \frac{|4-200|}{300-200} \times 100$$

$$Fe_{Qi} = 196$$

$$HPI_4 = \sum_{i=1}^{n} \frac{|W_i \times Q_i|}{W_i}$$

$$HPI_4 = \sum_{i=1}^{n} \frac{1.0399}{1.0062}$$

$$HPI_4 = 1.03$$

Table 4.26 is for Heavy Metal Pollution index (HPI) computation for borehole BH (5) during the rainy season.

Table 4.26: HPI Computation for Borehole BH (5) with not detected (ND) for Metals not detected.

Heavy Metal	Mean Value µg/L	Standard Permissible Value	Highest Desirable Value	Unit Weightage $(W_i)_5$	Sub – Index $(Q_i)_5$	$(W_i \times Q_i)_5$
Co	ND	10	10	0.001	nd	nd
Zn	178	2000	3000	0.0002	*282.8	0.05644
Cd	ND	3	3	0.3	nd	nd
Pb	ND	10	10	0.70	nd	nd
Fe	7	300	200	0.005	193	0.965
				$* \Sigma_{w_i}(5)$ = 1.0062		$* \Sigma_{Wi \times Qi}(5)$ = 1.02144

nd = not-defined

$$* \Sigma_{w_i}(1) = 0.001+0.0002+0.3+0.70+0.005 = 1.0062$$

$$* \Sigma_{Wi \times Qi}(1) = 0.05644 + 0.965 = 1.02144$$

$$Q_i = \sum_{i=1}^{1} \frac{|M_i - I_i|}{S_i - I_i} \times 100$$

$$*Zn_{Qi} = \sum_{i=1}^{1} \frac{|178-3000|}{2000-3000} \times 100$$

$$Zn_{Qi} = 282.8$$

$$*Fe_{Qi} = \sum_{i=1}^{1} \frac{|7-200|}{300-200} \times 100$$

$$Fe_{Qi} = 193$$

$$HPI_5 = \sum_{i=1}^{n} \frac{|W_i \times Q_i|}{W_i}$$

$$HPI_5 = \sum_{i=1}^{n} \frac{1.02144}{1.0062}$$

$$HPI_5 = 1.02$$

Table 4.27 is for Heavy Metal Pollution index (HPI) computation for borehole BH (5) during the rainy season.

Table 4.27: HPI Computation for Borehole BH (5) with the Limit of Detection of the Instrument for Metals not detected.

Heavy Metal	Mean Value µg/L	Standard Permissible Value	Highest Desirable Value	Unit Weightage $(W_i)_5$	Sub – Index $(Q_i)_5$	$(W_i \times Q_i)_5$
Co	10	10	10	0.001	0	0
Zn	178	2000	3000	0.0002	*282.2	0.05644
Cd	3	3	3	0.3	0	0
Pb	10	10	10	0.70	0	0
Fe	7	300	200	0.005	*193	0.965
				$* \Sigma_{w_i}(5) = 1.0062$		$* \Sigma_{Wi \times Qi}(5) = 1.02144$

$* \Sigma_{w_i}(1) = 0.001+0.0002+0.3+0.70+0.005 = 1.0062$

$* \Sigma_{Wi \times Qi}(1) = 0.05644 + 0.965 = 1.02144$

$$Q_i = \sum_{i=1}^{1} \frac{|M_i - I_i|}{S_i - I_i} \times 100$$

$$*Zn_{Qi} = \sum_{i=1}^{1} \frac{|178-3000|}{2000-3000} \times 100$$

$Zn_{Qi} = 282.2$

$$*Fe_{Qi} = \sum_{i=1}^{1} \frac{|7-200|}{300-200} \times 100$$

$Fe_{Qi} = 193$

$$HPI_5 = \sum_{i=1}^{n} \frac{|W_i \times Q_i|}{W_i}$$

$$HPI_5 = \sum_{i=1}^{n} \frac{1.02144}{1.0062}$$

$$HPI_5 = 1.02$$

Table 4.28 is for Heavy Metal Pollution index (HPI) computation for borehole BH (6) during the rainy season.

Table 4.28: HPI Computation for Borehole BH (6) with not detected (ND) for Metals not detected.

