

**Concentration and Exposure Assessment of Antibiotics and Heavy Metals in
Groundwater Sources in Two Rural Communities in Nigeria**

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Certification

This is to certify that Adesola Olubunmi, ADEDEJI with Matric Number LCU/PG/002183 carried out this research work titled “Concentration and Exposure Assessment of Antibiotics and Heavy metals in Groundwater sources in Two Rural Communities in Oyo and Ogun States in Nigeria” in the Department of Chemical Sciences (Chemistry Unit), Faculty of Natural and Applied Sciences, Lead City University, Ibadan, Oyo State, for the award of Master Degree (M.Sc) in Chemistry and that this work has not been previously submitted.

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Dedication

This study is dedicated to the Almighty God, the creator of heaven and earth who granted me the grace to complete this work against all odds. Blessed be His holy name forever.

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Acknowledgement

I want to appreciate the Lead City University, Ibadan, Oyo state, Nigeria for the opportunity given to me that led to the discovery of the inherent potentials in me through a well-guided academic training.

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Even though the above-mentioned institutions and persons have assisted in the process of this research work, I alone stand responsible for the errors, if any found in the work.

Abstract

In most rural communities in Nigeria, access to potable water is of great concern. Likewise, several studies have linked heavy metals to the co-selection of antibiotic resistance, and Antibiotic Resistant Genes (ARGs). However, co-occurrence and exposure assessment data for antibiotics and heavy metals are scarce and when available are limited to urban areas. Hence, this study aims to investigate the occurrence, source, concentration and risk associated with antibiotic chemical residues and heavy metals in groundwater sources. A total of 30 groundwater samples from two rural communities were assessed for physicochemical parameters (pH, Temperature, Total Dissolved Solids (TDS), Electrical Conductivity (EC), and Dissolved Oxygen (DO)), heavy metals (B, Ca, Cd, Co, Cr, Cu, Fe, K, Mg, Mn, Na, Ni, Pb, Se, and Zn) and common antibiotics (ampicillin, chloramphenicol, ciprofloxacin and metronidazole). Samples for elemental analysis were digested using HNO₃ and those for antibiotics analysis were extracted using Solid Phase Extraction (SPE). Elemental and antibiotics quantifications were done using Inductively Coupled Plasma-Optical Emission Spectrometry (ICP-OES) and high-performance liquid chromatography-UV/Visible (HPLC-UV) systems respectively. All calibration curves exhibited $r^2 > 0.999$ and relative recovery experiments were within the acceptable range. Concentration data obtained were subjected to descriptive, inferential and multivariate analyses. The average concentrations of all heavy metals in groundwater samples were below the WHO permissible limit for drinking water except for Cr, Ni and Pb at 0.05, 0.02 and 0.10 mg L⁻¹ respectively. Although Ampicillin and Chloramphenicol concentrations were below the limit of detection, Ciprofloxacin (76 to 1137 µg L⁻¹) and Metronidazole (1191 to 7846 µg L⁻¹) detection ranged between 30-60% in all groundwater samples. Data from this study indicated that Cr, Ni and Pb contamination in groundwater and may pose a potential health risk to the local inhabitants who depend on well water for consumption and other domestic uses.

Keywords: Trace metals, Health risk assessments, Multivariate statistical technique.

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List of Acronyms

| Abbreviation | Meaning |
|---------------------|--|
| PPCPs | Pharmaceuticals and Personal Care Products |
| DDD | Defined Daily Dose |
| ARB | Antibiotic Resistance Bacteria |
| ARG | Antibiotic Resistance Gene |
| AR | Antibiotic Resistance |
| PNEC | Predicted No Effective Concentration |
| MEC | Measured Environmental Concentration |
| WWTP | Waste Water Treatment Plants |
| PWS | Public Water Supply |
| RQ | Risk Quotient |
| HM | Heavy Metals |
| HHRA | Human Health Risk Assessment |
| Rfd | Reference Dose |

| | |
|---------|---|
| ED | Exposure Duration |
| BW | Body Weight |
| PHQ | Potential Hazard Quotient |
| CDI | Chronic Daily Intake |
| ADI | Acceptable Daily Intake |
| THQ | Target Hazard Quotient |
| HQ | Hazard Quotient indices |
| TCR | Target Carcinogenic Risk |
| SF | Slope Factor |
| HI | Health Index |
| FEPA | Federal Environmental Protection Agency |
| USEPA | United State Environmental Protection Agency |
| WHO | World Health Organization |
| IUPAC | International Union of Pure and Applied Chemistry |
| NAFDAC | National Agency for Food and Drug Administrative Control |
| LOD | Limit of Detection |
| LOQ | Limit of Quantification |
| SPE | Solid Phase Extraction |
| HPLC-UV | High Performance Liquid Chromatography- Ultraviolet Detection |
| ICP-OES | Inductively Coupled Plasma-Optical Emission Spectrometry. |

ANOVA Analysis of Variance

PTE Potentially Toxic Element.

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Chapter One

Introduction

1.1 Background to the Study

Groundwater is the main source of freshwater globally, which accounts for 97% of available freshwater on earth, while the remaining 3% is primarily surface water¹. Groundwater is considered the most important source of public water supply in many regions of the world and a fundamental tool for social and economic development². Groundwater is basic for social and economic development, and it is the sole source of drinking for about 2.5 billion people around the world³. There are many reasons to develop groundwater, but among the most important are⁴:

Firstly, groundwater usually lies in underground natural reservoirs. This boosts groundwater as a convenient source of water. Furthermore, groundwater can be found in different volumes depending on the aquifer capacity. Many times, aquifers detaining water larger than many human-made reservoirs; for example, the Ogallala aquifer located in the United States produced up to 500 kg/m³ of water for four decades, which is larger than Nasser Lake in Egypt⁴. The massive quantities of groundwater give the ability to pump water during the dry period, while surface water (in some places) is unable to be pumped in these quantities or at such top quality during such a period.

In many cases, groundwater quality is superior to surface water. This is due to the capability of aquifers to provide natural protection for groundwater from contamination.

Secondly, groundwater is an affordable and valid source of water. It can be pumped out using small capital and can be drilled close to the site needed for water. In addition, groundwater can be easily structured, controlled and developed. For example, individuals can easily construct and manage their groundwater well on their land.

However, anthropogenic activities, mainly industrial and agricultural, endanger groundwater quality because many pollutants can potentially reach the aquifers¹. Some newly recognized classes of environmental contaminants such as pharmaceuticals and personal care products (PPCPs) have become a subject of scientific and public interest because of their potential bioactive properties and unknown effects on the water in the environment^{5,6}. Pharmaceuticals and personal care products (PPCPs) include numerous chemical classes of pharmaceuticals such as antibiotics, anti-inflammatory drugs, β -blockers, lipid regulators, antiepileptics, and X-ray contrast media. It also includes personal care product ingredients such as antimicrobials, synthetic musks, insect repellents, preservatives or sunscreen UV filters, together with their metabolites or transformation products. Antibiotics are a widely studied class that inhibits or restricts microorganisms' growth, e.g., bacteria, fungi, and protozoa^{7,8}. Antibiotics can amass in water bodies because they are only partially degraded in the environment and pose ecological and human health risks⁹. Various veterinary and human drugs are continuously released into the environment during manufacturing, disposal, or metabolic-excretions¹⁰.

The continuous release of these antibiotics into groundwater selects for antibiotic-resistant bacteria (ARBs) and antibiotic resistance genes (ARGs), which presents significant ecological and human health concerns worldwide¹¹. Resistant bacteria and genes when entering a healthy organism, tend to proliferate in there, increasing in number, therefore forming a resistance module against the antibiotic within the organisms¹². As a result, the curative abilities of the antibiotics are diminished. Studies have shown that antibiotics make their way into the water reservoirs and aquatic environments due to the inability of treatment plants to remove them altogether¹⁴. They possess high biological activity even at low concentrations and can cause toxic effects to human and aquatic life. It has been reported that even low-level exposure (ng L^{-1}) shows notable influence in damaging the normal body

function, especially if the dose was administered without necessity^{15,16}. Their use is unlikely to be restricted owing to the benefits they provide¹³. However, the absence of advanced treatment processes and the unrestricted use, and sale of such products in developing countries further worsens the problem¹⁷. As a way forward, it is essential to develop a correlation between antibiotics, their metabolites, and conventional water quality parameters¹⁸. Antibiotics' susceptibility to various chemical, biological, and physical treatment processes varies due to the diverse nature of their chemical classes. This requires further extensive studies to understand their action in groundwater environment and treatment processes required for mitigation¹⁹. The occurrence of veterinary antibiotics in groundwater located near swine and beef cattle facilities showed antibiotic levels similar to that of drinking water²⁰. Antibiotics have been found in groundwater along with numerous other organic compounds including pharmaceuticals, pesticides, industrial compounds, hormones, and personal care items, but the amounts are substantially lower than those found in rivers and WWTPs^{21,22,23,24,25,26}.

Chemicals and contaminants may be present in groundwater as a result of human and natural activities. Groundwater may include significant concentrations of metals such as arsenic (As), cadmium (Cd) and iron (Fe) that could be dissolved in it¹. The primary cause of groundwater contamination is human activities, specifically industrial discharges, waste disposal and agriculture practices. In addition, it could occur as a result of urban activities such as the excessive use of fertilizers, pesticides and chemicals which causes pollutants to migrate to groundwater and reach the water table. Whatever the case, specific tests are necessary to ensure groundwater is appropriate for drinking, irrigation or industrial purposes².

1.11 Overview of Antibiotics in Groundwater

Antibiotics are the products of rapid innovations in the health sector and their usage has changed the pattern of modern way of living. The first antibiotic, Penicillin was discovered by late Sir Alexander Fleming, an English Bacteriologist, in September 1928. He accidentally obtained the drug while studying a soil inhabiting fungus *Penicillium notatum*. However, its discovery was first reported in 1929, and clinical trials first conducted on humans in 1940^{27,28}. Ever since, it has been recognized that they can be used as a medicine to cure and prevent infectious diseases, their market has been expanding out of bounds. They have been widely and successfully used in human and veterinary medicines and their benefits have also been acknowledged in agriculture, aquaculture, bee-keeping, and livestock as growth promoters. Antibiotics can be defined as chemotherapeutic agents who restrain or annul the growth of micro-organisms. There are several different kinds of antibiotics and they can be classified based on their chemical structure, action mechanism, action spectrum, and the route of administration²⁷.

Antibiotics are deemed indispensable for the protection of human life, and both their manufacture and use have continuously increased^{30,31,32}. Substantial amounts of antibiotics consumed by humans or those administered to livestock during breeding are discharged into the environment via excreta through various routes such as compost, liquid manure, and runoff from breeding facilities. Subsequently, such antibiotics flowing into the environment have emerged as a new global concern due to their potential adverse effects^{33,34}. Many studies have suggested that antibiotics present at concentrations of several ng L^{-1} to $\mu\text{g L}^{-1}$ can inhibit the growth of aquatic organisms, plants, and humans^{35, 36, 37}. Antibiotics in the environment can be toxic, and can promote the occurrence of resistant bacteria, leading to the occurrence of potentially disastrous problems. Based on previous studies, deaths attributed to infections with antibiotic-resistant bacteria have been estimated to be around 700,000 a year^{38,39,40}.

Globally, the standards for the analysis and management of residual antibiotics in environmental media are insufficient; thus, it is necessary to evaluate their status^{31,32,33}. The concentrations of antibiotics in the environment are known to be impacted by various factors such as the pollution source, geography, climate, and usage patterns^{32,41,42}. As a result, it is important to monitor and analyse residual antibiotics in environmental media across space and time to understand their status in various watersheds and to establish effective management strategies to mitigate their environmental effects. Antibiotics are developed to induce biological effects, and can exert a wide range of impacts on ecosystems once released into the environment; therefore, it is crucial to evaluate their risks^{32,43}. Many studies have evaluated the ecological risk assessment of antibiotics, and it has been reported that a few antibiotic types pose potential risks^{44,45,46}. In general, risk quotient (RQ) values are majorly used for ecological risk assessment, which is calculated by dividing the maximum residual concentration by the predicted no effective concentration (PNEC)^{32,45,47}. Therefore, further ecological risk assessments must include the risk posed by the resistant bacteria, as they can lead to fatalities in both humans and other biota^{34,45,48}.

1.12 Overview of Elementals in Groundwater

Elements that have specific gravity ≥ 5 are regarded as heavy metals⁴⁹. Environmental scientists have recently been quite concerned about heavy metals monitoring in sources of potable water⁵⁰. Common heavy metals detected in effluents are iron (Fe), manganese (Mn), copper (Cu), lead (Pb), cadmium (Cd), chromium (Cr), mercury (Hg), cobalt (Co), and nickel (Ni)^{50,51,52}. Depending on the type, many heavy metals in water are toxic even at extremely low concentrations and can accumulate in the human body⁵³. These heavy metals have certain negative impacts on the living beings when they exceed permissible limits in potable water sources.

Typically, heavy metals in water cannot be degraded easily due to their complex bioaccumulation properties⁴⁹. Pb, Zn, Cd, Fe, Co, Mn, and Cr are frequently studied and reported in the potable water sources of Nigeria⁵³. Disease conditions may occur when humans are exposed to heavy metals above the permissible limits. Kolo and Waziri stated that heavy metals are very toxic and are mostly carcinogenic in nature because of their ability to accumulate in visual and sensory organs⁵⁴. They also possess the tendency to affect the tissue and other organs and cause various types of diseases including cancer.

1.2 Statement of the Problem

The continuous release of antibiotics into the environment can affect groundwater quality²⁴. Drinking such water can lead to toxicity and negative effect on non-target organisms. Consequently, this may result in antibiotic resistance which is currently the most serious global threat to the effective treatment of bacterial infections. Antibiotic resistance has been established to adversely affect both clinical and therapeutic outcomes, with consequences ranging from treatment failures and the need for expensive and safer alternative drugs to the cost of higher rates of morbidity and mortality, longer hospitalization, and high healthcare costs. Similarly, heavy metals in drinking water may pose a threat to human health. Populations are exposed to heavy metals primarily through water consumption, but few heavy metals can bioaccumulate in the human body and may induce cancer and other risks.

1.3 Justification of the Study

Antimicrobial resistance (AMR) is estimated to account for 700,000 deaths annually worldwide, which may increase by 2050 to approximately 10 million deaths annually⁵⁵. Lately, rural communities have experienced a sudden rise in the number of small and medium-scale animal productions coupled with the indiscriminate use of pharmaceutical products such as antibiotics. Antibiotics are continuously been released into the environment

during waste disposal, metabolic-excretions and may threaten groundwater quality because they can potentially reach the aquifers²². Antibiotics persist after application and exhibit a novel pattern of action hence; they are categorized as chemicals of emerging concerns. Similarly, metal contamination of groundwater has been linked to anthropogenic inputs and this has led to a gradual deterioration in the quality as well as constituting health risks to the populace; even at trace concentrations.

Data from developed countries have shown that antibiotics and heavy metal contamination are ubiquitous in the environment and responsible for extensive antibiotic resistance of microorganisms and carcinogens respectively. However, data from developing countries like Nigeria are inadequate due to a shortage of laboratory infrastructure and research funding. Therefore, in this study, the antibiotics and elemental quantification in groundwater samples from rural communities were done using a high-performance liquid chromatography-UV/Visible (HPLC-UV) system and Inductively Coupled Plasma Optical Emission Spectroscopy (ICP-OES) respectively.

1.4 Aim and Objectives of the Study

The study aims to assess the occurrence of selected antibiotics (ampicillin, chloramphenicol, metronidazole and ciprofloxacin) and their co-existed metals in groundwater samples within two rural communities in Ogun and Oyo states in Nigeria.

The specific objectives are to:

- i. determine the physicochemical status of groundwater samples.
- ii. determine the concentrations of ampicillin, chloramphenicol, metronidazole and ciprofloxacin in groundwater samples.

- iii. determine the concentrations of Ca, Mg, K, Na, Fe, Cu, Zn, Mn, B, Al, Co, Se Cd, Cr, Ni and Pb in groundwater samples.
- iv. assess the relationship between the studied parameters.

1.5 Research Questions

- i. What are the concentrations of antibiotics in the investigated groundwater samples?
- ii. What are the concentrations of the heavy metals in the groundwater samples investigated?
- iii. What are the relationships between parameters investigated in the sampling sites?
- iv. What are the environmental and human health impacts of these antibiotics and heavy metals in the rural communities?

1.6 Significance of the Study

Antibiotics and heavy metals are major pollutants in our environment causing grave and harmful consequences particularly on human health in the past few years. The study- area, two rural communities in Oyo and Ogun states in Nigeria is averagely populous and there are obvious pieces of evidences of freelance grazing of animals, poultry farming, open dump site and siting of groundwater near the main road which may result in elevated levels of contamination of the groundwater. The results of this study will provide a baseline information about the presence of antibiotics and heavy metals around the two rural communities and will also indicate the extent of health risks the children and adults are exposed to because of consumption of these groundwater.

1.7 Scope of the Study

This study considered four common antibiotics (Ampicillin, Chloramphenicol, Ciprofloxacin and Metronidazole) and sixteen inorganic elements (Ca Mg, K, Na, Fe, Cu, Zn, Mn, B, Al, Co, Se Cd, Cr, Ni and Pb) in groundwater samples. The sampling carried out in this study is within two rural communities in Oyo and Ogun States, Southwest Nigeria.

1.8 Limitations of the Study

The study considers the concentration and exposure assessment of antibiotics and heavy metals in only groundwater samples. Consequently, this work is limited to the determination of concentrations of four antibiotics (Ampicillin, Chloramphenicol, Ciprofloxacin and Metronidazole) and sixteen heavy metals (Ca Mg, K, Na, Fe, Cu, Zn, Mn, B, Al, Co, Se Cd, Cr, Ni and Pb).

1.9 Operational Definition of Terms

Antibiotic resistance: occurs when bacteria change as a result of antibiotic use.

Environment: the natural world, as a whole or in a particular geographical area especially as affected by human activity.

Pollution: the presence or introduction into the environment of a substance which have poisonous or harmful effects.

Contamination: the action or state of making or being made impure by polluting or poisoning.

Concentration: is the degree to which one substance is present in a mixture

Assessment: the collection of data to describe or better understand an issue

Hazardous: dangerous or risky, has potential to cause harm.

Toxic: poisonous substances

Anthropogenic: originating from human activity

Endnotes

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Chapter Two

Literature Review

2.1 Antibiotic Consumptions and Occurrences in the Environment

Over the decades, following the discovery of antibiotics, it has been observed that antibiotics use in human medicine, veterinary medicine, and agriculture is linked to environmental contamination. Contamination of different environmental compartments such as surface water, groundwater, drinking water, municipal sewage, soil, vegetables, and sludge has been widely reported and subsequently, leading to the increase in antibiotic resistance and its negative ecological effects¹. Furthermore, antibiotic use promotes antibiotic-resistant bacteria or resistance genes, which could be transferred from the environment to humans². It is assumed that increased antibiotic consumption may cause the failure of treatments in human medicine (infections caused by antibiotic-resistant bacteria), increasing the duration of illness, morbidity, and mortality^{3,4,5}.

Equally, antibiotics used in veterinary medicine and intensive livestock operations could lead to groundwater pollution. A study conducted by Balzer on 48 groundwater-sampling sites located in the high livestock density areas of Germany reported that of the 23 antibiotics

investigated; three sulphonamides were detected and quantified⁶. At the majority of the locations (39 sites), no antibiotics were detected; however, sulfadimidine and sulfadiazine were detected at concentrations less than $0.012 \mu\text{g L}^{-1}$, and sulfamethoxazole was detected at a concentration of above $0.1 \mu\text{g L}^{-1}$ ⁶. The study shows that in most locations in Germany, antibiotics pollution due to intensive livestock operations is below the detection limits. Similarly, the occurrence of a variety of antibiotics in groundwater and surface water was also reported in a catchment located in Lower Saxony, Germany⁷. Of the 15 shallow groundwater samples analysed for antibiotics concentrations, trimethoprim was detected in 11 samples⁷. This study demonstrated that the application of liquid manure eventually contaminated the surface and groundwater in the Lower Saxony area⁷.