Heavy Metal	Mean Value µg/L	Standard Permissible Value	Highest Desirable Value	Unit Weightage $(W_i)_6$	Sub – Index $(Q_i)_6$	$(W_i \times Q_i)_6$
Co	ND	10	10	0.001	nd	nd
Zn	11	2000	3000	0.0002	*298.9	0.05978
Cd	ND	3	3	0.3	nd	nd
Pb	ND	10	10	0.70	nd	nd
Fe	183	300	200	0.005	*17	0.085
				$* \Sigma_{w_i}(6)$ = 1.0062		* $\Sigma_{W_i \times Q_i}(6)$ = 0.14478

nd = not-defined

$* \Sigma_{w_i}(1)$= 0.001+0.0002+0.3+0.70+0.005 = 1.0062

$* \Sigma_{W_i \times Q_i}(1)$= 0.05978+ 0.085= 0.14478

$$Q_i = \sum_{i=1}^{1} \frac{|M_i - I_i|}{S_i - I_i} \times 100$$

$$*Zn_{Qi} = \sum_{i=1}^{1} \frac{|11-3000|}{2000-3000} \times 100$$

$$Zn_{Qi} = 298.9$$

$$*Fe_{Qi} = \sum_{i=1}^{1} \frac{|183-200|}{300-200} \times 100$$

$$Fe_{Qi} = 17$$

$$\mathrm{HPI}_6 = \sum_{i=1}^{n} \frac{|W_i \times Q_i|}{W_i}$$

$$\mathrm{HPI}_6 = \sum_{i=1}^{n} \frac{0.14478}{1.0062}$$

$$\mathrm{HPI}_6 = 0.144$$

Table 4.29 is for Heavy Metal Pollution index (HPI) computation for borehole BH (6) during the rainy season.

Table 4.29: HPI Computation for Borehole BH (6) with the Limit of Detection of the Instrument for Metals not detected.

Heavy Metal	Mean Value µg/L	Standard Permissible Value	Highest Desirable Value	Unit Weightage $(W_i)_6$	Sub – Index $(Q_i)_6$	$(W_i \times Q_i)_6$
Co	10	10	10	0.001	0	0
Zn	11	2000	3000	0.0002	*298.9	0.05978
Cd	3	3	3	0.3	0	0
Pb	3	10	10	0.70	0	0
Fe	183	300	200	0.005	*17	0.085
				$* \Sigma_{w_i}(6)$ $= 1.0062$		$* \Sigma_{Wi \times Qi}(6)$ $= 0.14478$

$* \Sigma_{w_i}(1) = 0.001 + 0.0002 + 0.3 + 0.70 + 0.005 = 1.0062$

$* \Sigma_{Wi \times Qi}(1) = 0.05978 + 0.085 = 0.14478$

$$Q_i = \sum_{i=1}^{1} \frac{|M_i - I_i|}{S_i - I_i} \times 100$$

$$*\mathrm{Zn}_{Qi} = \sum_{i=1}^{1} \frac{|11 - 3000|}{2000 - 3000} \times 100$$

$$\mathrm{Zn}_{Qi} = 298.9$$

$$*\mathrm{Fe}_{\mathrm{Qi}} = \sum_{i=1}^{1} \frac{|183-200|}{300-200} \times 100$$

$$\mathrm{Fe}_{\mathrm{Qi}} = 17$$

$$\mathrm{HPI}_6 = \sum_{i=1}^{n} \frac{|W_i \times Q_i|}{W_i}$$

$$\mathrm{HPI}_6 = \sum_{i=1}^{n} \frac{0.14478}{1.0062}$$

$$\mathrm{HPI}_6 = 0.144$$

Descriptive summary statistics table for heavy metals during the raining season.

Table 4.30: Descriptive Summary Statistics for Heavy Metals during the Raining Season

Parameter	Units	Min	Max	Mean	Median	Stdev	Mac^a
Temp	^{0}C	24.4	25.5	24.88	24.8	0.41	
pH		7.4	8.6	7.71	7.6	0.47	6.5-8.5
E.C	µS/cm	887	7380	2865.17	2590	2383.23	1400
COD	mg/L	17.6	41.6	31.73	33.6	8.84	250
Co	µg/l	<0.010	<0.010	<0.010	<0.010	<0.010	1000
Zn	µg/l	6	178	40.8	11	67.73	5000
Cd	µg/l	<0.003	<0.003	<0.003	<0.003	<0.003	3
Pb	µg/l	<0.010	<0.010	<0.010	<0.010	<0.010	1.5
Fe	µg/l	10	183	35.17	17	72.77	200

Source: Laboratory data, 2021

Correlation matrix between the parameters during the raining season

Table 4.31: Correlation Matrix between the Parameters during the Raining Season

	pH	**Temp**	**E.C**	**COD**	**Zn**	**Fe**	**HPI$_1$**	**HPI$_2$**
pH	1	-0.343	-0.648	-0.882*	-0.458	-0.451	-0.959**	-0.955**
Temp		1	-0.318	-0.046	-0.293	-0.256	0.355	0.358
E.C			1	0.781	0.936**	0.914*	0.530	0.541
COD				1	0.538	0.529	0.902*	0.905*
Zn					1	0.993**	0.277	0.291
Fe						1	0.272	0.286
HPI$_1$							1	0.999**
HPI$_2$								1

Source: Laboratory data, 2021

*. Correlation is significant at the 0.05 level (2-tailed).