Several studies have been conducted to further understand the occurrence, behaviour and fate of PPCPs in the environment in developed nations like the United Kingdom, the United States of America, Australia and Japan. However, very few studies in developing countries in Africa and South America have addressed this field of study^{8,9}. With a population of nearly 200 million people, Nigeria's lack of sufficient data on the prevalence and behaviour of PPCPs, compounded with the country's inadequate sewage treatment system (probably direct discharge into waterways) represent a cause for concern and a significant research gap. Most urban communities in Nigeria, with the exception of the capital Abuja and limited areas in Lagos, have no sewage system. Consequently, the sewage and sullage are either left to stagnant or are disposed of through the stormwater drainage system¹⁰. This is reinforced by the scarce data available on PPCPs in the environment of Nigeria, where high concentrations of 20 mg L^{-1} of paracetamol, chloroquine, diclofenac and ciprofloxacin were found in four surface water and groundwater samples collected from an industrial area of Sango Ota, Ogun State, Nigeria¹¹. In the absence of wastewater treatment procedures, dilution and degradation factors were suggested as natural mechanisms capable of lowering PPCPs concentrations in

Nigerian surface water¹². Many investigations have demonstrated that environmental conditions (weather/season), source characteristics, and water flow rates play significant roles in regulating the frequency of detection and concentrations of PPCPs in natural waters^{13,14}. There are just two major seasons in Nigeria (dry and rainy seasons). The dry season, known locally as the “Harmattan” is accompanied by a predominance of dust-laden air masses from the Sahara Desert. It usually starts in late October and lasts until early March with peak dry conditions between early December and late February. April marks the beginning of the rainy season and lasts until early October with peak wet conditions in June. The South Atlantic Ocean wind, also referred to as the South West wind has an impact on this season. At the peak of the rainy season, the weather in Lagos is wet about half the time¹⁵. In Sub-Saharan Africa, the provision of adequate high-quality drinking water has grown to be a significant challenge due to limited financial resources and rising climatic variability. Increasing trends in flash flood and drought in semi-arid region of Nigeria has contributed to decline in groundwater quality and quantity¹⁶. Extreme precipitation frequently causes the pollution of shallow aquifers and renders the groundwater unsafe for human consumption¹⁶. The provision of adequate and high-quality potable water is very important to good health and human development.

According to recent statistics, 33,000 persons in the EU die yearly as a result of infections with antibiotic-resistant bacteria, with 39% of the cases of death being associated with infections with bacteria resistant to last-line antibiotics such as carbapenems and colistin¹⁷. Similar circumstances exist in the U.S., where 2.8 million patients contract an antibiotic-resistant infection annually, and over 35,000 people die¹⁸. Unfortunately, antibiotic-resistant infections have a huge cost to the economy and healthcare system. The cost incurred is related to the fact that these infections require therapy with last-line antibiotics, which are significantly more expensive than first- and second-line antibiotic therapy. Also, the length of

hospitalization of the patient with antibiotic-resistant infections can be prolonged by 6.4 to 12.7 days. According to estimates, the economic burden caused by infections with antibiotic-resistant bacteria is EUR 1.5 billion per year in the EU in healthcare costs and productivity losses and \$55 billion in the U.S.^{19,20}. One of the recent comprehensive analyses of human antibiotic consumption estimated that between 2000 and 2015, antibiotic consumption, expressed in defined daily doses (DDD) increased by 65%, with a particularly rapid increase of the last resort antibiotics such as glycyclines, oxazolidinones, carbapenems and polymyxins. Also, we could also anticipate an increase up to 200% until 2030, if no policy modifications will be made²¹.

The advancement in instrumental analytical chemistry, employing electrophoretic and chromatographic techniques, like liquid chromatography-tandem mass spectrometry, enables us to reveal several various kinds of antibiotics at levels of ng L⁻¹, following solid-phase extraction^{22,23}. The development of screening and quantification methods, improvements in sample preparation for various environmental matrices and advancements in analytical accuracy and sensitivity are all necessary for improving assays and subsequently, assessments that address the risk to ecosystems and human health due to the presence of antibiotics in Agro-ecosystems and wastewaters.

2.2 Occurrence and Distribution of Antibiotics and Antibiotic Resistant Genes in Groundwater

Many regions worldwide have done studies on the occurrence and distribution of antibiotics and ARGs in groundwater^{24,25}. The levels of antibiotics and ARGs in groundwater vary across the countries and amongst different regions of the same country. In developed regions, data on antibiotics and ARGs groundwater contamination are more prevalent in Europe and the United States, but in developing regions, the data is more prevalent in China. China is the only nation in Asia with well-established literature on the occurrence of antibiotics and their

associated genes in groundwater²⁵. Whereas, In the American continent, the United States has the most published research on the concentration of antibiotics and ARGs in groundwater^{26,27}. Due to the limited availability of analytical techniques, the data on the occurrence of antibiotics in Africa is scarce. However, considerable data is available in Europe compared to other countries.

2.3 Occurrence of Antibiotic Resistant Bacteria in Groundwater

For billions of people across the world, groundwater serves as the main source of drinking water²⁸. Perhaps finding the sources and identifying the pathways for ARBs is critical, little is known about their proliferation in groundwater^{29,30}. Four-fifths of the isolates obtained from samples were resistant to one or more antimicrobial agent, according to an analysis of the occurrence of ARBs in the global groundwater samples³⁰. A study conducted by Akaniro and colleagues showed that about 86% of the isolates detected in groundwater samples were multidrug-resistant³¹. The results provided sufficient proof of the prevalence of ARBs in well water, indicating that they are the reservoirs for antibiotic-resistance genes³².

Dissemination and transport of bacteria into and within groundwater can be influenced by different environmental factors, such as characteristics of soil, pH, temperature, nature, the magnitude of organic matter, redox potential, water table depth, salinity, and other physiological parameters³³. Nevertheless, there is a requirement for systematic studies on the impact of human activities, such as septic tanks, livestock production facilities, and environmental factors on the transport and dissemination of ARBs in groundwater, particularly, in developing nations where the consumption of untreated potable water is common.

2.4 Antibiotic Resistance and Disease Outbreak

Available studies documenting human health risks of Antibiotic Resistance (AR) in potable water are largely limited to disease outbreaks attributed to the occurrence of antibiotic-resistant bacteria in drinking water. For example, a study in Pakistan investigated incidences of typhoid fever caused by ceftriaxone resistant *Salmonella enterica* serotype Typhi³⁴. In 2015, there was a Shigella outbreak at a kindergarten in China attributed to poor sanitary conditions of the drinking water supply in the canteen³⁵. Resistance to azithromycin and nalidixic acid was observed in Shigella isolates obtained from food and drinking water samples³⁵. *Escherichia coli* was found in 69% of 13 drinking water samples (n = 13) taken from the homes of people infected with ceftriaxone-resistant Salmonella Typhi indicating a possible fecal contamination of the drinking water³⁴. In Tajikistan, consumption of treated water contaminated with multi-drug resistant Salmonella Typhi resulted in nearly 9,000 cases and 100 deaths³⁶. A study using minimum inhibitory concentration by agar dilution, detected ampicillin and cotrimoxazole resistance in Cholera vibrio isolates from diarrheal stool (n =116) following a cholera outbreak³⁷. Although cholera outbreaks are associated with consumption of contaminated drinking water, the study did not identify whether AR was of human or environmental origin³⁸.

2.5 Antibiotics and Metals

Low sub-inhibitory antibiotic concentrations enhance the spread of ARGs in the water environment³⁹. For instance, sulfamethoxazole slightly increased antibiotic resistance's transfer frequency at sub-inhibitory concentration of antibiotics in an aquatic environment⁴⁰. The role of metals (e.g., Hg, Zn, Cu, and Cd) in the co-selection of antibiotic resistance might be another significant factor contributing towards ARGs' spread⁴¹. Compared with control areas, bacteria in metal-contaminated environments easily obtain antibiotic resistance phenotypes⁴². Co-selection mechanisms include co-resistance and cross-resistance. Co-resistance occurs when a single genetic element carries various resistance determinants,

whereas, in cross-resistance, a single genetic determinant lead to antibiotic as well as metal resistance. Thus, metal contamination is a major contributor to antibiotic resistance and is crucial in environmental and clinical settings⁴³. Since the literature on fate and transport of ARGs in groundwater is limited, more comprehensive research is needed to identify the key factors influencing ARGs spread.

2.6 Chemistry of Antibiotics

Over 10,000 antibiotics have been identified, characterized and the chemical structures of the majority have been determined. For the remaining ones, sufficient knowledge of their activities and their main physicochemical properties is available to allow us to identify their structures. It is clear that chemically, antibiotics are a very heterogenous group. As a group, antibiotics include substances of molecular weight from 150 to 5000. Their molecules may contain only carbon and hydrogen, or, more commonly, carbon, hydrogen, oxygen, and nitrogen; others also contain sulphur, phosphorus, or halogen atoms. Almost all the organic chemical functional groups are represented (hydroxyl, carboxyl, carbonyl, nitrogen functions, etc.) as are all the organic structures (aliphatic chains, alicyclic chains, aromatic rings, heterocycles, carbohydrates, polypeptides, etc.)⁴⁴.

The only property that all antibiotics have in common is that they are organic solids. Organic is obvious from their definition as products of microbial metabolism. It is less obvious why liquid antibiotics should be almost unknown. Molecules that are rather large or have several polar groups are solids at room temperature. Usually, antibiotics have several polar groups, which are involved in their interaction with bacterial macromolecules resulting in the inhibition of bacterial growth. We must therefore accept this as the reason why even the smaller antibiotic molecules are solid substances. Common antibiotics to be studied are:

2.6.1 Ampicillin

Ampicillin is an antibiotic used to prevent and treat a variety of bacterial infections, including meningitis, salmonellosis, endocarditis, respiratory tract infections and urinary tract infections⁴⁵. It may also be used to prevent group B streptococcal infection in newborns⁴⁵. It can be administered orally, intramuscularly, or intravenously⁴⁵. Common side effects include rash, nausea, and diarrhea⁴⁵. It should not be used in people who are allergic to penicillin⁴⁵. Serious side effects may include *Clostridium difficile* colitis or anaphylaxis⁴⁵. While usable in those with kidney problems, the dose may need to be decreased⁴⁶. It can be used during pregnancy, and breastfeeding because it appears to be generally safe^{45,46}.

Ampicillin was first used commercially in 1961 after its discovery in 1958^{47,48}. It is on the World Health Organization's List of Essential Medicines⁴⁹. The World Health Organization classifies ampicillin as critically important for human medicine⁴⁹. It is available as a generic medication⁵⁰. The molecular weight and formula are 349.41 g mol⁻¹ and C₁₆H₁₉N₃O₄S respectively. The IUPAC name is (2S,5R,6R)-6-([(2R)-2-Amino-2-phenylacetyl] amino)-3,3-dimethyl-7-oxo-4-thia-1-azabicyclo [3.2.0] heptane-2-carboxylic acid.

2.6.2 Metronidazole

Metronidazole is an antibiotic and antiprotozoal medication sold under the brand-name Flagyl among others⁵⁰. It is used either alone or with other antibiotics to treat pelvic inflammatory disease, endocarditis, and bacterial vaginosis⁵⁰. It is also effective for treating dracunculiasis, giardiasis, trichomoniasis, and amebiasis⁵⁰. It is an option for a first episode of mild-to-moderate *Clostridium difficile* colitis if vancomycin or fidaxomicin is unavailable^{50,51}. Metronidazole can be taken orally, applied topically or administered intravenously⁵⁰.

Common side effects include nausea, loss of appetite, and headaches⁵⁰. On rare occasions, seizures or drug allergies could happen⁵⁰. While some claim that metronidazole doses for trichomoniasis are safe, others claim that early pregnancy should not be treated with it⁵². Metronidazole is generally considered compatible with breastfeeding^{52,53}.

Metronidazole began to be commercially used in 1960 in France⁵³. It is on the World Health Organization's List of Essential Medicines⁵⁵. It is available in most areas of the world⁵⁶. In 2019, it was the 138th most commonly prescribed medication in the United States, with more than 4 million prescriptions^{57,58}. The molecular weight is 171.15 g mol⁻¹ and the molecular formula is C₆H₉N₃O₃. The IUPAC name is 2-(2-Methyl-5-nitro-1H-imidazol-1-yl) ethanol.

2.6.3 Chloramphenicol

Chloramphenicol is an antibiotic useful for the treatment of some bacterial infections⁵⁹. This includes use as an eye ointment to treat conjunctivitis⁶⁰. It is used orally or intravenously to treat meningitis, plague, cholera, and typhoid fever⁵⁹. Its use by mouth or by injection is only recommended when safer antibiotics cannot be used⁵⁹. Monitoring both blood levels of the medication and blood cell levels every two days is recommended during treatment⁵⁹. Bone marrow suppression, nausea, and diarrhea are typical adverse effects⁵⁹. The bone marrow suppression may result in death⁵⁹. To reduce the risk of side effects treatment duration should be as short as possible⁵⁹. People with liver or kidney problems may need lower doses⁵⁹. In young children a condition known as gray baby syndrome may occur which results in a swollen stomach and low blood pressure⁵⁹. Its use near the end of pregnancy and during breastfeeding is typically not recommended⁶¹. Chloramphenicol is a broad-spectrum antibiotic that typically stops bacterial growth by stopping the production of proteins⁵⁹.

Chloramphenicol was discovered after being isolated from *Streptomyces venezuelae* in 1947⁶². Its chemical structure was identified and it was first synthesized in 1949. It is on the World

Health Organization's List of Essential Medicines⁶². It is available as a generic medication⁶⁰. The molecular weight is 323.13 g mol⁻¹ and the molecular formula is C₁₁H₁₂Cl₂N₂O₅. The IUPAC name is 2,2-dichloro-N-[(1R,2R)-1,3-dihydroxy-1-(4-nitrophenyl) propan-2-yl] acetamide⁶².

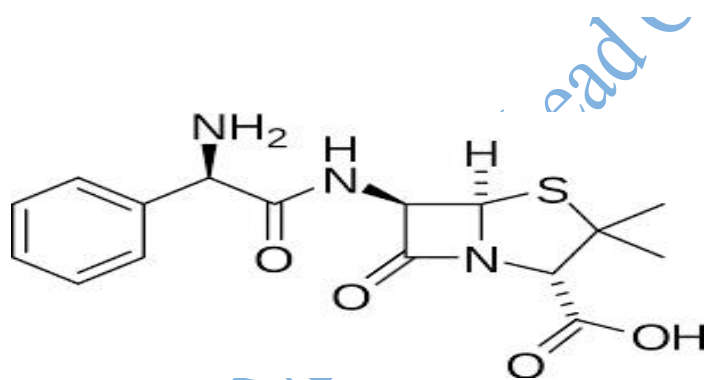
2.6.4 Ciprofloxacin

Ciprofloxacin is a fluoroquinolone antibiotic used to treat a variety of bacterial infections⁶³. This includes among others, bone and joint infections, intra abdominal infections, certain types of infectious diarrhea, respiratory tract infections, skin infections, typhoid fever, and urinary tract infections⁶³. It is used in conjunction with other antibiotics for some infections⁶³. It can be taken by mouth, as eye drops, as ear drops, or intravenously^{63,64}.

Consequences like nausea, vomiting, and diarrhea are frequent⁶⁴. Severe side effects include an increased risk of tendon rupture, hallucination and nerve damage⁶³. In people with myasthenia gravis, there is worsening muscle weakness⁶³. Rates of side effects appear to be higher than some groups of antibiotics such as cephalosporins but lower than others such as clindamycin⁶⁵. Studies in other animals raise concerns regarding use in pregnancy⁶⁶. No problems were identified, however, in the children of a small number of women who took the medication⁶⁶. It appears to be safe during breastfeeding⁶³. It is a second-generation fluoroquinolone with a broad spectrum of activity that usually results in the death of the bacteria^{63,67,68}.

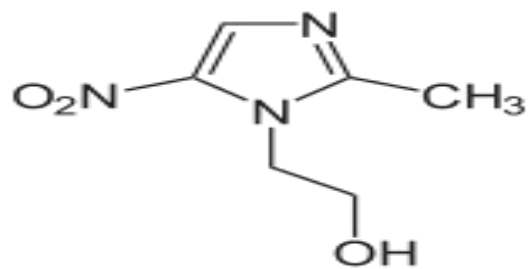
Ciprofloxacin was patented and introduced respectively in 1980 and 1987^{69,70}. It is on the WHO's list of essential medicines⁷¹. The World Health Organization classifies ciprofloxacin as critically important for human medicine⁷². It is available as a generic medication^{63,73}. In 2019, it was the 113th most commonly prescribed medication in the United States, with more than 5 million prescriptions⁷⁴. The molecular formula of Ciprofloxacin is C₁₇H₁₈FN₃O₃ and th

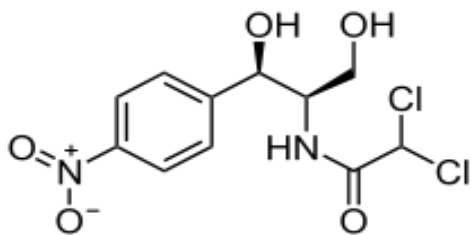
e molecular weight is $331.347 \text{ g mol}^{-1}$. The IUPAC name is 1-cyclopropyl-6-fluoro-4-oxo-7-(piperazin-1-yl)-quinoline-3-carboxylic acid.



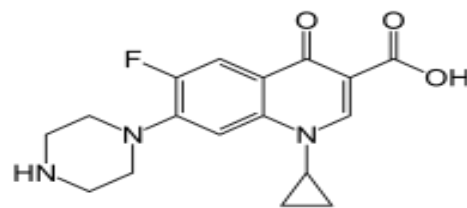
Ampicillin

Metronidazole





Chloramphenicol



Ciprofloxacin

Figure 2.1: Chemical Structures of Selected Antibiotics

Source ^{45, 50,59,63}

2.7 Elemental Components of Groundwater

Heavy metals are among the major contaminants of groundwater sources⁷⁵. Some of these heavy metals are essential for the growth, development and health of living organisms and others are non-essential as they are indestructible and most of them are categorized as toxic species on organisms⁷⁶. Nonetheless, the concentration of heavy metals in the environment determines how toxic they are. As environmental concentrations increase and soils lose their ability to hold onto heavy metals, they leach into groundwater and soil solution. Thus, these toxic heavy metals can accumulate in living tissues and become concentrated throughout the food chain.

Only less than 3% of the water resources of the Earth are freshwaters, and only one-hundredths of a percent of these are adapted to human consumption. Due to the rapid and disorganized growth of the population, careless management, and excessive consumption in agricultural and industrial activities, these valuable resources are facing a serious crisis^{77,78,79,80}.

Groundwater is at risk of exposure to heavy metals (HMs) from different sources, including agricultural runoffs as well as urban and industrial wastewaters^{81,82}. Heavy metals are stable contaminants, unlike their organic counterpart, are not degradable in nature through biological processes^{83,84,85}. The degree of groundwater contamination depends on the size of the affected area, concentration, solubility, toxicity, and density of the contaminant. Rainfall pattern, water table depth, rate of filtration, rocks, and hydraulic features of the soils such as texture and structure are also regulatory factors for the groundwater contamination level⁸⁶.

Heavy metals have been regarded as one of the significant contaminants of groundwater resources⁸⁷. However, some of these metals such as Zn and Fe are essential for the growth and healthy development of living organisms while others such as Cd, Hg, and Pb are categorized as potentially toxic elements to living organisms due to their toxicity level. Regardless, the toxicity of these heavy metals relies on their level in the environment. With expanding consideration in the environment, these toxic heavy metals can be accumulated in living tissues and concentrated through the food chain⁸⁸. Heavy metals such as Pb, Cd, Cr, and Mn are some examples of toxic metals. When consumed above the permissible level, they can lead to lingering ailments such as kidney problems, high blood pressure, liver crises, skin irritation, etc^{89,90}. Groundwater degradation is a direct cause of Nigeria's rapid industrialization. Several industrial activities introduce pollutants into the groundwater resources by discharging effluents into nearby pits or through unlined canals that move to the low-lying depressions on land. Human consumption of contaminated water results in serious

health effects. However, adverse impacts from groundwater pollution are subjected to specific contaminants in the water. Drinking polluted water often causes diarrhea, stomach irritation, and others⁹¹.

2.7.1 Sources of Heavy Metal Pollution in Groundwater

Heavy metals are metallic elements that have relatively high atomic weight and are poisonous even at low concentrations⁹². Heavy metals may contaminate the drinking water sources through natural or anthropogenic activities. Foroughi and Khiadani reported that heavy metals enter into the environment through emissions from the industries like electroplating, metal finishing, textile, storage batteries, lead smelting, mining, plating, ceramic, and glass industries⁹³. Some other reports have shown heavy metals as a major contaminant of surface and groundwater sources through several human activities like large-scale use of chemicals in agriculture and improper disposal of industrial and municipal wastes as well^{94,95}. In automobile industries, bearing wear, engine part, brake emission, and mining process are among the major sources of copper in the environment⁹⁶. Idris and Kolo reported that pharmaceutical and personal care products industries are also releasing adequate effluents without treatment which contain recalcitrant substances such as antibiotics, antiepileptics, tranquilizers, etc into the environment⁹⁷. Muhammad and Ashiru stated that mining activities have also accounted for heavy metal contamination with diverse concentrations in groundwater resources of Nigeria, especially in the Northern region⁹⁸. According to Butu and Iguisi, rivers flowing through populated areas are highly vulnerable to heavy metal pollution due to urbanization and industrialization activities⁹². Also, the geologic process could also be a major contributor.

2.7.2 Heavy Metal Concentration in Groundwater in Nigeria

Heavy metals are basically classified into essential and non-essential based on their biological functions. Essential heavy metals including iron, zinc, copper, chromium, cobalt, and manganese are required by human health at concentrations which could be beneficial to the body's metabolites⁹⁹. According to Prashanth, the daily requirement of essential heavy metals includes 2–5 mg/day (manganese), 0.005 mg/day (chromium), 0.0001 mg/day (cobalt), 15–20 mg/day of which 99 % is found intracellularly and 1 % in the plasma (zinc), 1–2 mg/day of which 75 % is found in the blood and the rest 25 % in the bone marrow, liver, etc. (iron) and 2–5 mg/day of which 50 % is absorbed from the gastrointestinal tracts (copper)⁹⁹. Generally, these essential trace elements are taken in indirectly through the consumption of different types of food products. Non-essential heavy metals that are commonly found in potable water include cadmium, lead, nickel, and mercury. However, at a concentration above the threshold limit thus exceeding the permissible limit for potable water as stipulated by WHO such water could be detrimental to the organs/tissues of the body. Duru and Enedoh stated that heavy metals' concentrations above permissible limits are generally not safe for human consumption¹⁰⁰. The concentration of frequently reported heavy metals in potable water sources in Nigeria as well as the regulatory limit are specified by WHO and USEPA as well as SON etc. However, in Nigeria, heavy metals found in potable water sources often exceed the concentration recommended by SON, USEPA, and WHO.

2.8 Essential and Non-Essential Elements

Essential elements are required by the body in considerable amounts while the non-essential elements are those needed by the body in lesser amounts⁹⁹. Essential elements can produce toxic effects if intake is in high concentration while non-essential or potentially toxic elements are toxic even at trace concentration The essential elements are classified under two

categories essential macro and essential micro-elements. Calcium, Magnesium, Potassium and Sodium are macro elements while the micro-elements are Copper, Cobalt, Aluminium, Boron, Selenium, Zinc, Iron, and Manganese.

Calcium (Ca) and Magnesium (Mg)

Calcium and Magnesium in drinking water have many beneficial effects and are therefore essential to human health although, very high levels can have some negative health effects. For instance, low calcium levels increase the risk of vascular (cerebral) haemorrhage, while high levels promote vascular degeneration (arteriosclerosis). With arthritis, low calcium levels cause inflammatory types of joint disease, while high levels cause degenerative (osteoarthritic) joint damage. Lack of the nutrients calcium and magnesium will cause you to wake up after a few hours and not be able to return to sleep¹⁰¹. Both elements are abundant in groundwater, but the role of groundwater as the essential source of these important nutrients is often neglected. In developed countries, calcium (Ca) and magnesium (Mg) have become the "Gold Standard" when discussing nutritional supplements, mineral ratios, paired cell receptors, or many nutrition related health issues in general. Calcium is now the most promoted nutrient by proponents of conventional, nutritional, as well as alternative medicine - yet at the same time, the assumed need is based purely on the speculation that the body's dietary calcium intake is well below its requirements¹⁰². Chronic calcium deficiency is associated with some forms of hypertension, prostate and colorectal cancer, some types of kidney stones, miscarriage, birth (heart) defects in children. When a mother is deficient in calcium during pregnancy, it can result in menstrual and premenstrual problems, various bone, joint and periodontal diseases, muscle spasms and cramps, sleep disturbances, mental health / depressive disorders, cardiovascular and/or haemorrhagic diseases, and others. Elevated calcium levels are associated with arthritic/joint and vascular degeneration, calcification of soft tissue, hypertension and stroke, an increase in triglycerides, gastrointestinal disturbances,

mood and depressive disorders, chronic fatigue, increased alkalinity, and general mineral imbalances. Calcium and Mg are effective in the treatment of Insomnia (an inability to fall asleep or remain asleep) and one of the many sources of calcium and magnesium is hard water. Individuals vary considerably in their needs for and consumption of these elements. Available evidence suggests that, because of food habits, many people in most countries fail to obtain from their diets the recommended intakes of one or both of these nutrients. While the concentrations of calcium and magnesium in drinking water vary markedly from one supply to another, mineral-rich drinking waters may provide substantial contributions to total intakes of these nutrients in some populations or population subgroups¹⁰³.

Potassium (K)

The likely sources of potassium in groundwater are silicate minerals and igneous and metamorphic rocks. The permissible limit of K concentration in the groundwater as per WHO, as well as BIS standards, is 10 mg L⁻¹. The main cause for the increase in potassium levels in groundwater is agricultural activities. Water softeners that regenerate using potassium chloride can also raise the level of potassium in water significantly. The research by Durkowski demonstrated that such high potassium concentrations occur in groundwater of urban areas due to sewage infiltration¹⁰⁴. Excess amounts of potassium present in the water sample may lead to nervous and digestive disorders.

Sodium (Na)

Sodium is essential to health and resides in the extracellular fluid, regulating plasma volume as well as cellular transport. It serves many physiological functions, including nutrient absorption and maintaining fluid balance. Humans can obtain sufficient sodium from the low amounts present in many foods, including fresh meat, fish, and vegetables, but most of the

sodium we now consume is added in food processing or at the table. Although small amounts of sodium are necessary for health, too much may cause health problems. For example, because sodium affects fluid regulation, a high sodium intake may increase blood pressure through volume expansion¹⁰⁵.

Copper (Cu)

Copper at very high levels is toxic and can cause vomiting, diarrhea, loss of strength, and cirrhosis of the liver¹⁰⁷. Water turns blue-green in colour as the corroded copper comes off the inside of pipes and appears in the water as a precipitate^{106,107}. It is one of the essential micro elements for human beings. It is widely distributed metal in nature. Copper can exist in aquatic environment in three forms namely soluble, colloidal and particulate. It is found in less quantity as an essential element for organisms. Excess copper in the human body is toxic and causes hypertension and produces pathological changes in brain tissues. Excessive ingestion of copper is responsible for specific disease of the bone¹⁰⁸.

Cobalt (Co)

Cobalt is one of the heavy metals found in potable water sources of Nigeria. Like other trace metals, high concentration of cobalt is also toxic to human beings. Cobalt enters the water through combustion of coal or oil and use of cobalt-related chemicals. Based on geographical coverage, cobalt shows similar trend in various potable water sources and occasional increase may be due to industrial activities. Its high concentration may create problems like diarrhea, bone deformation etc. Cobalt increases the incidence of goitre, vomiting and nausea, optical, cardiovascular, and thyroid damage^{109,110}.

Aluminium (Al)

Sources are from groundwater that passes through some kind of rocks and mines discharge. If present in drinking water, it could cause turbidity increment besides water discolouring. The main concern with respect to aluminium and health is its potential toxicity if exposure is

excessive. The symptoms of higher amounts of aluminium in humans are Nausea, vomiting, mouth ulcers, skin rashes, skin ulcers, diarrhea and arthritic pain but these symptoms are however reported to be mild and short-lived¹¹¹.

Boron (B)

Boron is normally considered as a minor constituent within groundwater as it is generally detected in small concentrations. However, in many areas of the Mediterranean, contamination with boron is a serious problem. The presence of boron not only limits the use of groundwater for public water supply (PWS) and irrigation but can also lead to ineffective water treatment strategies. Excluding anthropogenic contamination, boron present within groundwater can only be the product of rock/water interaction that typically occurs within aquifers. Boron in groundwater might derive from the leaching of parent rocks, infiltration of meteoric cyclic salts, mixing with adjacent groundwater bodies, and contamination by anthropogenic sources. Boron deprivation results in decreased brain electrical activity similar to that observed in non-specific malnutrition and poorer performance in tasks of motor speed and dexterity, attention and short-term memory in humans¹¹².

Selenium (Se)

Selenium released through weathering of Se-rich rocks and soils may enter groundwater via leaching along with excess water from irrigation and rainfall. Human exposure to Se is mainly through food and water consumption. Contribution of drinking water to Se in total diet can vary extensively, although in many regions it is very low. Public health standards for unsafe, safe and toxic levels of Se in drinking waters vary very widely. Recent epidemiologic studies describing the effects of selenate, an inorganic Se species commonly found in drinking water, coupled with evidence of inorganic Se toxicity at low levels indicate that health risks may occur at exposures well below the current EU and WHO upper limit guidelines and thereby prompting to reassess the upper safe limit of Se in drinking water¹¹³.

Zinc (Zn)

Zinc is one of the important trace elements that play a vital role in the physiological and metabolic processes of many organisms. Nevertheless, at higher concentrations, zinc can be toxic to the organisms. It plays an important role in protein synthesis. Zinc is a metal that shows a fairly low concentration in surface water, which is due to its restricted mobility from the place of rock weathering or from the natural sources¹¹⁴. The permissible limit of zinc in water is 0.5 mg L⁻¹.

Iron (Fe)

It is another heavy metal of concern, particularly because ingesting dietary Fe supplements may acutely poison young children. Ingestion accounts for the most toxic effects of Fe because iron is absorbed rapidly in the gastrointestinal tract. It can cause a metallic taste in drinking water, and exposure to high concentrations of Fe exerts adverse effects on target organs, such as liver, the cardiovascular system, and kidneys¹¹⁵. It is the fourth most abundant element by mass in the earth's crust. In water, it occurs mainly in the ferrous and ferric states. Iron in surface water is generally present in the ferric state. It is an essential and non-conservative trace element found in significant concentrations in drinking water because of its abundance in the earth's crust. Usually, iron occurring in groundwater is in the form of ferric hydroxide, in a concentration less than 0.5 mg L⁻¹. The shortage of iron causes a disease called "anaemia" and prolonged consumption of drinking water with a high concentration of iron may lead to a liver disease called as haemosiderosis¹¹⁶.

Manganese (Mn)

Manganese occurs naturally with iron and is used as an oxidant for cleaning, bleaching, disinfection process, and in the production of iron and steel alloys⁹⁰. Manganese can exist in eleven oxidative states with low concentrations (0.02 mg L⁻¹)^{117,118}. It enters into potable water source through both natural and man-made activities. The unsustainable discharge of

wastes could be due to the source of manganese in the surface water. Excess manganese concentration increases the growth of bacteria in water and can cause hypertension in patients older than 40 years and neurological disorders in protracted patients^{90,119}. Lenntech reported that the adsorption of excess manganese will deposit in the liver, kidneys, pancreas, and endocrine glands through the blood vessels and can also cause respiratory system and brain disorder¹¹⁰.

However, cadmium, chromium, lead and nickel are considered potentially toxic elements because exposure to these elements in groundwater even at trace concentrations can cause adverse health effects.

Cadmium (Cd)

It is a non-essential non-beneficial element known to have toxic potential. The concentration of cadmium in lithosphere is low. It normally ranges from 1×10^{-4} to 2×10^{-4} mg L⁻¹. The main sources of cadmium are industrial activities as the metal is widely used in electroplating, pigments, plastic, stabilizers and battery industries. Cadmium is highly toxic and responsible for several cases of poisoning through food. Small quantities of cadmium cause adverse changes in the arteries of the human kidney. It replaces zinc biochemically and causes high blood pressure, kidney damage and etc. It interferes with enzymes and causes a painful disease called Itai-itai. Nevertheless, cadmium in low concentration is quite toxic to human health¹²⁰. Sources are Industrial and mining waste, phosphate fertilizers and landfills leachate. It can cause high blood pressure, liver damage and also destroy testicular tissues and blood cells (red). It can severely irritate the stomach and cause vomiting and diarrhoea if taken in large quantities.

Chromium (Cr)

It occurs in a free state as a mineral in several oxidative forms¹²¹. Sevcikova reported the most common biologically essential oxidative state of chromium are trivalent Cr (III) and

hexavalent Cr (VI)¹²². Chromium enters the water through the discharge of effluent water containing chromium including tanning, electroplating, pigment production, refractory technologies, and ferrochrome production¹²³. Chromium is very toxic due to strong oxidation properties; hence, it can cause diseases like gastrointestinal, central nervous system disorder, and cancer¹²⁴. Fu and Wang also stated that prolonged contact with Cr could lead to dysfunctions of the kidney and even death¹²⁵. Generally, the oxidative state of chromium that is found in the water will determine the nature of disease conditions that could follow. Lenntech also reported that Cr (III) is a vital nutrient for humans and its deficiency increases the chance of heart diseases, disruption of metabolisms, diabetes, over-ingestion, and skin rashes¹¹⁰. Chromium (VI) causes allergic reactions including skin rash, nose irritations and bleeds, stomach upset, ulcers, respiratory disorders, lower immune system, kidney, lung, liver disorders, and mutation.

Lead (Pb)

When lead is ingested by humans, they are mostly removed through urination but in children, it could wreak havoc and make them more vulnerable than adults¹²¹. Lead is a bluish-gray metal present as a trace element in the earth's crust and mainly comes into the environment through the combustion of fossil fuels, mining, and manufacturing industries such as paint and leaded gasoline, tyre wear, lubricating oil, grease, batteries production and ceramics, remains of batteries, cosmetics, medicine/pharmaceutical, food supplements^{98,119,121,127,128}. The high concentration is also attributable to anthropogenic activities especially petroleum products (i.e., sales, spill and combustion), mining activities, and paint making. Lead is a very toxic element which can accumulate in the skeletal structures of both man and animal¹²⁹. Lead enters the body through ingestion and inhalation of lead-containing compounds, and causes multiple body and nervous systems disorders, especially in children¹²¹. Moreover, in children it also boosts problems like inattention, hallucinations, and delusions, manifesting as

poor memory and irritability, decreased mental ability, learning difficulties, reduced growth, blood anaemia, severe stomach ache, muscle weakness, and brain damage^{119,121,130}. Premature birth by pregnant women may also be induced by lead poisoning¹²¹. Fu and Wang stated that lead damages the cellular activities leading to brain, central nervous system, kidney, liver, and reproductive system disorder¹²⁵. Other pathological effects of lead include vomiting, loss of appetite, central nervous system defects, liver problems, kidney damage.

Nickel (Ni)

Nickel occurs in natural water as a divalent cation with pH range between 5-9. Nickel is a natural element of the earth's crust; therefore, small amounts are found in food, water, soil and air. Nickel occurs naturally in the environment at low levels. Nickel is used for nickel alloys, electroplating, machinery parts, stainless steel, spark plugs and also as catalysts. Nickel is found in ambient air at very low levels as a result of releases from oil and coal combustion, nickel metal refining, sewage sludge incineration and other sources. Nickel in general, is associated with basic and ultra basic rocks. Nickel dermatitis, consisting of itching of the fingers, hands and forearms, is the most common effect in humans from chronic skin contact with nickel. Nickel enters into the human body through inhalation, water and food consumption, and its high concentration may pose threat to human health. It is mostly used in stainless steel and nickel alloys production companies. Elemental nickel and its compounds are noxious agent and used in industries, known to have adverse effects for individuals¹⁰⁰. Major sources are diesel and gasoline, lubricating oil, and brake emission⁹⁶.

Excess concentration of these essential and non-essential heavy metals found in groundwater sources can be harmful to human. de Namor have summarized the target organs of some heavy metals found in potable water including Cu 29 (liver, gastrointestinal tracts), Cd 48 (lungs, gastrointestinal tracts, heart, bone, kidney), Ni 28 (lungs, skin, heart), Pb 82 (eye, kidney, heart, gastrointestinal tracts, muscular and skeletal system and bone), Co 27 (heart

and lungs), Cr 28 (kidney, lungs), Zn 30 (gastrointestinal tracts, lungs), Hg 80 (bone, eye, lungs and kidney)¹²³. A number of these heavy metals are carcinogenic and could also affect the children even at low level of exposure. However, in Nigeria, the National Agency for Food and Drug Administration and Control (NAFDAC) has already mandated the enforcement of rules in compliance with international drinking water guidelines¹³¹.

Today, health risk assessment is an important method to assess potential negative outcomes for people exposed to a risk factor^{132,133}. In this regard, recognizing HM contaminations and their possible sources is an issue which requires investigation. The information obtained from risk assessment serves as an important instrument for helping authorities and decision-makers in environmental and sanitary risk management and communication.

2.9 Physicochemical Parameters

Groundwater samples were examined for quality parameters like pH, temperature, conductivity, dissolved oxygen and total dissolved solids (TDS), and were measured on the field via a portable meter (model HI 98130 HANNA, Mauritius, Iramac Sdn. Bhd.).

Determination of pH

pH is a measure of how acidic/basic water is. The range goes from 0 to 14, with 7 being neutral. pHs of less than 7 indicate acidity, whereas a pH of greater than 7 indicates a base. The pH of water is a very important measurement concerning water quality.

Before taking a pH measurement, the meter must be "calibrated". The pH of water determines the solubility (amount that can be dissolved in the water) and biological availability (amount that can be utilized by aquatic life) of chemical constituents such as nutrients (phosphorus, nitrogen, and carbon) and heavy metals (lead, copper, cadmium, etc.). pH also determines whether aquatic life can use it. In the case of heavy metals, the degree to which they are

soluble determines their toxicity. Metals tend to be more toxic at lower pH because they are more soluble.

Excessively high and low pHs can be detrimental for the use of water. High pH causes a bitter taste, water pipes and water-using appliances become encrusted with deposits, and it depresses the effectiveness of the disinfection of chlorine, thereby causing the need for additional chlorine when pH is high. Low-pH water will corrode or dissolve metals and other substances.

Determination of Total Dissolved Solids

Total dissolved solid is a measure of the dissolved combined content of all inorganic and organic substances present in a liquid in molecular, ionized, or micro-granular suspended form. TDS concentrations are often reported in parts per million. Water TDS concentrations can be determined using a digital meter.

Total dissolved solids (TDS) comprise inorganic salts, principally calcium, magnesium, potassium, sodium, bicarbonates, chlorides, and sulphates and some small amounts of organic matter that are dissolved in water. It has been concluded that the consumption of low TDS water, naturally occurring or received from a treatment process, does not result in harmful effects to the human body¹³⁴.

Total Dissolved solids comprise of organic matter and inorganic salts, which may originate from sources such as sewage, effluent discharge, urban run-off or from natural bicarbonates, chlorides, sulphate, nitrate, sodium, potassium, calcium and magnesium. The major determinant of the TDS level in water is the geochemical characteristics of the ground it comes in contact with, for example granite and silicons sands, and well leached soils have TDS less than 360 mg L⁻¹, the WHO (1984) gave the palatability of drinking water according

to its TDS level with rating given by Bruvold as less than 500 mg L⁻¹ excellent level and greater than 1500 mg L⁻¹ as unacceptable¹³⁵.

Determination of Conductivity

Electrical conductivity is a measure of water capacity to convey electric current. It has direct relationship with salinity and amount of total dissolved salts¹³⁶. The conductivity of water is a measure of the capability of water to pass electrical flow. This ability is directly dependent on the concentration of conductive ions present in the water. These conductive ions are originated due to inorganic materials such as chlorides, alkalis, carbonate and sulphides compounds and dissolved salts.

The factors affecting the conductivity of water are the type of substance that dissolves in water, temperature and the concentration of ions in solution.

Determination of Temperature

Temperature is the measure of hotness or coldness expressed in terms of any of several scales, including Fahrenheit and Celsius.

Water temperature, of course, expresses how hot or cold the water is. Technically, heat is an indicator of the kinetic energy of water, or energy of motion. Increasing temperature indicates increasing energy, or molecular motion, of water. Water temperature affects the growth and reproduction of living organisms. Many animals use temperature as a signal for when to reproduce and when to migrate. Generally, animals and plants grow faster at warmer temperatures, although all organisms have an upper temperature limit.

A property that is unique to water versus other substances is that it is most dense at 4 degrees Celsius, or 39 degrees Fahrenheit, and is less dense at either higher or lower temperatures. Most other substances continue to become denser as their temperature drops. Water at higher or lower temperatures will float on top of water that is 4 °C.

Determination of Dissolved Oxygen

Dissolved oxygen (DO) is the amount of oxygen that is present in water. Running water, such as that of a swift moving stream, dissolves more oxygen than the still water of a pond or lake. The amount of oxygen that can be dissolved in water depends on several factors, including: water temperature, the quantity of dissolved salts presents in the water (salinity), and atmospheric pressure. Healthy water should generally have dissolved oxygen concentrations between 6.5-8 mg L⁻¹ and between about 80-120 %. The level of dissolved oxygen in water is used as an indication of pollution and its potability. This thus forms a key test in water pollution control activities and waste treatment process control activities and waste treatment process control. The recommended guideline value for drinking water is a level not below 8 mg L⁻¹. Lower levels indicate microbial contamination or corrosion.

2.10 Instrumentation for Elemental and Antibiotics Quantification

2.10.1 Inductively Coupled Plasma Optical Emission Spectroscopy (ICP-OES)

Inductively Coupled Plasma Optical Emission Spectroscopy is one of the most powerful and popular analytical tools for the determination of trace elements in a myriad of sample types. The ICP was developed for optical emission spectrometry (OES) by Wendt and Fassel at Iowa State University in the United States, and by Greenfield and others at Albright & Wilson, Ltd. in the United Kingdom in the mid-1960s^{136,37,138}. The first commercially available ICP OES instrument was introduced in 1974. ICP OES is a proven commercial success, and the future is still bright for ICP-based spectroscopic techniques. Detectability has been continuously and dramatically improved over the past 50 years.

Limit of Detections (LODs), for example, have improved by a factor of four to six orders of magnitude for many elements. Nevertheless, research and commercial opportunities for further development of ICP OES remain active^{139,140}. The instrumentation associated with an ICP OES system is relatively simple. A portion of the photons emitted by the ICP is collected

with a lens or a concave mirror. This focusing optics forms an image of the ICP on the entrance aperture of a wavelength selection device such as a monochromator. The particular wavelength of light exiting the monochromator is converted to an electrical signal by a photodetector. The signal is amplified and processed by the detector electronics, then displayed and stored by a personal computer. ICP-OES enjoys a higher atomization temperature, a more inert environment, and the natural ability to provide simultaneous determinations for up to 70 elements. This makes the ICP less susceptible to matrix interferences, and better able to correct for them when they occur.