**. Correlation is significant at the 0.01 level (2-tailed).

Table 4.32: HPI of Groundwater at each Sampling Point during the Rainy Season (Mean HPI$_1$ = 0.832 and HPI$_2$ = 0.832)

Sampling Point	**HPI$_1$**	**HPI$_2$**	**HPI Classification**
1	0.76	0.76	LOW
2	1.000	1.000	LOW
3	1.04	1,04	LOW
4	1.03	1.03	LOW
5	1.02	1.02	LOW
6	0.144	0.144	LOW

Source: Laboratory data, 2021

Table 4.33: HPI Classification Table

HPI	Quality of Water
0-25	Very good
26-50	Good
51-75	Poor
Above 75	Very poor (unsuitable for drinking)

(Majhi & Biswal. 2016)

The HPI for the raining season was calculated by taking the mean concentration value of the selected metals determined using the two equations discussed in the indexing approach. The standards used for the computation of the HPI are given in Table 2 with unit weightage (Wi), standard permissible values (Si), highest permissible values (Ii) and maximum admissible concentration (MAC) are presented for the groundwater under study. Two approaches have been used to calculate the HPI values. In the first instance, heavy metals that were not detected by the instrument is assigned zero concentration. In the second instance, these heavy metals were assigned the limit of detection of the instrument as if they were present to that extent. The two HPI computations for not detected (ND) for metals not detected and for the limit of detection of the instrument for metals not detected for the groundwater were calculated to be 0.832 and 0.832 respectively. The near sameness of these values indicates that both approaches could be used to calculate the HPI. This assertion is buttressed by strong positive significant correlation ($P<0.01$) between the two HPI. The mean HPI were below the critical value of 100. The HPI of each sampling point was also calculated separately (Table 4.32). This enabled comparison of quality of water at each ground water sampling point with respect to the determined heavy metals. The HPI of the groundwater was below the critical index value of 100. In fact all the HPI could be classified as low because they are lower than 25 and the quality of water being very good.

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The correlation analysis of parameters using the Statistical Package for the Social Sciences (SPSS 16.0 package) is presented in Table 4.31. Correlation at 99% level of confidence ($P<0.01$) demonstrated significant correlation between Zn and E.C; and Fe and E.C**.** Which corresponds to the increase in the concentration of Zn and Fe as E.C increases.

Furthermore, the pH also correlated negatively with all metals. The pH of a solution is dependent on hydrogen ion concentration. Therefore, the negative correlation between pH and all metals analysed in this work is remarkable and consistent with the redox potential of the metals relative to hydrogen.

4.3 Inferential Statistics

Table for the Heavy Metal Pollution Index computation during the dry and rainy season.

Table 4.34: Heavy Metal Pollution Index during the Dry and Rainy Season

HPI_A	HPI_B	HPI_1	HPI_2
0.730	0.730	0.76	0.76
0.929	0.929	1.000	1.000
0.999	0.999	1.04	1,04
0.984	0.984	1.03	1.03
0.663	0.663	1.02	1.02
1.019	0.979	0.144	0.144

HPI_A = Heavy Metal Pollution Index with not detected (ND) for metals not detected during the dry season.

HPI_B = Heavy Metal Pollution Index with limit of detection of the instrument for metals not detected during the dry season.

HPI_1 = Heavy Metal Pollution Index with not detected (ND) for metals not detected during the rainy season.

HPI_2 = Heavy Metal Pollution Index with limit of detection of the instrument for metals not detected during the rainy season.

4.4 One Factor Anova Analyses

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

$HPI_A = HPI_B = HPI_1 = HPI_2$

Alternate Hypothesis: Ha: There is a statistically significant difference between the means of HPI for the dry season and the raining season (using not detected (ND) for metals not detected and the limit of detection of the instrument for metals not detected).