The main application is environment (water, soils, sludges, air) as there is a strong need to monitor element presence and content as it relates to human consumption and impact.

2.10.2 High Performance Liquid Chromatography-Ultraviolet Visible HPLC-UV

High-performance liquid chromatography (HPLC) is a technique used to separate molecules based on sizes and surface charge among other properties. The incorporation of ultraviolet (UV) spectroscopy with HPLC allows the concentration of molecules to be determined following separation. The HPLC Ultraviolet-Visible detectors operate by passing visible and UV light through a sample in a flow cell, then measuring the absorption of the different wavelengths that pass through the cell. The amount of light absorbed provides information on the properties of the sample of interest¹⁴¹.

Table 2.1: List of Elements That Can be Determined by ICP-OES

| Alkaline and Alkaline earth | Lanthanides and Actinides | Transition Metals | Others |
|-----------------------------|---------------------------|-------------------|--------|
|-----------------------------|---------------------------|-------------------|--------|

Li, Na, K, Rb, Cs, Be, Mg, Ca, Ce, Pr, Nd, Sm, Eu, Gd, Tb, Sc, V, Ti, Cr, Mn, Fe, B, C, N, Al, Si,
Sr, Ba Dy, Ho, Er, Tm, Yb, Lu, Th, U Co, Ni, Cu, Zn, Y, P, S, Cl, Ga, Ge,
Nb, Zr, Mo, Ru, Th, As, Se, Br, In,
Pd, Ag, Cd, La, Hf, Sn, Sb, Te, I, Tl,
Ta, W, Re, Os, Ir, Pt, Pb, Bi
Au, Hg

Source: ¹³⁶

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2.11 Human Health Risks Assessment

The aim of risk assessment is to identify and evaluate the health risks and mitigation strategies associated with a pollutant, in this case antibiotic resistance. Antibiotic resistance may result in enhanced virulence, pathogenicity, disease outbreaks and transmission, leading to prolonged morbidity and hospitalization, and even mortality¹⁴². Once bacterial infections develop resistance to common first-line antibiotics, the control of human infections and diseases becomes problematic and costly, as this may require the use of last-resort antibiotics and even the development of new ones¹⁴³. Although AR is a global problem, the human health risks are likely to be more pronounced in developing countries than developed ones. This is because developing countries have poor health care systems characterized by lack of basic facilities and medications, and high disease burden typical of tropical environments, which in turn, necessitates frequent use of antibiotics^{144,145}. These conditions create a self-reinforcing or positive feedback mechanism that promotes the persistence and proliferation of antibiotic resistance, with far-reaching implication on human health. However, investigations on the implications of AR in the drinking water to human health remain scarce and has been mostly limited to epidemiological studies. There are at least three mechanisms by which AR in drinking water can threaten human health and these are; (1) humans are directly infected by an antibiotic-resistant pathogen following consumption of contaminated water, but no human to human transmission occurs; (2) sustained human to human transmission occurs following direct infection with an ARB that is pathogenic or opportunistic resulting; and (3) environmental ARGs in drinking water transfer into human pathogens via horizontal gene transfer with the antibiotic-resistant pathogens selected by human antibiotics and/or co-selecting agents¹⁴⁶. ARB may cause serious disease; for example, *Klebsiella pneumoniae* is one the main global cause of urinary tract, lower respiratory tract, and bloodstream infections that are due to carbapenem-resistance¹⁴³. In African and Asian regions with poor sanitation and unsafe drinking water, ciprofloxacin-resistant *Shigella* spp. continues to cause diarrhea

and dysentery, which is sometimes fatal in infants¹⁴³. As a result, in 2017, WHO identified a list of medium to critical priority pathogenic ARB that pose the greatest threat to human health. The WHO recommended global surveillance of these priority pathogenic ARB^{143,147}.

Similarly, the source of heavy metals can be geogenic and environmental degradation, and are being catalysed due to anthropogenic activities such as industrial production, unsafe disposal of industrial wastes, agricultural wastes and domestic sewage and this release heavy metals into the environment¹⁴⁸. Water contamination from industrial areas is compounded usually due to the high concentration of industries over a small area. The percolating wastewater picks up a large number of heavy metals and reaches the aquifer system and contaminates groundwater. Health risks of heavy metals include reduced growth and development, cancer, organ damage, nervous system damage and, in extreme cases, death. Heavy metals become toxic when they are not metabolized by the body and accumulate in the soft tissues¹⁴⁹.

Risk assessment using geostatistical methods is an important tool to assess the anthropogenic impact on the natural environment as the excess contamination over background loads can be determined.

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Chapter Three

Methodology

3.1 Description of the Study Area

The study area lies in the tropical rainforest climate region between two rural border communities in Ogun and Oyo states in the South-West of Nigeria. It lies between Lat. 06° 30' N and Long. 04° 30' E (Figure 3.1). The study area has an annual average maximum day temperature of 36.5 °C (February) and a night-time temperature range of 17 °C (January) – 23°C (May)¹. Annually, the study area's humidity ranged from 75 to 94.5% with humidity of 70% in February. The study area receives a cumulative annual rainfall of 60–100 mm for a maximum number of five (5) days in February². In total, the study area receives a cumulative annual rainfall of 1300–1500 mm and the least amount of rainfall occurs in August (0–50 mm of rain)¹.

In some of the sampling sites, there are obvious pieces of evidence of freelance grazing of animals, poultry farming, open dump site and siting of groundwater near the main road which may result in elevated levels of contamination of the groundwater.

3.2 Sample Collection and Preservation

Manual sampling with a plastic container in compliance with established standard norms was adopted. Labels were used to prevent sample misidentification. Sample preservation was done in tune with Groundwater Board guidelines with minimum possible time lapse between collection and analyses.

Grab groundwater samples were taken randomly from ten (10) hand dug wells from two neighbouring rural communities in Ogun and Oyo States (Figure 3.1 and Table 3.1). Samples for Antibiotics analysis were collected in 500 mL Amber glass bottles to prevent photocatalytic breakdown while samples for Elemental analysis were collected in 75 mL plastic bottles and fixed with 5 mL Conc. HNO₃. All preserved samples were kept cool in a Styrofoam cooler at sampling sites, transported to the laboratory and stored at 4⁰C in the refrigerator until further analysis. All plastic containers for elemental samples analyses were pre-washed and later rinsed thoroughly with distilled water before being used.

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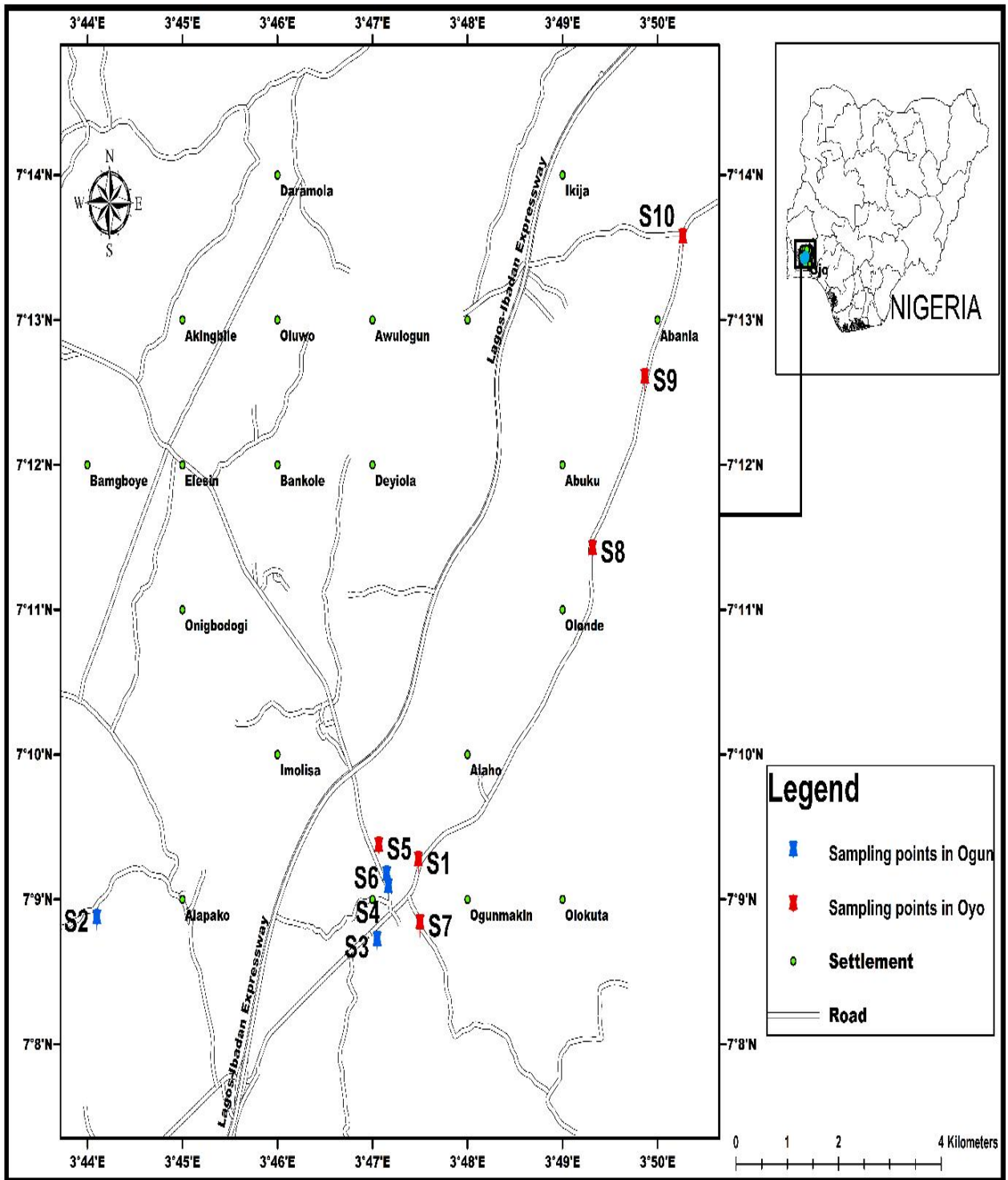


Figure 3.1: Map of the Study Area showing Sampling Points.

Source: Author's Analysis 2023

Table 3.1: Sampling Points Designation and Details

| Site | Coordinates | State | Elevation (m) | Apparent Water Quality | Source |
|------|----------------------|-------|---------------|---------------------------------|--------------|
| S1 | 7°09'15"N, 3°47'29"E | Oyo | 100 | Colourless, odourless | Shallow well |
| S2 | 7°08'51"N, 3°47'06"E | Ogun | 100 | Brownish and dirty | Shallow well |
| S3 | 7°08'42"N, 3°47'03"E | Ogun | 100 | Colourless, odourless | Shallow well |
| S4 | 7°09'04"N, 3°47'10"E | Ogun | 100 | Colourless, odourless | Shallow well |
| S5 | 7°09'21"N, 3°47'04"E | Ogun | 90 | Colourless. Odourless | Borehole |
| S6 | 7°09'09"N, 3°47'09"E | Ogun | 90 | Colourless, odourless | Shallow well |
| S7 | 7°08'49"N, 3°47'30"E | Oyo | 100 | Colourless with tiny particles | Shallow well |
| S8 | 7°11'24"N, 3°49'19"E | Oyo | 110 | Turbid | Shallow well |
| S9 | 7°12'35"N, 3°49'52"E | Oyo | 130 | Colourless with some particles | Shallow well |
| S10 | 7°13'33"N, 3°50'16"E | Oyo | 140 | Colourless with black particles | Shallow well |

Source: Author's Analysis 2023

3.3 Physicochemical Analysis

Physico-chemical parameters such as pH, Temperature, Total Dissolved Solids (TDS), Electrical Conductivity (EC) and Dissolved Oxygen (DO) were determined on-site with aid of a calibrated digital meter. The apparent colour was checked visually on site and recorded accordingly.

3.3.1 pH

The pH of water samples was determined by a portable pH meter (model HI 98130 HANNA, Mauritius, Iramac Sdn. Bhd.). The pH meter was calibrated using a three-point calibration method using three standard solutions with pH 4.0, 7.0, and 10.0. The sample was allowed to stand to allow for temperature stabilization and then the pH meter electrode was immersed into each water sample and allowed to stabilize while immersed in the sample before the reading was made. After each reading, the electrode was rinsed thoroughly with distilled water and then dabbed lightly with tissues to remove any film formed on the electrode. Measurement was done in triplicates.

3.3.2 Temperature

The temperature was measured using a portable meter (model HI 98130 HANNA, Mauritius, Iramac Sdn. Bhd.) at the sampling locations. Temperature measurement was made by taking a portion of the water sample (about 50 mL) and immersing the meter probe in it for a sufficient period of time until the reading stabilized.

3.3.3 Total Dissolved Solids (TDS)

Total Dissolved Solids (TDS) for all groundwater samples were measured in-situ using a combined pH/EC/TDS combo (Hanna instruments) Model HI 98130.

3.3.4 Electrical Conductivity

Electrical conductivity was measured using a conductivity meter (model HI 98130 HANNA, Mauritius, Iramac Sdn. Bhd.). The meter probe was calibrated using standard solutions with known conductivity before each use. The probe was submerged in the water sample and the reading was recorded after steady stability was achieved. After the measurement of each sample, the probe was rinsed with deionized water to avoid cross-contamination among different samples.

3.3.5 Dissolved Oxygen (DO)

Each sample was poured into the sample holder and kept inside for a few minutes. After achieving the reading stability, the value was recorded.

3.4 Elemental Analysis

3.4.1 Digestion and Elemental Analysis of Samples

Heavy metal was determined by digesting 100 mL of a well-mixed water sample with 10 mL analytical grade of Conc. HNO₃. The resulting mixture was then heated until the volume was reduced to about 15-20 mL. After cooling, the digested sample was filtered through a Whatman 0.45µm filter paper into a 25 mL standard flask, made up to the mark with deionized water and stored in a Nitric acid pre-washed polyethylene bottle in the refrigerator prior to chemical analysis³.

3.4.2 Elemental Quantification

Elemental quantification of all digested water samples was done by inductively coupled plasma-optical emission spectrometry (ICP-OES) using a Perkin Elmer®OptimaTM 8000V ICP-OES. All digested samples were analysed for B, Ca, Cd, Co, Cr, Cu, Fe, K, Mg, Mn, Na, Ni, Pb, Se, and Zn. in triplicates. The accuracy of analytical procedures was checked by analysing certified reference materials (CRMs).

Table 3.2: Recovery Experiment for Elemental Analysis

| Elements | Measured Value ^b | Certified Value ^a | % of recovery |
|----------|-----------------------------|------------------------------|---------------|
| Cd | 1.31 | 1.34 | 98.5 |
| Cr | 5.18 | 5.19 | 99.8 |
| Ni | 8.24 | 8.25 | 99.9 |
| Pb | 1.23 | 1.24 | 99.2 |

a Values are in $\mu\text{g g}^{-1}$ (mean \pm standard deviation, 95% confidence interval, n = 3).

b Values are in $\mu\text{g g}^{-1}$ (mean \pm standard deviation).

Source: Author's Analysis, 2023

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3.4.3 Elemental Human Health Risk Assessment

3.4.3.1 Chronic Daily Intake (CDI) Indices

The Chronic daily intake (CDI) of heavy metals through the consumption of the studied daily water intake was computed using the heavy metal concentrations (C) in mg L⁻¹ daily water intake (DI) in (litres/day), as well as body weight (BW) in kg as input through **Eq. 1**.

$$CDI = (C \times DI) / (BW) \dots\dots\dots (1)$$

3.4.3.2 Target Hazard Quotient (THQ)

The health risk associated with the consumption of water from the studied groundwater was evaluated as the non-carcinogenic hazard through the Target hazard quotient (HQ) using **Eq. 2**.

$$THQ = CDI / RfD \dots\dots\dots (2)$$

where the oral toxicity reference dose (RfD) values in (mg/kg/day) according to USEPA IRIS are given as: 0.005, 0.003, 0.02, 0.04, 0.8, 0.14, 0.0035 and 0.3 mg/kg/day for Cd, Cr, Ni, Cu, Fe, Mn, Pb and Zn respectively⁴. The exposed population is assumed to be safe when THQ < 1, but if the value of THQ > 1, there is an unacceptable risk of adverse non-carcinogenic effects on human health³.

3.4.3.3 Target Carcinogenic Risk (TCR)

The potential cancerous health risk via the consumption of the medicinal plants was estimated using the toxicity index known as slope factor (SF) to compute the potential cancerous health risk of an individual developing cancer over a lifetime as a result of exposure to possible carcinogen using **Eq. 3**.

$$\text{TCR} = \text{SF} \times \text{CDI} \dots \dots \dots (3)$$

Where the oral carcinogenic slope factor (SF) from USEPA (2015)⁴ was; 0.38, 0.5, 1.7, and 0.009 (mg/kg/day) for Cd, Cr, Ni, and Pb respectively converts the CDI to the incremental risk of individual developing cancer. TCR values higher than the USEPA recommended safe limit of (1×10^{-4}) ^{5,6} for cancer risk indicate possible carcinogenic risk.

3.5 Antibiotic Analysis

3.5.1 Sample Preparation using Solid Phase Extraction (SPE)

Solid-phase extraction (SPE) is an extractive technique by which compounds that are dissolved or suspended in a liquid mixture are separated from other compounds in the mixture according to their physical and chemical properties. Analytical laboratories use solid-phase extraction to concentrate and purify samples for analysis. Solid-phase extraction can be used to isolate analytes of interest from a wide variety of matrices, including urine, blood, water, beverages, soil, and animal tissue.

The principle of the SPE is the partitioning of compounds between two phases (solid and liquid) and the analyte of interest has a greater affinity for the solid phase than for the sample matrix. Hence, the compounds (analyte) will be retained on the solid phase and can later be removed by eluting solvent with a greater affinity for the analyte (Figure 3.2). The general extraction procedure is highlighted below:

- i. **Conditioning:** The Solid Phase Extraction (SPE) cartridges will be conditioned with about 3 mL of HPLC-grade methanol
- ii. **Equilibration:** This is followed by equilibration with 3 mL of ultrapure water.
- iii. **Loading:** Specified volume of sample will be passed through the cartridges at a determined flow rate.

- iv. **Washing:** Washing will be done by passing a specified volume (3 mL) of ultrapure water through the cartridges.
- v. **Elution:** The cartridges will be eluted with a specified volume (3 mL) of HPLC-grade methanol, and then followed by HPLC-grade acetonitrile.

For this study, 200 mL of each sample was spiked with a known concentration of the mixed analytes (ampicillin, chloramphenicol, metronidazole, tetracycline and ciprofloxacin). A blank sample containing no analyte was prepared with Milli-Q water. The Solid Phase Extraction (SPE) cartridges (Oasis HLB, 500 mg, 12 mL) were conditioned with 3 mL of HPLC grade methanol followed by equilibration with 3 mL of Milli-Q water. 200 mL of samples adjusted to pH 6.0 was passed through the cartridges at a flow rate of between 5-8 mL/min. Washing was done by passing 3 mL of Milli-Q water through the cartridges. The cartridges were dried in the vacuum oven for 5 min and elution was done with 3 mL of HPLC grade methanol, followed by 3 mL of HPLC grade acetonitrile. The eluate was evaporated to dryness in the vacuum oven and reconstituted with 0.5 mL of HPLC-grade methanol.

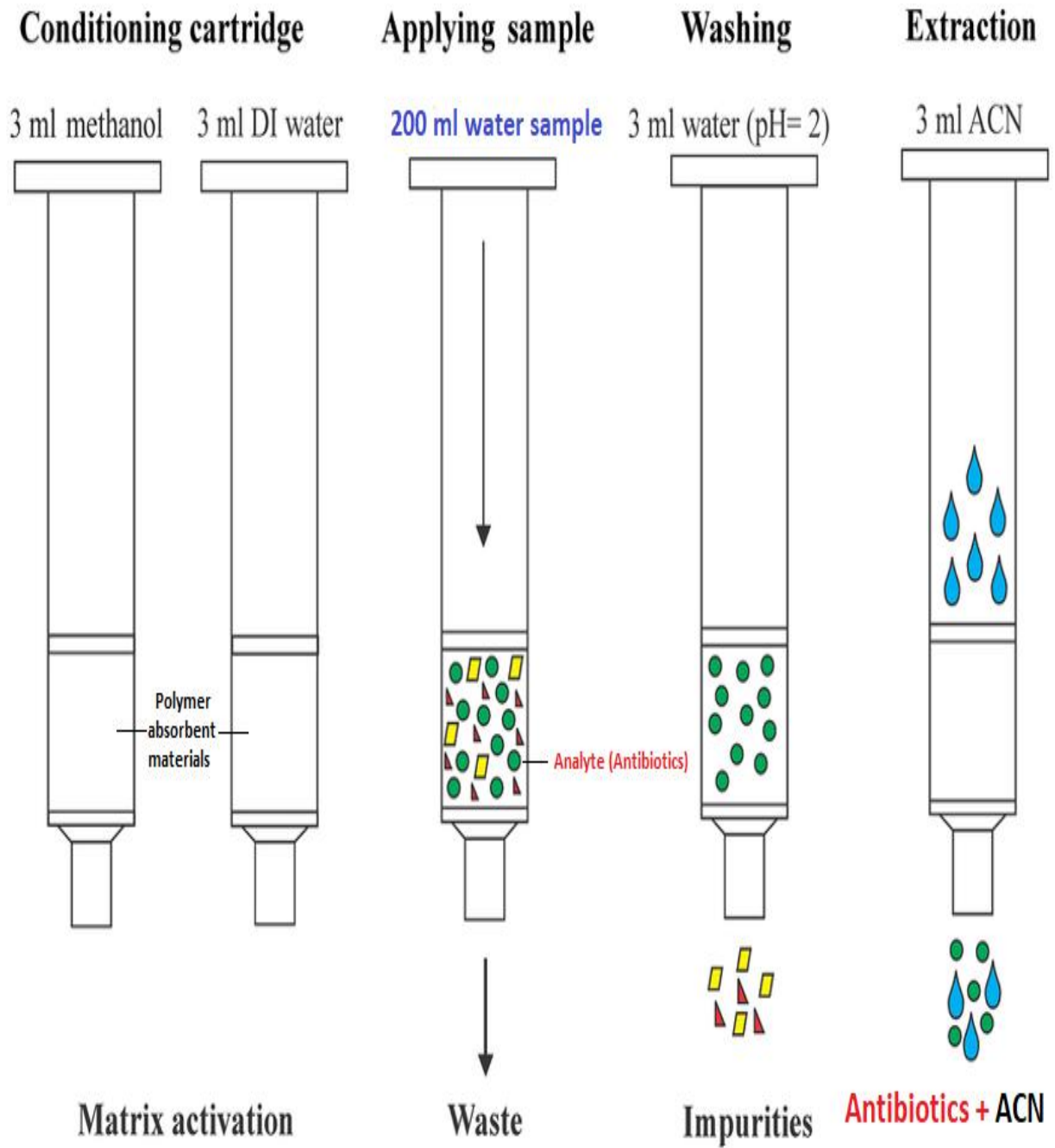


Figure 3.2: Solid Phase Extraction (SPE) Extraction Process

Source⁷

3.5.2 Antibiotics Quantification

High-performance liquid chromatography (HPLC) is a technique used to separate molecules based on sizes and surface charge among other properties, the incorporation of ultraviolet (UV) spectroscopy with HPLC allows the concentration of molecules to be determined following separation.

All analyses were carried out using an HPLC-UV system comprised of the Agilent Series 1100 LC system (Agilent Technologies, Germany). Separation of analytes was done on LC C₁₈ column (5µm particle size, 250 x 4.6 mm I.D) and all injections were done automatically by an autosampler. The chromatographic conditions were as follows: mobile phase, isocratic elution of water/methanol (30/70, v/v); flow rate, 0.5 mL/min; injection volume, 40 µL; column temperature, 20°C and detector wavelengths, 220 nm (ampicillin), 278 nm (chloramphenicol and ciprofloxacin) and 320 nm (metronidazole).

3.5.3 Antibiotics Health Risk Assessment

As per USEPA, human health risk assessment (HHRA) is the procedure to evaluate the nature and likelihood of adverse health effects in humans who may be exposed to various hazards in contaminated environmental media, today or in the future⁸. The potential human health risk of antibiotics was estimated for the worst-case scenario in groundwater samples.

3.5.3.1 The Potential Target Hazard Quotient

The health risks for human from exposure to environmental pollutants through drinking water is evaluated by the target hazard quotient (THQ), which is extrapolated from the measured environmental concentration (MEC, ng/L) through the division of the predicted no-effect concentrations in drinking water (PNEC_{DW}, ng/L)⁹. An obvious risk for human health exposed to antibiotics is defined as THQ > 1, while no discernible risk is defined as THQ < 1.

$$\text{THQ} = \frac{\text{MEC}}{\text{PNEC}_{\text{DW}}} = \frac{\text{MEC} \times \text{EF} \times \text{ED} \times \text{IR}}{\text{Bw} \times \text{AT} \times \text{ADI}}$$

Where,

MEC-measured environmental concentration

EF-exposure frequency (365 days/ year)

ED-exposure duration (70 years)

IR- daily drinking water ingestion (2 L/person/day)

Bw- BW is the body weight (15kg and 72kg for children and adults, respectively)¹⁰

AT- average time of exposure (365 days/year × 70 years, i.e., 25,550 days)

ADI- acceptable daily intake (ng/kg bw/day)

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Table 3.3: List of Accepted Daily Intake (ADI) Values for Some Antibiotics

| Antibiotics | ADI µg/kg/day |
|-------------------------------|------------------|
| Sulfapyridine ^a | 10 |
| Sulfamethoxazole ^a | 10 |
| Ciprofloxacin ^b | 7.1 |
| Enrofloxacin ^c | 6.2 |
| Levofloxacin ^d | 0.15 |
| Norfloxacin ^b | 11.4 |
| Chloramphenicol ^e | - |
| Florfenicol ^d | 1.0 |
| Doxycycline ^f | 3 |
| Metronidazole ^g | 0.6 |

Note: ADI were adopted from provisional values established in the literature as follows.

a ADI for sulfapyridine, sulfamethoxazole¹¹.

b ADI for ciprofloxacin, norfloxacin¹².

c ADI for enrofloxacin¹³

d ADI for levofloxacin, and florfenicol¹⁴.

e ADI for chloramphenicol could not be set^{15,16}.

f ADI for doxycycline¹⁷

g ADI for metronidazole¹⁸

Table 3.4. Parameters Relating to Adults and Children Exposure

| Parameter | Units | Adult | Children |
|---|-----------|-------|----------|
| Body weight (BW) | Kg | 70 | 14 |
| Averaging time (AT) | Days | 10950 | 2190 |
| Water consumption (Ing _{RDW}) | L/day | 2 | 1 |
| Exposure frequency (EF) | days/year | 350 | 350 |
| Exposure duration (ED) | Years | 30 | 6 |

Data recommended by U.S. EPA¹⁹; Guidelines for Drinking water Quality²⁰

3.5.3.2. Ecological Risk for Development of Resistance to Antibiotics.

Ecological risk for development of resistance to antibiotics was estimated by means of risk quotient (RQ) values. The RQ values are expressed as the ratio of the measured environmental concentration (MEC) to the predicted no-effect concentration (PNEC), for any particular antibiotic compound as shown below:

$$\text{RQ} = \frac{\text{MEC}}{\text{PNEC}}$$

The risk will be classified into three levels, i.e.

Low risk with the RQs ranging between 0.01 and 0.1,

Moderate risk with the RQs ranging between 0.1 and 1, and

High risk with the RQs > 1²¹

Note: To calculate the RQs, PNECs were used²².

PNEC for Ciprofloxacin is 0.064^a

PNEC for Metronidazole is 0.125^a

The PNEC corresponds to the size-adjusted lowest MIC divided by an assessment factor of 10 (rounded down to the closest concentration on the EUCAST testing scale)²².

3.6 Reagents, Standards and Analytical Quality Assurance

Analytical standards for antibiotics (ampicillin trihydrate (≥ 96.0%), ciprofloxacin (≥ 98.0%), chloramphenicol (≥ 98.0%) and metronidazole) were purchased from Sigma-Aldrich (St. Louis, MO, USA). Acetonitrile and methanol of HPLC grade and Oasis HLB SPE cartridges (500 mg, 12 mL) were purchased from Sigma-Aldrich (St. Louis, MO, USA). Milli-Q water was obtained with Milli-Q Direct 8/16 System. The standard stock solutions of each analyte (50 mg L⁻¹) were prepared singly in methanol and stored at 4 °C for antibiotics analysis. Elemental calibration standards were prepared from spectroscopic grade stock standard solutions of 1000 mg L⁻¹.

Ultrapure water was used throughout the experiments. All plastic containers were washed with double distilled water and then soaked overnight in 1M HNO₃. The accuracy of the

analytical procedure will be authenticated by concurrent analysis of Certified Reference Materials (CRM) for elemental analysis^{23,24}. The % recovery is within acceptable ranges when compared to certified ($p = 0.05$) values of experimental mean values (Table 3.2). Parameters such as pH, DO, Temperature, TDS and Conductivity were determined on-site. Quality control procedures were implemented, which included reagent blanks, triplicate samples, and recovery studies.

3.7. Statistical Analysis

Data obtained were subjected to descriptive (mean \pm SD) and to a one-way analysis of variance (ANOVA) to determine significant differences ($P < 0.05$) between mean concentrations of elements among hand-dug Wells. Tukey's test was used for post-hoc analyses and Pearson's correlation matrix was also performed on the element data. All statistical analyses were performed using the Statistical Package for the Social Sciences, (PASW version 24, IBM Corporation, Cornell, NY, USA).

Endnotes

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Chapter Four

Results and Discussion of Findings

4.1 Physico-Chemical Analysis

The water samples from the randomly selected groundwater samples from the two rural communities varied in appearance from colourless to slightly brown and the temperature of the water samples was within acceptable limits for groundwater quality. Table 4.1 summarizes the result of the physicochemical characteristics such as Dissolved oxygen (DO), Temperature (Temp), hydrogen ion concentration (pH), Total dissolved solids (TDS), and Conductivity (Cond) of groundwater samples from the two rural communities.

The pH, Temp and DO values ranged from 6.34 to 7.57, 29.6 to 31.7, and < LOD to 0.04 $\mu\text{g L}^{-1}$ respectively, with S₉, S₆, and S₁ having the highest value for pH, Temp, and DO respectively. Similarly, TDS and Cond values ranged from 0.04 to 0.39 $\mu\text{g L}^{-1}$ and 0.18 to 40.7 $\mu\text{S cm}^{-1}$ respectively. Dissolved oxygen is an important parameter in water quality assessment and reflects the physical and biological processes prevailing in the water. The DO values indicate the degree of pollution in water bodies. When the temperature of water increases, a portion of oxygen converts from a liquid state to a gaseous state. Thus, the ability of water to maintain oxygen in the dissolved state decreases with increasing temperature. As a result, colder water can potentially contain more dissolved oxygen than warm water¹.

In all, the physicochemical characteristics were not significantly different ($p > 0.05$) across the two communities, indicating similarities in their physicochemical profile and influencing factors except for conductivity at S₁₀ (40.7 ± 0.58) which was significantly different. Furthermore, all the physicochemical parameters were within the WHO and FEPA

permissible limit except for pH at S₃ (6.3 ± 0.02). The physicochemical values were also higher than those reported by Oloruntoba and Ogunbunmi².

Table 4.1: Physico-Chemical Parameters of Groundwater Samples

| Sample location | pH | DO* | Temp | TDS* | Cond.* |
|-----------------|-------------------------------------|-------------------|-------------------|----------------------|-------------------|
| S1 | 6.53 ± 0.02^a | 0.04 ± 0.04^a | 30.3 ± 0.40^a | 0.04 ± 0.01^a | 8.0 ± 0.00^a |
| S2 | 7.28 ± 0.02^a | < LOD | 30.1 ± 0.50^a | 0.37 ± 0.00^b | 0.74 ± 0.00^b |
| S3 | 6.34 ± 0.02^a | < LOD | 29.6 ± 0.10^a | 0.10 ± 0.01^a | 0.18 ± 0.02^a |
| S4 | 6.99 ± 0.04^a | < LOD | 30.5 ± 0.12^a | 0.39 ± 0.00^b | 0.77 ± 0.01^b |
| S5 | 7.21 ± 0.01^a | 0.01 ± 0.00^a | 31.7 ± 0.30^a | 0.27 ± 0.00^b | 0.56 ± 0.02^b |
| S6 | 6.92 ± 0.02^a | < LOD | 31.7 ± 0.47^a | 0.21 ± 0.01^b | 0.42 ± 0.01^b |
| S7 | 6.72 ± 0.02^a | < LOD | 30.2 ± 0.15^a | 0.09 ± 0.01^a | 0.19 ± 0.00^a |
| S8 | 6.96 ± 0.01^a | < LOD | 30.6 ± 0.10^a | 0.24 ± 0.00^b | 0.49 ± 0.02^b |
| S9 | 7.57 ± 0.01^a | < LOD | 31.1 ± 0.06^a | 0.39 ± 0.01^b | 0.78 ± 0.01^b |
| S10 | 7.07 ± 0.01^a | 0.01 ± 0.00^a | 31.5 ± 0.44^a | 0.20 ± 0.01^{ab} | 40.7 ± 0.58^c |
| WHO** | 6.5-8.5 | ≥ 6 | 40 | 500 | 300 |
| FEPA | 6.0-9.0 | ≥ 4 | 26 | 500 | 70 |

The values are reported in (Mean \pm SD), n = 3. < LOD= Limit of Detection. *Values are in $\mu\text{g L}^{-1}$; DO; Dissolved Oxygen. Different superscript letters in the same column indicate mean separations by Tukey's post hoc tests at the 5% level. **World Health Organization³.

Source: Author Analysis, 2023

4.2 Elemental Analysis

Groundwater samples from ten (10) hand-dug wells collected from Oyo and Ogun states were analysed for sixteen elements namely Ca, Mg, Na, K, B, Cr, Cu, Co, Fe, Mn, Ni, Pb, Se, Zn, Cd, and Al. The elemental analysis results were divided and reported in three major categories namely essential macro-elements, essential micro-elements, and potentially toxic elements (PTEs).

4.2.1 Concentrations of Essential Macro-Elements in Groundwater Samples

The concentrations of Ca, Mg, Na and K in the ten randomly selected hand-dug wells were summarised in Table 4.2. The concentrations of Ca ranged from 9.14 mg L⁻¹ to 52.8 mg L⁻¹ with S2 having the highest value and all results were below the WHO permissible limit of 75 mg L⁻¹. The groundwater samples in these locations were characterized by low calcium ion contents. There is no ill health expressly linked to calcium in potable water, however, its presence in potable water may result in the hardness of the water.

Magnesium concentrations in the investigated water samples ranged from 2.41 mg L⁻¹ to 27.7 mg L⁻¹ and these results were also below the WHO permissible limits. Similarly, Na concentrations were below the WHO permissible limits of 200 mg L⁻¹ and ranged between 2.23 mg L⁻¹ to 13.3 mg L⁻¹. Potassium (K⁺) concentration in the water samples varied from 1.29 mg L⁻¹ to 35.8 mg L⁻¹, with the lowest detected in S3 and the highest recorded in S2. This result is above the WHO permissible limits of 12 mg L⁻¹. This result indicated that there are some activities within S2 sampling location that are responsible for this high K than in other investigated locations. The apparent colour of the water indicates a likely source of pollution within that sampling site. Likewise, Figure 4.1 showed that the decreasing order of

the essential macro-elements in the groundwater samples from the selected locations is $Ca > Mg > Na > K$.

Table 4.2: Average Concentration of Essential Macro-Elements in Groundwater Samples

| Sample Location | Ca | Mg | Na | K |
|-----------------|------|------|------|-------------|
| S1 | 9.14 | 2.41 | 2.23 | 4.39 |
| S2 | 52.8 | 11.9 | 10.2 | 35.8 |
| S3 | 15.3 | 3.89 | 3.61 | 1.29 |
| S4 | 36.5 | 23.5 | 13.3 | 3.26 |
| S5 | 43.4 | 8.26 | 8.39 | 6.40 |
| S6 | 26.9 | 14.0 | 8.07 | 4.11 |
| S7 | 10.9 | 5.77 | 3.77 | 2.41 |
| S8 | 13.5 | 14.0 | 9.19 | 5.25 |
| S9 | 39.3 | 27.7 | 13.1 | 3.54 |
| S10 | 19.3 | 9.05 | 6.62 | 4.68 |

Source: Author Analysis, 2023

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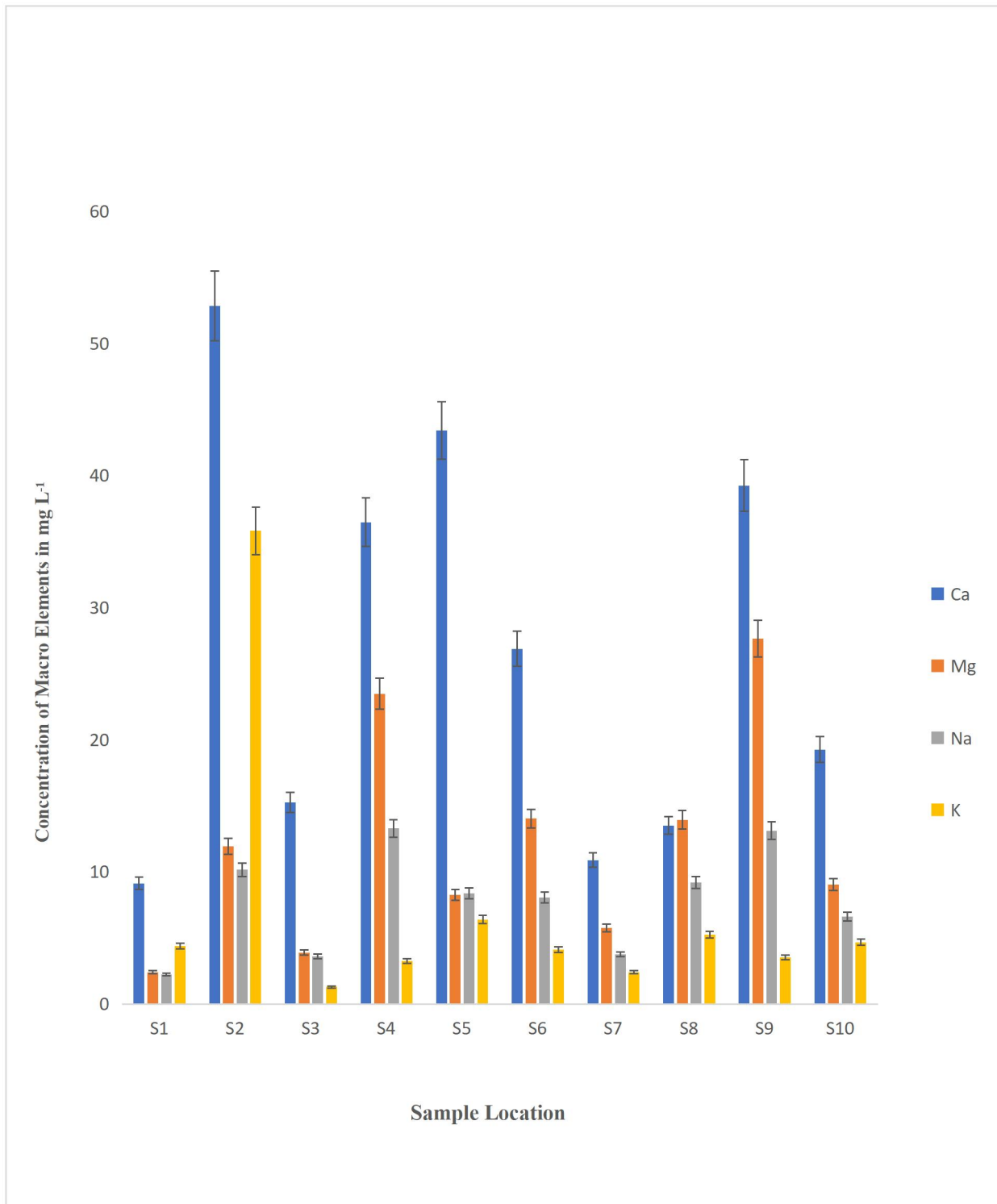


Figure 4.1: Distribution of Essential Macro-Elements in Groundwater Samples

Source: Author Analysis, 2023

4.2.2 Concentrations of Essential Micro-Elements in Groundwater Samples

Similarly, Table 4.3 summarised the concentrations of essential micro-elements in groundwater samples collected from selected locations in Oyo and Ogun States while Figure 4.2 shows the distribution across the sampling locations. The concentrations of Mn varied from 0.04 to 0.99 mg L⁻¹. Also, all results were below the WHO permissible limits except S2 (0.99 mg L⁻¹) which was above the WHO permissible limits of 0.05 mg L⁻¹. This high concentration is a possible risk to the lives of both adults and infants using water from this groundwater sample.

The concentrations of Fe in all the groundwater samples across the randomly selected sites were significantly above the WHO permissible limits of 0.3 mg L⁻¹ and ranged from 0.84 (S4) to 3.19 (S8) mg L⁻¹, indicating a form of contamination. Sustained consumption of water from these hand-dug wells may lead to adverse aesthetic and health effects in residents that depend on these for their domestic water supply⁴. The high concentration of Fe in most of the groundwater samples may be due to the leaching of Fe from point and non-point sources such as storm runoff and metal disposal. Jagaba and Kutty also reported a similar case⁴.