$HPI_A \neq HPI_B \neq HPI_1 \neq HPI_2$

Table 4.35: Anova Summary Table

Groups	Count	Sum	Average	Variance
HPI_1	6	4.994	0.832333	0.124913
HPI_2	6	4.994	0.832333	0.124913
HPI_A	6	5.324	0.887333	0.023193
HPI_B	6	5.284	0.880667	0.021353

Table 4.36: Anova Table

Source of Variation	SS	df	MS	F	P-Value	F Critical
Between Groups	0.01615	3	0.005383	0.07315	0.973693	3.098391
Within Groups	1.471857	2	0.073593			
Total	1.488007	23				

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From the Anova Table, because the calculated P-value is greater than 0.05, we fail to reject the null hypothesis because there is no significant difference between the means of HPI for the rainy season and the dry season using not detected (ND) for metals not detected and the limit of detection of the instrument for metals not detected. Therefore,

$HPI_A = HPI_B = HPI_1 = HPI_2$

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CHAPTER FIVE

CONCLUSION AND RECOMMENDATIONS

5.0 Overview

This chapter deals with the conclusions, recommendations and suggestions drawn from the study.

5.1 Conclusions

Water samples collected from the groundwater in Effutu district were analysed for groundwater quality and its suitability for drinking and domestic purposes. It was also analysed for the levels of heavy metals. The results of the study showed that the groundwater is not polluted in both seasons. The mean values for the selected heavy metals of the groundwater in both seasons at the various sampling sites were within GSA permissible level for drinking water.

The mean values of the pH (7.15) for the dry season and pH (7.08) for the raining season assayed for the groundwater sampling sites were within the permissible limits of World Health Organisation (WHO, 2002) of (6.5-8.5) and Ghana standards Authority (GSA) of (6.0-9.0) and similar to values obtained by Cobbina et al(2009) and Yankey et al, (2013).

The mean Chemical Oxygen Demand (COD)(26.466 mg/L) in the dry season and mean Chemical Oxygen Demand (COD)(31.73 mg/L) in the raining season assayed for at the groundwater sampling sites were within the permissible limits of WHO(2002) of 250 mg/L and GSA(2009) of 250 mg/L.

The mean Electrical Conductivity (2326.5 µS/cm) in the dry season and mean Electrical Conductivity(2865.17 µS/cm) in the raining season assayed for at the

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groundwater sampling sites were above the permissible limits of WHO(2002) of 1400µS/cm and GSA(2009) of 1413µS/cm.

The pollution index model proposed appears to be promising and proved to be a useful tool in evaluating the composite quality of heavy metal pollution of the water. The index is highly useful to get the rightful conclusion of overall quality of water with a systematic rating. The pollution index is also used for comparative purpose of quality characteristics at different sampling sites and also to discuss the quality criteria of particular area in detail. The study clearly indicates that, the selected groundwater sites in the Effutu district were found to be free from heavy metal pollution and can therefore be used for human consumption.

5.2 Recommendations

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

- There should be regular follow-up studies to measure the levels of heavy metals and other toxic chemicals in the ground water. This is necessary to further substantiate this study.
- There should be increased environmental sanitation education by the Effutu Municipal Assembly in communities to prevent contamination of this water resource and subsequent transmission of water-related diseases.

5.3 Suggestions for Further Studies

A modern study of water levels in the groundwater throughout the Effutu Municipality would improve the regional numerical model by providing more recent data for calibration. A study of bedrock elevations, especially near the alluvium would be beneficial for quantifying total stream and alluvial outflow. A better understanding of pumping schedules and rates would allow a more sophisticated analysis to be completed showing actual depletions of the groundwater. A regional hydraulic

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conductivity and specific yield study would enable one to validate the model inputs. Further studies of evapotranspiration and recharge would significantly improve the water balance and the calibration of numerical models.

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APPENDIX A

ANALYSIS RESULTS DURING THE DRY SEASON

CONCENTRATION (mg/L) OF HEAVY METALS DURING THE DRY SEASON

		BH(1)	**BH(2)**	**BH(3)**	**BH(4)**	**BH(5)**	**BH(6)**
Cobalt	1	< 0.010	< 0.010	< 0.010	< 0.010	< 0.010	< 0.010
	2	< 0.010	< 0.010	< 0.010	< 0.010	< 0.010	< 0.010
	3	< 0.010	< 0.010	< 0.010	< 0.010	< 0.010	< 0.010
Zinc	1	0.007	0.007	0.005	0.008	0.142	< 0.005
	2	0.007	0.007	0.005	0.008	0.144	< 0.005
	3	0.007	0.007	0.005	0.008	0.141	< 0.005
Cadmium	1	< 0.002	< 0.002	< 0.002	< 0.002	< 0.002	< 0.002
	2	< 0.002	< 0.002	< 0.002	< 0.002	< 0.002	< 0.002
	3	< 0.002	< 0.002	< 0.002	< 0.002	< 0.002	< 0.002
Lead	1	< 0.005	< 0.005	< 0.005	< 0.005	< 0.005	< 0.005
	2	< 0.005	< 0.005	< 0.005	< 0.005	< 0.005	< 0.005
	3	< 0.005	< 0.005	< 0.005	< 0.005	< 0.005	< 0.005
Iron	1	0.065	0.024	0.009	0.014	0.076	0.007
	2	0.063	0.025	0.013	0.012	0.078	0.007
	3	0067	0.026	0.011	0.016	0.080	0.007