Copper concentrations ranged from 0.02 to 0.20 mg L⁻¹, and all were found below the WHO permissible limit of 2.0 mg L⁻¹ for potable water. This suggests that the consumption of this groundwater poses no danger as far as the intake of copper is concerned⁵. Additionally, Zn concentrations in groundwater samples varied from 0.12 to 0.30 mg L⁻¹ and the analysed samples were all below the WHO permissible limit of 3.0 mg L⁻¹. Normally, Zn finds its way into groundwater via leaching. Aluminium (Al) concentration had its highest value of 4.21 mg L⁻¹ detected in S8 while the lowest concentration of 0.98 mg L⁻¹ was recorded at sampling site S6. All results obtained were significantly above the WHO permissible limit of 0.2 mg L⁻¹. The high concentrations could be traced to wastewater effluents and solid waste in the sampling locations. Exposure to aluminium is usually not harmful but high levels can affect

health of the consumer⁶. Briffa and Sinagra reported that the target of aluminium poisoning are the lungs, central nervous system and bone⁶.

The concentrations of B ranged from 0.05 in S2 to 0.25 mg L⁻¹ in S6 and were below the WHO permissible limit of 0.3 mg L⁻¹, however, B was not detected in S5, S7, and S9. Also, the concentrations of Co in water samples ranged from 2.67 to 5.38 mg L⁻¹ and were significantly higher than the WHO permissible limit of 0.01 mg L⁻¹. Cobalt enters the water through the combustion of coal or oil and the use of cobalt-related chemicals. High concentration of cobalt is also toxic to human beings. Popoola and Yusuff stated that people exposed to a high concentration of Co have been reported to have lung diseases such as wheezing, asthma and pneumonia⁷.

Furthermore, the detection frequency for Se was 20% across all the sampling locations, with a concentration of 0.03 mg L⁻¹ in S3, and S5, which was slightly higher than the WHO permissible limit of 0.01 mg L⁻¹. One of the sources of Se contamination in groundwater is through agricultural runoff leaching natural selenium compounds from dry, undeveloped lands. This was observed at these sampling locations. Extreme intake of Se has adverse effects on human health⁸. Based on their geometric mean values, the essential micro-elements distribution in the groundwater follows the trend: Co > Al > Fe > Mn > Zn > B > Cu > Se.

Table 4.3: Average Concentration of Essential Micro-elements in Groundwater Samples

| Sample Location | Mn | Fe | Cu | Zn | Al | B | Co | Se |
|-----------------|-------------|-------------|------|------|-------------|-------|-------------|-------------|
| S1 | 0.07 | 1.68 | 0.03 | 0.29 | 1.53 | 0.21 | 5.38 | < LOD |
| S2 | 0.99 | 2.86 | 0.02 | 0.24 | 3.52 | 0.05 | 5.38 | < LOD |
| S3 | 0.09 | 1.39 | 0.03 | 0.29 | 1.23 | 0.06 | 2.67 | 0.03 |
| S4 | 0.07 | 0.84 | 0.03 | 0.16 | 0.99 | 0.13 | 5.38 | < LOD |
| S5 | 0.04 | 1.09 | 0.02 | 0.13 | 1.08 | < LOD | 2.67 | 0.03 |
| S6 | 0.11 | 0.91 | 0.03 | 0.12 | 0.98 | 0.25 | 2.67 | < LOD |
| S7 | 0.11 | 3.16 | 0.20 | 0.18 | 3.11 | < LOD | 5.38 | < LOD |
| S8 | 0.47 | 3.19 | 0.03 | 0.14 | 4.21 | 0.08 | 2.67 | < LOD |
| S9 | 0.07 | 1.64 | 0.05 | 0.20 | 2.16 | < LOD | 5.38 | < LOD |
| S10 | 0.33 | 2.19 | 0.07 | 0.30 | 2.40 | 0.18 | 5.38 | < LOD |
| WHO | 0.5 | 0.3 | 2.0 | 3.0 | 0.2 | 0.3 | 0.01 | 0.01 |

Source: Author Analysis, 2023

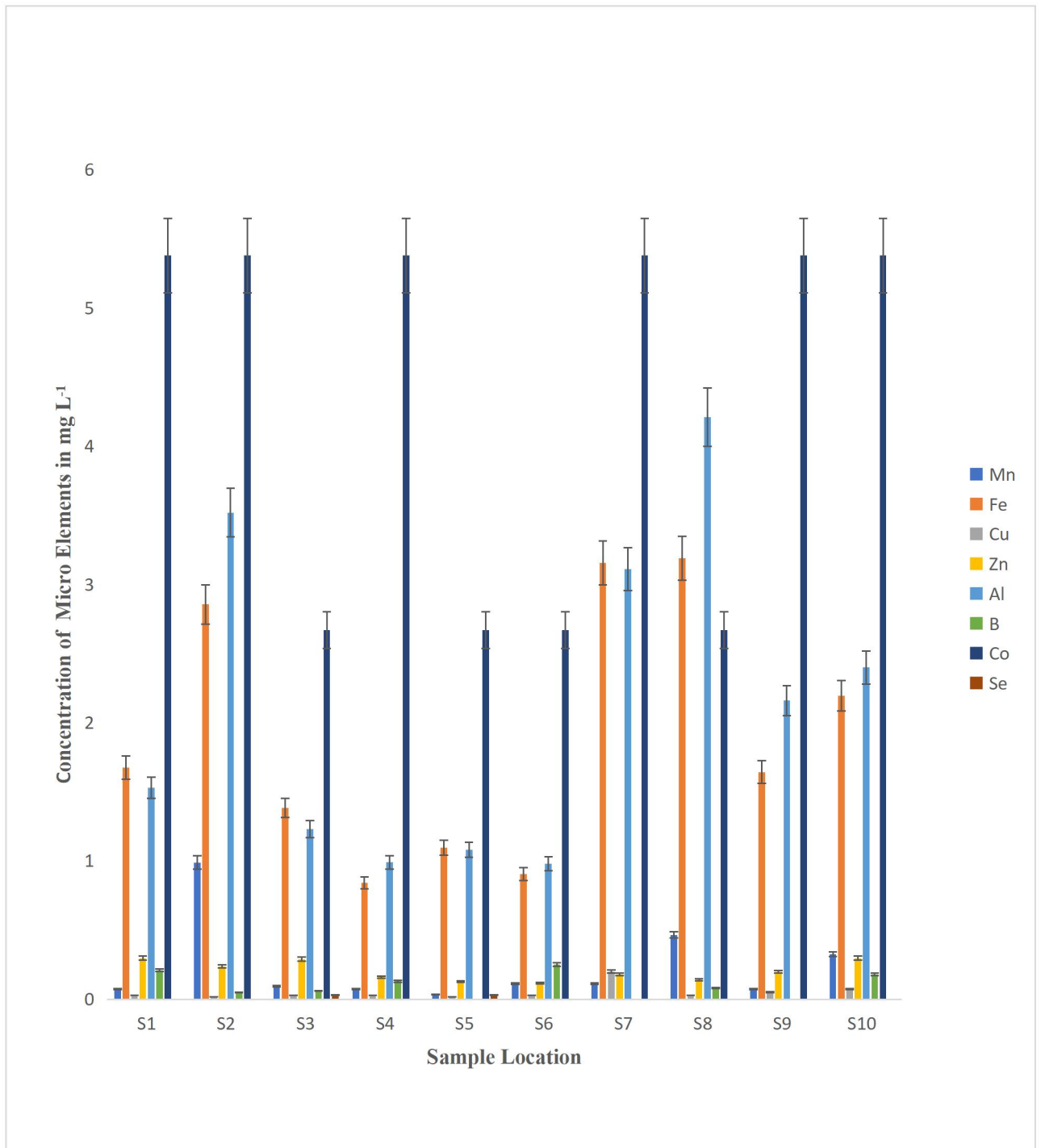


Figure 4.2: Distribution of Essential Micro Elements in Groundwater Samples

Source: Author Analysis, 2023

4.2.3: Concentrations of Potentially Toxic Elements in Groundwater Samples

Equally, the average concentrations and distribution of potentially toxic elements (PTEs) in groundwater samples collected from randomly selected locations are summarised and illustrated in Table 4.4 and Figure 4.3 respectively. Generally, the mean concentrations of the selected PTEs across all the sampling locations were all above the WHO permissible limits of 0.05, 0.02, 0.10, and 0.003 mg kg⁻¹ for Cr, Ni, Pb, and Cd respectively (Table 4.3) except for Pb at sites S3, S5, S6 and S8 and Cd at sites S1 to S9.

The average Cr concentration ranged from 0.45 mg L⁻¹ in S4 and S6 to 1.40 mg L⁻¹ in S8. All samples investigated in this location are beyond the WHO standard limit of 0.05 mg L⁻¹. The higher concentrations of Cr observed in the groundwater sources could be due to anthropogenic activities close to the source of the water. Chromium is very toxic due to strong oxidation properties; hence, it can cause diseases like gastrointestinal, and central nervous system disorders, and cancer⁹.

Similarly, the average concentration of Ni in the groundwater samples ranged from 0.08 to 0.24 mg L⁻¹. All the samples are higher than the WHO permissible limits of 0.02 mg L⁻¹. An increase in Ni concentration could be attributed to human interference and activities within the sampling locations. Nickel enters the human body through inhalation, water, and food consumption, and its high concentration may pose threat to human health. Chronic exposure may be responsible for a variety of adverse effects on the health of human beings, such as lung fibrosis, kidney and cardiovascular diseases and cancer of the respiratory tract¹⁰. Also, the average Pb concentration in all the analysed groundwater samples, which varied from 0.07 to 0.14 mg L⁻¹, in 60% of the samples is above the WHO permissible limit of 0.10 mg L⁻¹ while the other 40% of samples had similar Pb concentration of 0.07 mg L⁻¹. However,

groundwater with less than 0.05 mg L⁻¹ concentration of Pb may have a slight risk of behavioural changes and the possibility of neurological impairment in young children with developing brain tissues¹¹.

Furthermore, the concentration of Cd in 90% of the groundwater samples was below the detection limit of the instrument, S10 had an average concentration of 2.00 mg L⁻¹, which is significantly higher than the WHO permissible limit of 0.003 mg L⁻¹. Cadmium can enter the body through water intake as well as from other sources like the use of pesticides that get leached into the groundwater sources¹². Consumption of Cd above the permissible limit can cause liver and kidney damage¹². The order of distribution of the PTEs in groundwater samples from the selected locations in Oyo state was Cr > Cd > Ni > Pb.

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Table 4.4: Average Concentration of Potentially Toxic Elements from Selected Locations

| Sample Location | Cr | Ni | Pb | Cd |
|------------------------|-------------|-------------|-------------|-------------|
| S1 | 0.72 | 0.08 | 0.14 | < LOD |
| S2 | 1.18 | 0.08 | 0.14 | < LOD |
| S3 | 0.60 | 0.24 | 0.07 | < LOD |
| S4 | 0.45 | 0.08 | 0.14 | < LOD |
| S5 | 0.59 | 0.08 | 0.07 | < LOD |
| S6 | 0.45 | 0.16 | 0.07 | < LOD |
| S7 | 1.12 | 0.24 | 0.14 | < LOD |
| S8 | 1.40 | 0.16 | 0.07 | < LOD |
| S9 | 0.96 | 0.08 | 0.14 | < LOD |
| S10 | 0.88 | 0.16 | 0.14 | 2.00 |
| WHO | 0.05 | 0.02 | 0.10 | 0.003 |

Source: Author Analysis, 2023

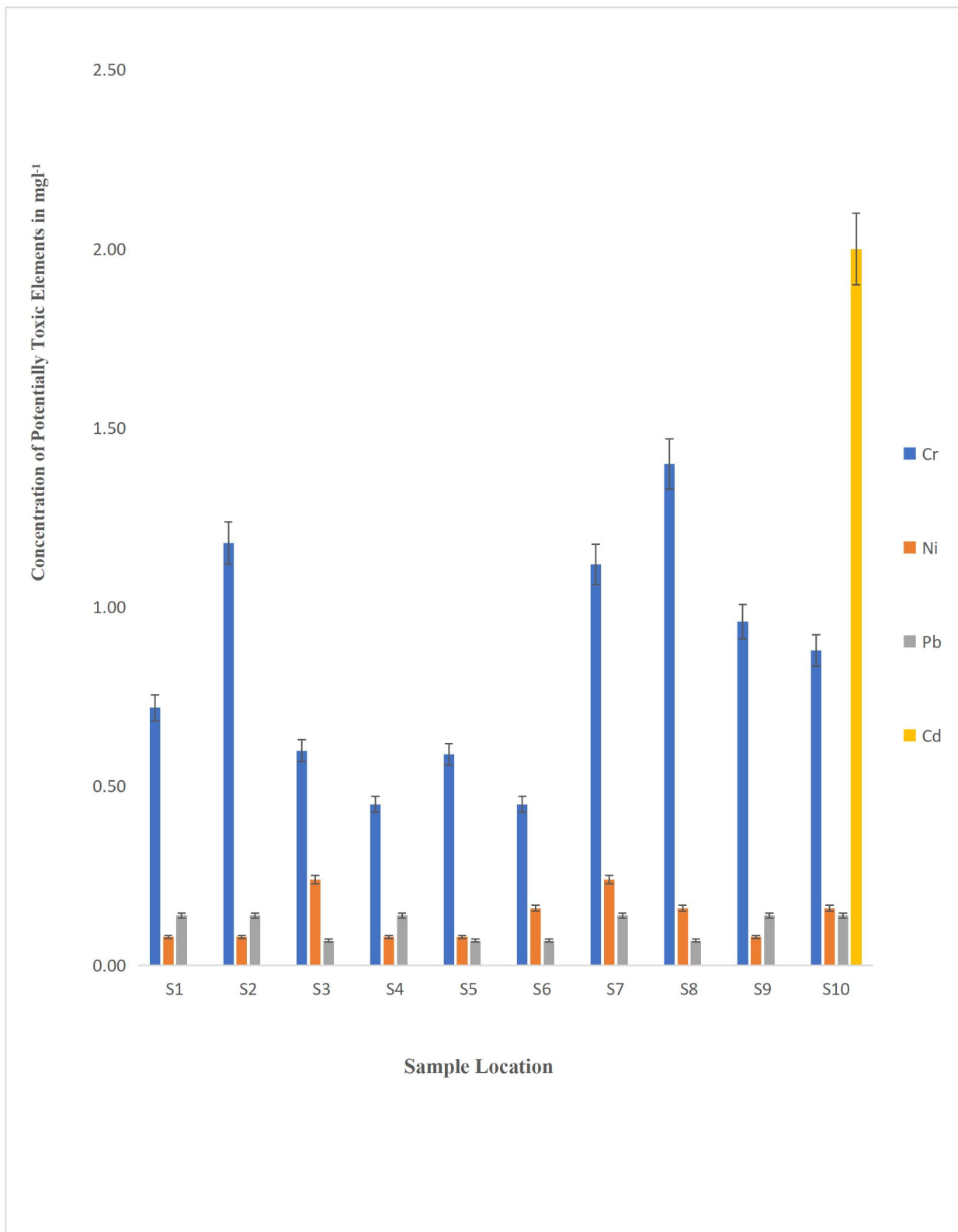


Figure 4.3: Distribution of Potentially Toxic Elements in Groundwater Samples

Source: Author Analysis, 2023

4.3 Antibiotic Analysis

4.3.1 Concentrations of Metronidazole in Groundwater Samples in Oyo and Ogun States

The groundwater samples collected from ten locations in Oyo and Ogun states were further investigated to determine the presence of common antibiotics in the samples. Four antibiotics (metronidazole, ciprofloxacin, chloramphenicol and ampicillin) were analyzed but only metronidazole and ciprofloxacin were detected in the groundwater samples. Table 4.5 shows the range of concentration of metronidazole in this order S1(7846 ± 62) > S8 (1191 ± 45). Both results are above the permissible level of LOD (128) and LOQ (428).

Similarly, the concentration of metronidazole in the Ogun State axis was high and above the permissible level in S6 (2834 ± 1.04), where it was detected as shown in Table 4.10. Metronidazole was not detected in other sampling locations in Ogun State. The high concentrations obtained can be traced to agricultural and domestic activities noticed in the community.

Figure 4.4 shows the plot of the concentration of metronidazole in all the selected sampling locations in descending order as follows: S1(7846 ± 62) > S6 (2834 ± 1.04) > S8 (1191 ± 45)

Table 4.5: Results of Metronidazole Analysis for Selected Groundwater Samples

| Sample Location | 1 | 2 | Mean ± SD |
|------------------------|-----------------|----------|------------------|
| S1 | 7908 | 7784 | 7846 ± 62 |
| S2 | < LOD | < LOD | < LOD |
| S3 | < LOD | < LOD | < LOD |
| S4 | < LOD | < LOD | < LOD |
| S5 | < LOD | < LOD | < LOD |
| S6 | 2835 | 2832 | 2834 ± 1.04 |
| S7 | < LOD | < LOD | < LOD |
| S8 | 1146 | 1236 | 1191 ± 45 |
| S9 | < LOD | < LOD | < LOD |
| S10 | < LOD | < LOD | < LOD |
| LOD | 128 | - | - |
| LOQ | 428 | - | - |
| Linear range | 100-8000 | - | - |
| r² | 0.9998 | - | - |

Source: Author Analysis, 2023

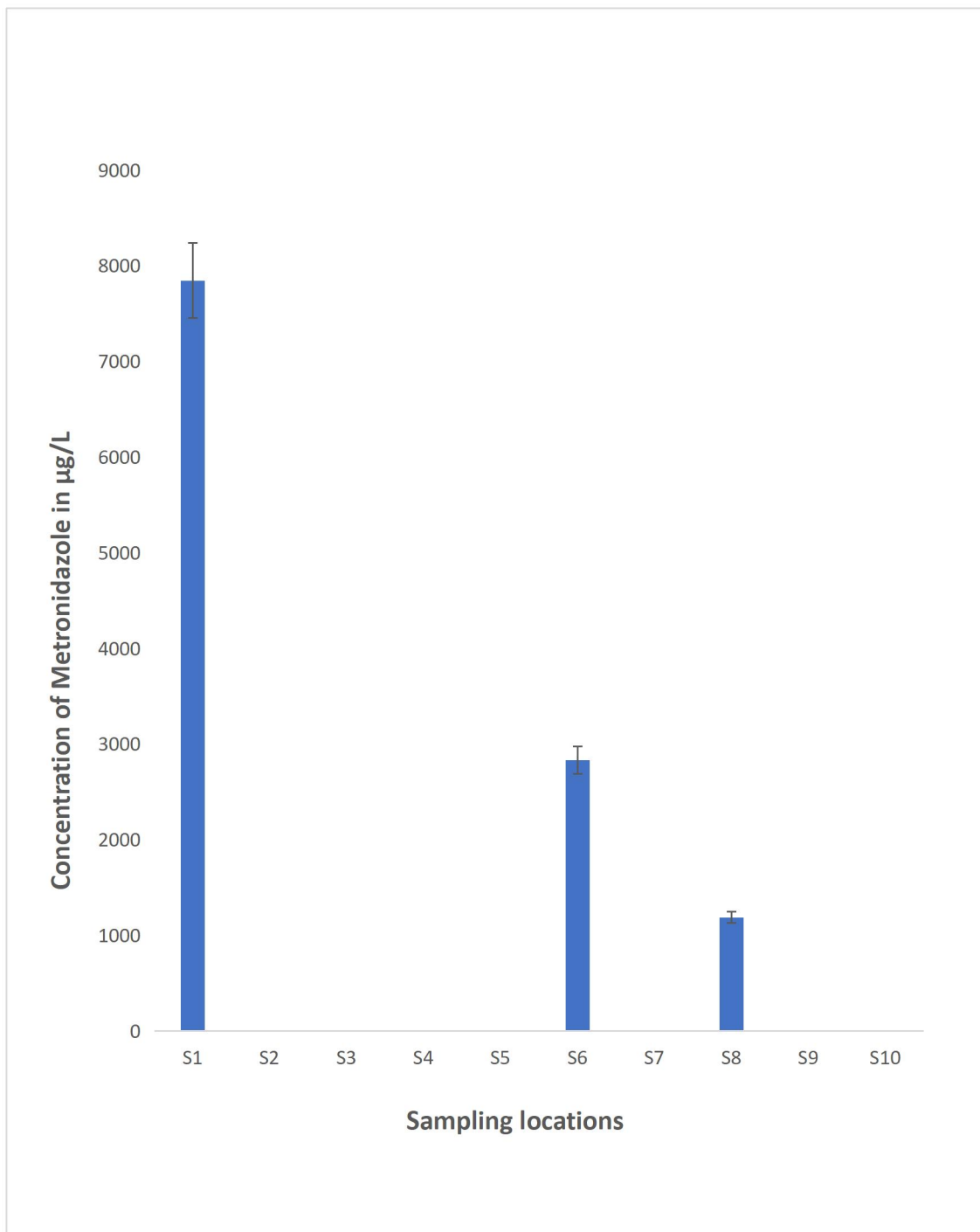


Figure 4.4: Distribution of Metronidazole in Groundwater Samples

Source: Author Analysis, 2023

4.3.2 Concentrations of Ciprofloxacin in Groundwater Samples in Oyo and Ogun states

Table 4.6 shows the range of concentration of ciprofloxacin in this order S10 (803 ± 37.8) > S8 (436 ± 62.48) > S9 (152 ± 11.5). The results obtained are above the permissible level of LOD (128) and LOQ (428) except in S9 where the result was below LOQ.

Similarly, the concentration of ciprofloxacin detected in Ogun State axis was high and above the permissible level in this arrangement: S4 (1137 ± 1.04) > S5 (943 ± 29.5) but in S3 (76 ± 4.93) the result obtained was below both LOD And LOQ. Ciprofloxacin was not detected in other sampling locations in Ogun State. The high concentrations obtained can be traced to agricultural and domestic activities noticed in the community.

Figure 4.5 shows the plot of concentration of ciprofloxacin in all the selected sampling location in this order S4 > S5 > S10 > S8 > S9 > S3.

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Table 4.6: Results of Ciprofloxacin Analysis for Selected Groundwater Samples in Oyo and Ogun State

| Sample Location | 1 | 2 | Mean ± SD |
|----------------------|-----------------|-------|-------------|
| S1 | < LOD | < LOD | < LOD |
| S2 | < LOD | < LOD | < LOD |
| S3 | 71 | 81 | 76 ± 4.93 |
| S4 | 1163 | 1110 | 1137 ± 26.3 |
| S5 | 972 | 913 | 943 ± 29.5 |
| S6 | < LOD | < LOD | < LOD |
| S7 | < LOD | < LOD | < LOD |
| S8 | 498 | 373 | 436 ± 62.48 |
| S9 | 140 | 163 | 152 ± 11.5 |
| S10 | 840 | 765 | 803 ± 37.8 |
| LOD | 79 | - | - |
| LOQ | 264 | - | - |
| Linear range | 100-2000 | - | - |
| r² | 0.9984 | - | - |

Source: Author Analysis, 2023

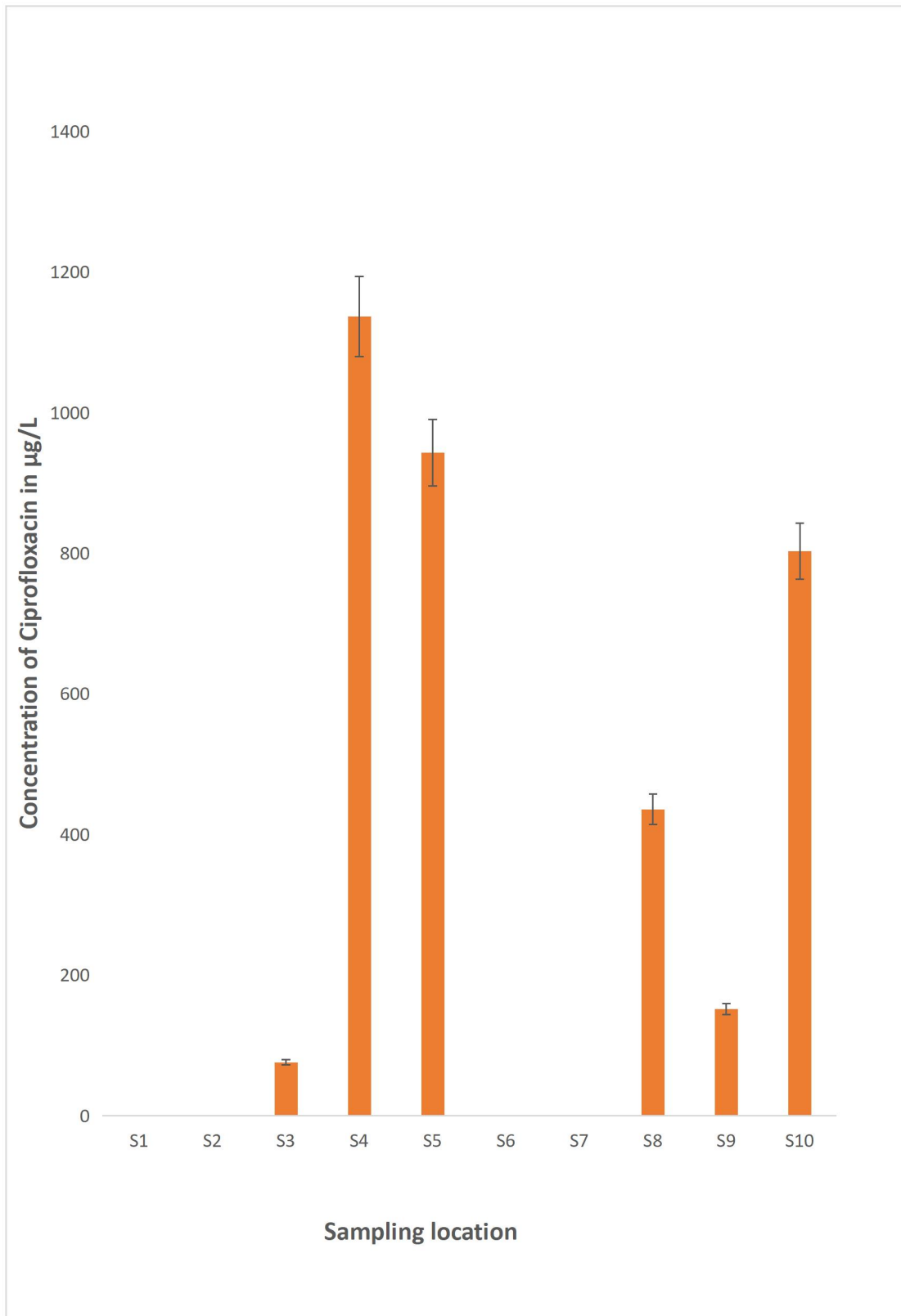


Figure 4.5: Distribution of Ciprofloxacin in Groundwater Samples.

Source: Author Analysis, 2023

The results obtained for the antibiotics analysis revealed that both metronidazole and ciprofloxacin were present in sample S8 located in the Oyo State in a significantly high concentration above LOD and LOQ of both antibiotics. This indicated that the domestic and agricultural activities within the location generate more antibiotics than other investigated sites and this might lead to antibiotic resistance for humans residing in that area. Furthermore, Figures 4.9 and 4.10 shows the calibration curve of metronidazole and ciprofloxacin respectively.

4.4. Statistical Analysis

4.4.1 Correlation Study

Correlation coefficients are a quantitative assessment that measures both the direction and the strength of a tendency to vary together either positively, negatively or neutrally. When the correlation coefficient matrix is positive, it may suggest similar contamination or pollution sources while when it is negative, it may suggest dissimilar contamination or pollution sources¹³. Table 4.7 shows the detailed summary of Pearson's correlation coefficient analysis performed using Microsoft Excel package at 95% confidence limit ($p < 0.05$) to determine the relationships between the physicochemical parameters, essential macro-elements, essential micro-elements, potentially toxic elements and antibiotics in the groundwater samples.

Generally, the relationship between the studied physicochemical parameters in groundwater samples from this study was similar to that reported by Popoola and his colleagues⁷. Similarly, Table 4.7 showed some significant relationships between studied elements. Sharma also reported similar correlation pattern between different parameters¹⁴. Consequently, the strong correlation among the elements suggests that significant associations existed between them in the studied groundwater samples. Heavy metals with a high positive correlation suggest the same pollution source¹⁵. This implies that the elements

were generally of similar anthropogenic origin. However, a weak correlation suggests a weak or no relationship between the studied parameters.

A three-way synergy between Na, Ca, and Mg was observed which is depicted by a significant ($P < 0.05$) coefficient of correlations (0.7 and 0.9) in groundwater samples. Likewise, a significant ($P < 0.05$) three-way relationship was observed between Na, pH, and TDS. These significant strong correlations suggest an existence of a strong relationship between these studied parameters (Na, Ca, and Mg) and (Na, pH, and TDS). Furthermore, a moderately strong positive relationship was observed for Ca-K and Ca-Mg with the values 0.6 and 0.5 respectively while a low correlation relationship was observed between Na-K (0.2). The strong correlation results suggest that a strong relationship exists between the elements in the samples analyzed.

Also, the results of the correlation analysis for essential micro-elements in groundwater samples are summarized in Table 4.7. A very strong positive correlation was observed for Fe-Al (1.0). Similarly, a fairly strong positive relationship was obtained for Mn-Al (0.8) and a moderate positive correlation of 0.6 was obtained for Mn-Fe. A weak positive correlation relationship was observed between Fe-Cu (0.5) and Zn-Co (0.4). Mn, Fe, Cu, Al, and B had a negative correlation with Cu, B, and Se indicating that no relationship existed between the elements.

Likewise, the correlation coefficients of the potentially toxic elements in the selected groundwater samples are presented in Table 4.7. The results showed a very weak positive correlation between Cr and Ni (0.1), Cr and Pb (0.2) and Cr and Cd (0.05) while a weak negative correlation existed between Ni-Pb (-0.3).

There were statistically important and perfect positive correlations ($r^2 = 1.0$) between Fe-Cr, Al-Cr, Co-Pb, Na-TDS, Cd-Cond. This indicated that the presence of one parameter could

promote the other in the groundwater samples. Similarly, a very strong correlation was obtained between Mg-Na, Mg-TDS, K-Mn and DO-MET. A moderately strong correlation existed between Cu-Ni, Zn-Cd, B-MET and Temp- pH. This suggests that the parameters were generally of similar anthropogenic sources such as human activity, agriculture and multi-element contamination. Correspondingly, the weak correlation obtained between Temp- Cond (0.4) > Temp-TDS (0.3) > pH- Cond (0.1) and DO-Cond (0.1) implies that a weak relationship exists between the parameters. Some of the variables are negatively correlated with other variables such as between pH- MET (-0.4), Ni-DO (-0.3), Ni-Temp (-0.3), Ni-pH (-0.6), Ni-TDS (-0.6), Ni-MET (-0.2) and Ni-CIP (-0.3). A negative correlation implies that as the value of one variable increases, the other decreases. Zero correlation indicating a lack of correlation relationship was equally obtained between some of the parameters.

Table 4.7: Correlation Matrix of Physicochemical, Elemental and Antibiotics in the Groundwater Samples

| | Ca | Mg | K | Na | Mn | Fe | Cu | Zn | Al | B | Cd | Co | Cr | Ni | Pb | Se | DO | Temp | pH | TDS | Cond | MET | CIP | |
|------|-------------|-------------|-------------|-------------|-------------|-------------|------------|------------|-------------|------------|-------------|-------------|------|------|------|------|-------------|------------|-------------|------|------|------|-----|--|
| Ca | 1.0 | | | | | | | | | | | | | | | | | | | | | | | |
| Mg | 0.5 | 1.0 | | | | | | | | | | | | | | | | | | | | | | |
| K | 0.6 | 0.0 | 1.0 | | | | | | | | | | | | | | | | | | | | | |
| Na | 0.7* | 0.9* | 0.2 | 1.0 | | | | | | | | | | | | | | | | | | | | |
| Mn | 0.4 | 0.0 | 0.9* | 0.2 | 1.0 | | | | | | | | | | | | | | | | | | | |
| Fe | -0.3 | -0.2 | 0.4 | -0.2 | 0.6 | 1.0 | | | | | | | | | | | | | | | | | | |
| Cu | -0.4 | -0.2 | -0.3 | -0.3 | -0.2 | 0.5 | 1.0 | | | | | | | | | | | | | | | | | |
| Zn | -0.3 | -0.4 | 0.1 | -0.5 | 0.2 | 0.1 | 0.0 | 1.0 | | | | | | | | | | | | | | | | |
| Al | -0.1 | 0.0 | 0.4 | 0.1 | 0.7* | 1.0* | 0.3 | 0.0 | 1.0 | | | | | | | | | | | | | | | |
| B | -0.3 | -0.1 | -0.2 | -0.2 | -0.1 | -0.3 | -0.3 | 0.2 | -0.3 | 1.0 | | | | | | | | | | | | | | |
| Cd | -0.2 | -0.1 | -0.1 | -0.1 | 0.1 | 0.1 | 0.2 | 0.5 | 0.1 | 0.3 | 1.0 | | | | | | | | | | | | | |
| Co | 0.1 | 0.2 | 0.2 | 0.1 | 0.2 | 0.2 | 0.4 | 0.4 | 0.2 | 0.0 | 0.3 | 1.0 | | | | | | | | | | | | |
| Cr | -0.1 | 0.0 | 0.4 | 0.0 | 0.6 | 1.0* | 0.3 | 0.1 | 1.0* | -0.4 | 0.0 | 0.2 | 1.0 | | | | | | | | | | | |
| Ni | -0.7* | -0.5 | -0.4 | -0.6 | -0.2 | 0.3 | 0.6 | 0.1 | 0.2 | -0.1 | 0.1 | -0.3 | 0.1 | 1.0 | | | | | | | | | | |
| Pb | 0.1 | 0.2 | 0.2 | 0.1 | 0.2 | 0.2 | 0.4 | 0.4 | 0.2 | 0.0 | 0.3 | 1.0* | 0.2 | -0.3 | 1.0 | | | | | | | | | |
| Se | 0.1 | -0.4 | -0.2 | -0.3 | -0.3 | -0.4 | -0.3 | 0.0 | -0.4 | -0.4 | -0.2 | -0.6 | -0.4 | 0.2 | -0.6 | 1.0 | | | | | | | | |
| DO | -0.3 | -0.5 | -0.1 | -0.5 | -0.2 | -0.1 | -0.2 | 0.5 | -0.2 | 0.4 | 0.1 | 0.2 | -0.2 | -0.3 | 0.2 | 0.0 | 1.0 | | | | | | | |
| Temp | 0.3 | 0.3 | -0.2 | 0.3 | -0.2 | -0.4 | -0.1 | -0.5 | -0.3 | 0.2 | 0.4 | -0.2 | -0.3 | -0.3 | -0.2 | -0.1 | 0.0 | 1.0 | | | | | | |
| pH | 0.8* | 0.7* | 0.4 | 0.8* | 0.3 | 0.0 | -0.2 | -0.4 | 0.2 | -0.3 | 0.1 | 0.2 | 0.2 | -0.6 | 0.2 | -0.3 | -0.3 | 0.6 | 1.0 | | | | | |
| TDS | 0.8* | 0.9* | 0.4 | 1.0* | 0.3 | -0.1 | -0.4 | -0.4 | 0.1 | -0.3 | -0.1 | 0.2 | 0.1 | -0.6 | 0.2 | -0.2 | -0.5 | 0.3 | 0.8* | 1.0 | | | | |
| Cond | -0.2 | -0.1 | -0.1 | -0.1 | 0.1 | 0.1 | 0.1 | 0.4 | 0.1 | 0.3 | 1.0* | 0.3 | 0.0 | 0.1 | 0.3 | -0.2 | 0.1 | 0.4 | 0.1 | -0.1 | 1.0 | | | |
| MET | -0.4 | -0.4 | -0.1 | -0.5 | -0.2 | -0.1 | -0.2 | 0.2 | -0.2 | 0.6 | -0.2 | 0.1 | -0.2 | -0.2 | 0.1 | -0.2 | 0.8* | 0.0 | -0.4 | -0.5 | -0.2 | 1.0 | | |
| CIP | 0.3 | 0.3 | -0.2 | 0.4 | -0.2 | -0.3 | -0.2 | -0.2 | -0.3 | 0.0 | 0.4 | 0.0 | -0.3 | -0.3 | 0.0 | 0.2 | -0.1 | 0.4 | 0.3 | 0.4 | 0.4 | -0.4 | 1.0 | |

* Correlations significant at $P \leq 0.05$

Source: Author's Analysis, 2023

4.5. ANOVA

The analysis of variance (ANOVA) at 5% ($p = 0.05$) confidence level was performed to determine the statistically significant differences between the mean of elemental and antibiotics concentration in groundwater samples collected from the ten (10) locations. The locations were within two neighbouring states (Oyo and Ogun states, Nigeria). The samples were analyzed for essential macro elements (Ca, Mg, K, and Na), essential micro-elements (Cu, Fe, Zn, Al, B, Mn, Co and Se), potentially toxic elements (Cd, Cr, Ni and Pb) and antibiotics (Metronidazole and Ciprofloxacin).

The result of the analysis of the variance of the mean concentrations of essential elements in groundwater samples revealed that $p < 0.05$. This result suggests that there is a significant difference in the concentrations of the macro elements (Na, K, Mg, and Ca) in groundwater samples analyzed. The calculated F value obtained was greater than the F-critical value, hence, the null hypothesis is rejected. Post-hoc analysis was further performed to find out where the significant variations existed by comparing the variation of each element to another. The q-stat value is greater than the calculated q-value (3.809) between Ca-Mg, Ca-K, and Ca-Na, suggesting that significant variations existed between the mean concentrations of these paired elements. This is further proven by the p-value ($\alpha > 0.05$) obtained for each group, showing that significant variations exist between each element investigated with the highest variation existing between Ca and K having the highest p-value of 6.02. Similarly, $P > 0.05$ was obtained for Mg-K, Mg-Na and K-Na. showing that there is no significant variation between the mean concentrations of these elements in the matrix. The calculated Cohen's d further proved that the highest standard deviation exists between Ca and K with a deviation of 1.91. Others occur in the order Ca-Na > Ca-Mg > Mg-K > Mg-Na > K-Na.

Also, the result of the analysis of variance of the mean concentrations of essential micro-elements in groundwater samples revealed that $p < 0.05$. This suggested that there is a

significant ($p < 0.05$) variation in the mean concentration of Cu, Fe, Zn, Al, B, Se, Co, and Mn in groundwater water samples. Since the F calculated (45.09) is greater than the critical value (2.12), the null hypothesis is rejected.

Post-hoc analysis further revealed that very high significant variations existed between seventeen (17) out of the 28 paired groups created such as Cu-Fe, Cu-Al, Cu-Co, Fe-Zn, Fe-B, Fe-Se, Fe-Co, Fe-Mn, Zn-Al, Zn-Co, Al-B, Al-Se, Al-Co, Al-Mn, B-Co, Se-Co, and Co-Mn. This is because the statistical q-value for these pairs is highly greater than the critical q-value (4.415). This was further proven by their p-value which is extremely less than 0.05. The calculated Cohen's d further proved that the highest standard deviation exists between Se and Co with a deviation of 5.89. Others occur in the order Cu-Co > B-Co > Zn-Co > Co-Mn.

Likewise, the result of the analysis of variance of the mean of potentially toxic elements of samples within Oyo and Ogun States showed that $p < 0.05$. This suggests that there are significant variations in the mean concentration of Cd, Cr, Ni, and Pb in the water samples analyzed ($p < 0.05$). Since the F calculated (9.28) is greater than the critical value (2.87), the null hypothesis is rejected.

Post-hoc analysis further revealed that significant variations existed between some pairs in the order Cr-Pb > Cr-Ni > Cd-Cr. This is because the statistical q-value for these pairs is highly greater than the critical q-value (3.809). This was further proven by their p-value which is extremely less than 0.05. Cohen's d value obtained further showed that the difference between the mean concentration of Cr and Pb, Cr – Ni and Cd – Cr are doubled their standard deviations having recorded Cohen's d value of approximately 2.

Furthermore, the result of the analysis of variance of the mean concentrations of antibiotics (metronidazole and ciprofloxacin) in groundwater samples from ten (10) sampling points showed that p value was greater than ($>$) 0.05, suggesting that there are no significant

variations in the mean concentration of the analyzed antibiotics in groundwater water samples analyzed. The F calculated (1.92) was less than the critical value (2.87) for all the sampling points. Therefore, the null hypothesis is accepted. The post-hoc analysis further revealed that no significant variations existed among any of the pairs. This is because the statistical q-value for these pairs is lower than the critical q-value (**3.809**). Cohen's d value obtained further showed that the difference between the mean concentration of MET– CIP, MET-AMP, MET – CHL differ by 1 standard deviation. CIP-AMP and CIP-CHL recorded deviation values less than 1.

4.6 Elemental Health Risk Assessment

4.6.1 Chronic Daily Intake (CDI) of Some Heavy Metals.

The average daily intake through water ingestion was calculated using the equation below

$$CDI = \frac{C \times DI}{BW} \dots\dots\dots \text{Equation 1}^{22,23,24,25}$$

Where CDI is the human exposure risk through the drinking water pathway (mg/kg/day)

C is the concentration of the potentially toxic elements (heavy metals) in drinking water in mg L⁻¹.

DI average daily intake (2.0 L/day/person)

BW is the body weight (15 kg and 72 kg for children and adults, respectively)¹⁶.

The chronic risk assessment of the investigated metals across different age groups (children and adults) is presented in Table 4.8 below.

The CDI values of chromium for children and adults were above oral reference dose (RfD) (0.0003 mg/kg/day) for Cr in S1 (0.096, 0.02), S2 (0.157, 0.033), S3 (0.08, 0.017), S4 (0.06, 0.013), S5 (0.079, 0.016), S6 (0.06, 0.013), S7 (0.149, 0.031), S8 (0.187, 0.039), S9 (0.128,

0.027) and S10 (0.117, 0.024). Ayantobo et al and Ekere et al equally recorded high chromium CDI values^{17,18}. Chromium levels in S1 could be as a result of geological influence than anthropogenic activities such as various agricultural and domestic activities noticed in this community. High concentrations of chromium may cause liver and kidney toxicity and genotoxic carcinogen¹⁹.

The CDI values of nickel for children and adults were below oral reference dose (RfD) (0.02 mg/kg/day) for Ni in S1 (0.011, 0.002), S2 (0.011, 0.002), S3 (0.007) adult, S4 (0.011, 0.002), S5 (0.011, 0.002) and S6 (0.021, 0.004) but slightly above in S3 (0.032) children. S7 (0.007) adult, S8 (0.021, 0.004), S9 (0.011, 0.002), and S10 (0.021, 0.004) but slightly above in S7 (0.032) children.