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pH OF GROUND WATER DURING THE DRY SEASON

	BH(1)	BH(2)	BH(3)	BH(4)	BH(5)	BH(6)
1	7.00	7.29	7.27	7.15	6.78	7.41
2	7.00	7.29	7.27	7.15	6.78	7.41

CONDUCTIVITY (µS/cm) OF GROUND WATER DURING THE DRY SEASON

	BH(1)	BH(2)	BH(3)	BH(4)	BH(5)	BH(6)
1	740	1882	2155	2168	5500	1514
2	740	1882	2155	2168	5500	1514

TEMPERATURE (°C) READINGS OF GROUND WATER DURING THE DRY SEASON

	BH(1)	BH(2)	BH(3)	BH(4)	BH(5)	BH(6)
1	26.8	26.8	26.8	26.8	26.8	26.7
2	26.8	26.8	26.8	26.8	26.8	26.8

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CHEMICAL OXYGEN DEMAND (mg/L) READINGS OF GROUND WATER DURING THE DRY SEASON

	BH(1)	**BH(2)**	**BH(3)**	**BH(4)**	**BH(5)**	**BH(6)**
1	32.0	24.0	24.0	30.4	46.4	8.00

APPENDIX B

ANALYSIS RESULTS DURING THE RAINING SEASON

CONCENTRATION (mg/L) OF HEAVY METALS DURING THE RAINING SEASON

		BH(1)	BH(2)	BH(3)	BH(4)	BH(5)	BH(6)
Cobalt	1	< 0.010	< 0.010	< 0.010	< 0.010	< 0.010	< 0.010
	2	< 0.010	< 0.010	< 0.010	< 0.010	< 0.010	< 0.010
	3	< 0.010	< 0.010	< 0.010	< 0.010	< 0.010	< 0.010
Zinc	1	0.011	0.029	0.007	0.006	1.180	0.011
	2	0.009	0.030	0.011	0.004	0.178	0.012
	3	0.013	0.032	0.009	0.008	0.176	0.011
Cadmium	1	< 0.002	< 0.002	< 0.002	< 0.002	< 0.002	< 0.002
	2	< 0.002	< 0.002	< 0.002	< 0.002	< 0.002	< 0.002
	3	< 0.002	< 0.002	< 0.002	< 0.002	< 0.002	< 0.002
Lead	1	< 0.005	< 0.005	< 0.005	< 0.005	< 0.005	< 0.005
	2	< 0.005	< 0.005	< 0.005	< 0.005	< 0.005	< 0.005
	3	< 0.005	< 0.005	< 0.005	< 0.005	< 0.005	< 0.005
Iron	1	0.057	0.008	0.003	0.004	0.007	0.181
	2	0.055	0.010	0.003	0.004	0.007	0.185
	3	0.059	0.012	0.003	0.004	0.007	0.183

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pH OF GROUND WATER DURING THE RAINING SEASON

	BH(1)	BH(2)	BH(3)	BH(4)	BH(5)	BH(6)
1	7.3	6.52	7.16	7.31	6.71	7.46
2	7.3	6.52	7.16	7.31	6.71	7.46

CONDUCTIVITY (µS/cm) OF GROUND WATER DURING THE RAINY SEASON

	BH(1)	BH(2)	BH(3)	BH(4)	BH(5)	BH(6)
1	887	2850	2410	2770	7380	894
2	887	2850	2410	2770	7380	894

TEMPERATURE (°C) READINGS OF GROUND WATER DURING THE RAINY SEASON

	BH(1)	BH(2)	BH(3)	BH(4)	BH(5)	BH(6)
1	25.5	25.2	24.9	24.7	24.6	24.4
2	25.5	25.2	24.9	24.7	24.6	24.4

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CHEMICAL OXYGEN DEMAND (mg/L) READINGS OF GROUND WATER DURING THE RAINY SEASON

	BH(1)	**BH(2)**	**BH(3)**	**BH(4)**	**BH(5)**	**BH(6)**
1	25.6	32.0	35.2	38.4	41.6	17.6