Likewise, the CDI values of cobalt for children and adults were significantly above the oral reference dose (RfD) (0.02 mg/kg/day) for Co in S1 (0.717, 0.149), in S2 (0.011, 0.002), S3 (0.007) adult, S4 (0.011, 0.002), S5 (0.011, 0.002) and S6 (0.021, 0.004) but slightly above in S3 (0.032) children, S7 (0.717, 0.149), S8 (0.356, 0.074), S9 (0.717, 0.149) and S10 (0.717, 0.149) but slightly above in S7 (0.032) children. The results revealed that a child that drinks 2L of groundwater daily will take a higher dose of Co 3 times than an adult of higher body weight. A high concentration of Co is a potential health threat to the health of residents of the sampling locality, especially children.

The CDI values of Lead (Pb) for children and adults were above oral reference dose (RfD) for lead (0.0035 mg/kg/day) in S1 (0.019, 0.004) mg/kg/day, S2 (0.019, 0.004 mg/kg/day), S3 (0.009), S4 (0.019, 0.004), S5 (0.009), S6 (0.009 mg/kg/day), S7 (0.019, 0.004,) S9 (0.019, 0.004), S10 (0.019, 0.004) and S8 (0.009 mg/kg/day) for children only but below for adult only in S8 (0.002 mg/kg/day). Lead is of health concern in all selected locations, especially for children. Ayantobo and Ekere recorded high lead CDI values^{17,18}. However, WHO reported that exposure to Pb through water is generally low as the main source of lead in

drinking water is old lead piping and lead-combing solders²⁰. The amount of lead that may dissolve in water depends on acidity (pH), temperature, water hardness, and the standing time of the water. High concentrations of lead can affect the central nervous, renal, hematopoietic, developmental, and immunological systems¹⁹.

The CDI values of iron for children and adults were all above the oral reference dose (RfD) (0.007 mg/kg/day). S1 (0.224, 0.047), S2 (0.381, 0.079), S3 (0.185, 0.039), S4 (0.112, 0.023), S5 (0.147, 0.031) and S6 (0.121, 0.025). S7 (0.421, 0.088), S8 (0.425, 0.089), S9 (0.219, 0.046), and S10 (0.293, 0.061). Ekere and Maigari equally recorded high iron CDI values^{18, 21}. Thus, high iron CDI values obtained could be attributed to human activities and geogenic influence. In high concentrations, iron may produce neurological effects²².

The CDI values of cadmium for children and adults were not detected in all the selected groundwater samples except in S10 (0.267, 0.056) and were significantly above the oral reference dose (RfD) (0.0005 mg/kg/day). Also, Ayantobo, Ekere and Maigari all recorded similar higher cadmium CDI values^{17, 18, 21}. The high cadmium CDI values could be as a result of some triggering activities in that location. Thus, cadmium poses a health risk for those exposed to drinking water from the groundwater. At high concentrations, cadmium affects the liver, placenta, kidneys, lungs, brain, and bones. Experimental data in humans and animals showed that cadmium may cause cancer in humans²².

4.6.2 The Non-Carcinogenic Hazard, HQ

This was evaluated through Hazard Quotient, HQ

$$HQ = \frac{CDI}{RfD} \dots\dots\dots \text{Equation 2}$$

Where RfD is the oral reference dose (mg/kg/day) for individual potentially toxic elements that humans can be exposed to.

If the value of $HQ < 1$, it is considered safe,

but if $HQ > 1$, there is an unacceptable risk of adverse non-carcinogenic effects on human health²⁰.

The Non-Carcinogenic Hazard, HQ of groundwater samples is presented in Table 4.8. The hazard quotient (HQ) results of the potentially toxic elements in all the selected groundwater samples were greater than 1 in all the children and adult samples in S1, S2, S3, S4, S5, S6 S7, S8, S9, and S10 for Chromium, Cobalt and Iron. Similarly, HQ results in Lead were higher than 1 except for adult value in S3, S5, S6, and S8 which was lower than 1. Nickel exceeded unity for children in S3, S6, S7 and S8 while HQ values in other samples were below one, thereby considering the groundwater safe in those areas. Cadmium was not detected in all the selected groundwater samples except in S10 and the HQ value is outrageously higher than 1 (> 1). In most of the sampling locations, HQ values were generally high for children hence, making them more vulnerable, especially for a rural setting like the sampling site for this study. Ekere equally recorded $HQ > 1$ for some of the metals considered in this study in the rivers studied while Maigari did not record any except for cobalt^{18, 21}. The high HQ values recorded in this study were a result of the high CDI values of the metals involved. These metals pose long-term health risks to groundwater users in all the locations concerned.

Table 4.8: Chronic Daily Intake and Hazard Quotient of Heavy Metals in Samples

| Sampling Location | Category | Cr | | Ni | | Co | | Pb | | Fe | | Cd | |
|---------------------|----------|--------------|--------------|-------|-------------|--------------|--------------|--------------|-------------|--------------|---------------|--------------|------------|
| | | CDI | HQ | CDI | HQ | CDI | HQ | CDI | HQ | CDI | HQ | CDI | HQ |
| S1 | Children | 0.096 | 32 | 0.011 | 0.55 | 0.717 | 35.85 | 0.019 | 5.28 | 0.224 | 32 | 0.00 | 0.00 |
| | Adult | 0.02 | 6.6 | 0.02 | 0.10 | 0.149 | 7.45 | 0.004 | 1.11 | 0.047 | 6.71 | 0.00 | 0.00 |
| S2 | Children | 0.157 | 52.33 | 0.011 | 0.55 | 0.717 | 35.85 | 0.019 | 5.28 | 0.381 | 54.42 | 0.00 | 0.00 |
| | Adult | 0.033 | 11 | 0.002 | 0.10 | 0.149 | 7.45 | 0.149 | 1.11 | 0.079 | 11.29 | 0.00 | 0.00 |
| S3 | Children | 0.08 | 26.67 | 0.032 | 1.60 | 0.356 | 17.8 | 0.356 | 2.50 | 0.185 | 26.42 | 0.00 | 0.00 |
| | Adult | 0.017 | 5.67 | 0.007 | 0.35 | 0.074 | 3.70 | 0.074 | 0.56 | 0.039 | 5.571 | 0.00 | 0.00 |
| S4 | Children | 0.06 | 20 | 0.011 | 0.55 | 0.717 | 35.85 | 0.717 | 5.28 | 0.112 | 16 | 0.00 | 0.00 |
| | Adult | 0.013 | 4.33 | 0.002 | 0.10 | 0.149 | 7.45 | 0.149 | 1.11 | 0.023 | 3.29 | 0.00 | 0.00 |
| S5 | Children | 0.079 | 26.33 | 0.011 | 0.55 | 0.356 | 17.80 | 0.356 | 2.50 | 0.147 | 21 | 0.00 | 0.00 |
| | Adult | 0.016 | 5.33 | 0.002 | 0.10 | 0.074 | 3.70 | 0.074 | 0.56 | 0.031 | 4.43 | 0.00 | 0.00 |
| S6 | Children | 0.06 | 20 | 0.021 | 1.05 | 0.356 | 17.80 | 0.356 | 2.50 | 0.121 | 17.29 | 0.00 | 0.00 |
| | Adult | 0.013 | 4.33 | 0.004 | 0.20 | 0.074 | 3.70 | 0.074 | 0.56 | 0.025 | 3.57 | 0.00 | 0.00 |
| S7 | Children | 0.149 | 49.67 | 0.032 | 1.60 | 0.717 | 35.85 | 0.019 | 5.28 | 0.421 | 60.140 | 0.00 | 0.00 |
| | Adult | 0.031 | 10.33 | 0.007 | 0.35 | 0.149 | 7.45 | 0.004 | 1.11 | 0.088 | 12.57 | 0.00 | 0.00 |
| S8 | Children | 0.187 | 62.33 | 0.021 | 1.05 | 0.356 | 17.80 | 0.009 | 2.50 | 0.425 | 60.71 | 0.00 | 0.00 |
| | Adult | 0.039 | 13.0 | 0.004 | 0.20 | 0.074 | 3.70 | 0.002 | 0.56 | 0.089 | 12.71 | 0.00 | 0.00 |
| S9 | Children | 0.128 | 42.67 | 0.011 | 0.55 | 0.717 | 35.85 | 0.019 | 5.28 | 0.219 | 31.29 | 0.00 | 0.00 |
| | Adult | 0.027 | 9.0 | 0.002 | 0.10 | 0.149 | 7.45 | 0.004 | 1.11 | 0.046 | 6.57 | 0.00 | 0.00 |
| S10 | Children | 0.117 | 39.0 | 0.021 | 1.05 | 0.717 | 35.85 | 0.019 | 5.27 | 0.293 | 41.86 | 0.267 | 267 |
| | Adult | 0.024 | 8.0 | 0.004 | 0.20 | 0.149 | 7.45 | 0.004 | 1.11 | 0.061 | 8.71 | 0.056 | 56 |
| RfD* (mg/kg/day) | | 0.003 | | 0.02 | | 0.02 | | 0.036 | | 0.007 | | 0.001 | |

HQ- Hazard Quotient, CDI-Chronic Daily Index, Bold figures for HQ indicate values >1

*US EPA IRIS (2011)

Source: Author's Analysis 2023

4.6.3 Health Index Assessment, HI

Health Index is the sum of the Hazard Quotient HQ, of all the potentially toxic elements and this determines the noncarcinogenic risk of the metals.

If $HI > 1$, it implies an unacceptable risk of non-carcinogenic effects on health²³.

If $HI < 1$, It suggests an acceptable level of risk²⁴.

Health Index HI for the heavy metals is presented in Table 4.9

All the hazard index (HI) values recorded in this investigation for all selected groundwater samples were well above 1 across all water sources and age groups, suggesting an unacceptable risk of non-carcinogenic effects on the health of the local inhabitants. It is in line with the study of Ogunlaja²⁴.

4.6.4 Target Carcinogenic Risk Assessment (TCR)

The lifetime exposure to the incremental risk of an individual developing cancer was evaluated using the lifetime target risk. (TCR)

$$TCR = SF \times CDI \dots \dots \dots \text{Equation 3}$$

Where SF the slope factor converts the CDI of the potentially toxic elements in the body over a lifetime of exposure directly to the incremental risk of an individual developing cancer.

If $TCR > 1 \times 10^{-4}$, then it is considered unacceptable and intolerable.

Target Carcinogenic Risk (TCR) of heavy metals is presented in Table 4.9

TCR assessment was calculated for Chromium, Nickel and Lead. The results obtained revealed that all the groundwater samples analysed have Chromium and Nickel values that

are higher than 1×10^{-4} , hence considering it unacceptable and intolerable while the results for Lead showed greater than 1 value for children in S1, S2, S4, S7, S9 and S10 (1.71×10^{-4}).

Table 4.9: Hazard Index and Target Carcinogenic Risk Assessment

| Sampling Location | Category | HI | Cr TCR ($\times 10^{-2}$) | Ni TCR ($\times 10^{-2}$) | Pb TCR ($\times 10^{-2}$) |
|-------------------|----------|----------------|--------------------------------|--------------------------------|--------------------------------|
| S1 | Children | 105.744 | 4.8 | 1.87 | 1.71 |
| | Adult | 21.985 | 1.0 | 0.34 | 0.36 |
| S2 | Children | 149.37 | 7.85 | 1.87 | 1.71 |
| | Adult | 31.15 | 1.65 | 0.34 | 0.36 |
| S3 | Children | 75.075 | 4.0 | 5.44 | 0.81 |
| | Adult | 15.872 | 0.85 | 1.19 | 0.18 |
| S4 | Children | 74.744 | 3.0 | 1.87 | 1.71 |
| | Adult | 16.294 | 0.65 | 0.34 | 0.36 |
| S5 | Children | 68.22 | 3.95 | 1.87 | 0.81 |
| | Adult | 14.127 | 0.8 | 0.34 | 0.18 |
| S6 | Children | 58.79 | 3.0 | 3.57 | 0.81 |
| | Adult | 12.39 | 0.65 | 0.68 | 0.18 |
| S7 | Children | 155.647 | 7.45 | 5.44 | 1.71 |
| | Adult | 31.831 | 1.55 | 1.19 | 0.36 |
| S8 | Children | 96.84 | 9.35 | 3.57 | 0.81 |
| | Adult | 30.263 | 1.95 | 0.68 | 0.18 |
| S9 | Children | 115.704 | 6.40 | 1.87 | 1.71 |
| | Adult | 24.244 | 1.35 | 0.34 | 0.36 |
| S10 | Children | 390.344 | 5.85 | 3.57 | 1.71 |
| | Adult | 81.534 | 1.20 | 0.68 | 0.36 |
| SF* | | | 0.5 | 1.7 | 0.009 |

(mg/kg/day)

TCR-Target carcinogenic risk and HI- Hazard index (overall toxic risk)

Bold figures for $TCR > 1 \times 10^{-4}$ and $HI > 1$

*US EPA 2015

Source: Author's Analysis 2023.

4.6.5 Comparison of (Recommended Dietary Allowance (RDA) and Tolerable Upper Intake Level (UL)) of Elements for Individuals to the Average Concentration of Elements in Groundwater in Oyo state axis

The elemental concentration in the groundwater samples investigated was compared to the Dietary Reference Intake (DRIs) in Table 4.10. It was observed from the results that the groundwater can have an important contribution to the health and nutritional needs of consumers for some elements. The consumption of 2 liters of water which is the average daily intake contributed between 18.61 – 79.75% towards the RDA for Fe in both adults and children. It was also recorded that all the groundwater sources investigated in Oyo axis contributed significantly to RDA for Fe. Occurrence of Iron in water is mainly in the ferrous and ferric state and caused by dissolved iron from the soil and rock formation through the seeping, percolation and draining of rainwater down the soil and rocks. It is the fourth most abundant element by mass in the earth's crust. Magnesium is an essential macro element which helps in the formation of bones, development of strong teeth, regulation of muscles and blood pressure. However, Mg only showed significant results in S9 (17.28-17.84 %) and S10 (24.39-54.88%). Significant contribution was also observed for Mn in S8 (40.44 -58.13%) and S10 (28.26-40.63%) and Cu only in S7 (44.44%). Ca, Zn, Se and Cr showed no significant results.

| | Ca | Cu | Fe | Mg | Mn | Zn | Se | Cr |
|--------------------------------|-----------|-------|-------------|-------------|-------------|-----------|-------|-----------|
| S1 (mg/2L) ^x | 18.28 | 0.06 | 3.35 | 4.87 | 0.15 | 0.59 | ND | 1.44 |
| RDA | 1000-1300 | 0.9 | 8- 18 | 310-320 | 1.6-2.3 | 8 - 11 | 40-55 | 25-35 |
| UL | 2500 | 10 | 45 | 350 | 11 | 40 | 0.4 | ND |
| RDA% | 1.41-1.83 | 6.67 | 18.61-41.88 | 1.52-1.57 | 6.52-9.38 | 5.36-7.38 | ND | 4.11-5.76 |
| S7 (mg/2L) ^x | 21.77 | 0.4 | 6.31 | 11.53 | 0.22 | 0.36 | ND | 2.24 |
| RDA | 1000-1300 | 0.9 | 8- 18 | 310-320 | 1.6-2.3 | 8 - 11 | 40-55 | 25-35 |
| UL | 2500 | 10 | 45 | 350 | 11 | 40 | 0.4 | ND |
| RDA% | 1.68-2.18 | 44.44 | 35.06-78.88 | 3.60-3.72 | 9.57-13.75 | 3.27-4.5 | ND | 6.4-8.96 |
| S8 (mg/2L) ^x | 27.04 | 0.06 | 6.38 | 27.9 | 0.93 | 0.28 | ND | 2.8 |
| RDA | 1000-1300 | 0.9 | 8- 18 | 310-320 | 1.6-2.3 | 8 - 11 | 40-55 | 25-35 |
| UL | 2500 | 10 | 45 | 350 | 11 | 40 | 0.4 | ND |
| RDA% | 2.08-2.70 | 6.67 | 35.44-79.75 | 9.28-9.58 | 40.44-58.13 | 2.55-3.5 | ND | 8-11.2 |
| S9 (mg/2L) ^x | 78.49 | 0.1 | 3.28 | 55.3 | 0.15 | 0.4 | ND | 1.92 |
| RDA | 1000-1300 | 0.9 | 8- 18 | 310-320 | 1.6-2.3 | 8 - 11 | 40-55 | 25-35 |
| UL | 2500 | 10 | 45 | 350 | 11 | 40 | 0.4 | ND |
| RDA% | 6.04-7.85 | 11.11 | 22-41.18 | 17.28-17.84 | 6.52-9.38 | 3.64-5 | ND | 5.49-7.68 |
| S10(mg/2L)^x | 38.54 | 0.15 | 4.39 | 18.1 | 0.65 | 0.59 | ND | 1.76 |
| RDA | 1000-1300 | 0.9 | 8- 18 | 310-320 | 1.6-2.3 | 8 - 11 | 40-55 | 25-35 |
| UL | 2500 | 10 | 45 | 350 | 11 | 40 | 0.4 | ND |
| RDA% | 2.97-3.85 | 16.67 | 24.39-54.88 | 24.39-54.88 | 28.26-40.63 | 5.36-7.38 | ND | 5.03-7.04 |

Table 4.10: Comparison of (Recommended Dietary Allowance (RDA) and Tolerable Upper Intake Level (UL)) of Elements for Individuals to the Average Concentration of Elements in Groundwater in Oyo axis

All values are mg/ day, x = Average concentration (mg/2L), RDA (%) = Estimated contribution to diet for each element. ND = Not determinable

Source: Author's analysis 2023

4.6.6 Comparison of (Recommended Dietary Allowance (RDA) and Tolerable Upper Intake Level (UL)) of Elements for Individuals to the Average Concentration of Elements in Groundwater in Ogun state axis

The elemental concentration in the groundwater samples investigated was compared to the Dietary Reference Intake (DRIs) in Table 4.11. It was discovered from the results that the groundwater can have a significant contribution to the health and nutritional needs of consumers for some elements. The consumption of 2 liters of water which is the average daily intake contributed between (10.06 – 71.38%) towards the RDA for Fe in both adults and children. It was also recorded that all the groundwater sources observed in Ogun axis contributed significantly to RDA for Fe. Mg is an essential macro element. However, it only showed significant contribution in S4 (14.68-15.15%). Significant contribution was also observed for Mn in S2 (86.09-123.75%) and S3 (8.26-11.88%). The high percentage contribution of Mn observed in S2 might lead to health-related issues such as loss respiratory and brain disorder, as well as retarded growth and it may also cause anaemia. Ca, Cu, Zn, and Se showed no significant contribution.

Table 4.11: Comparison of (Recommended Dietary Allowance (RDA) and Tolerable Upper Intake Level (UL)) of Elements for Individuals to the Average Concentration of Elements in Groundwater in Ogun axis

| | Ca | Cu | Fe | Mg | Mn | Zn | Se | Cr |
|-------------------------------|-----------|------|-------------|-------------|--------------|-----------|-----------|-----------|
| S2 (mg/2L)^x | 105.69 | 0.03 | 5.71 | 23.92 | 1.98 | 0.47 | ND | 2.36 |
| RDA | 1000-1300 | 0.9 | 8 - 18 | 310-320 | 1.6-2.3 | 8 - 11 | 40 – 55 | 25-35 |
| UL | 2500 | 10 | 45 | 350 | 11 | 40 | 0.4 | ND |
| RDA% | 8.1-10.57 | 3.33 | 31.72-71.38 | 7.48-7.72 | 86.09-123.75 | 4.27-5.88 | ND | 9.44-6.74 |
| | | | | | | | | 1.2 |
| S3 (mg/2L)^x | 30.56 | 0.06 | 2.77 | 7.83 | 0.19 | 0.58 | 0.06 | |
| RDA | 1000-1300 | 0.9 | 8 – 18 | 310-320 | 1.6-2.3 | 8 – 11 | 40 – 55 | 25-35 |
| UL | 2500 | 10 | 45 | 350 | 11 | 40 | 0.4 | ND |
| RDA% | 2.35-3.06 | 6.67 | 15.39-34.63 | 2.53-2.45 | 8.26-11.88 | 5.27-7.25 | 0.11-0.13 | 4.8-3.43 |
| S4 (mg/2L)^x | 72.95 | 0.06 | 1.68 | 46.97 | 0.15 | 0.32 | ND | 0.9 |
| RDA | 1000-1300 | 0.9 | 8 – 18 | 310-320 | 1.6-2.3 | 8 – 11 | 40 – 55 | 25-35 |
| UL | 2500 | 10 | 45 | 350 | 11 | 40 | 0.4 | ND |
| RDA% | 5.61-7.30 | 6.67 | 9.33-21 | 14.68-15.15 | 6.52-9.38 | 2.91- 4 | ND | 3.6-2.57 |
| S5(mg/2L)^x | 86.86 | 0.03 | 2.19 | 16.53 | 0.07 | 0.26 | 0.06 | 1.18 |
| RDA | 1000-1300 | 0.9 | 8-18 | 310-320 | 1.6-2.3 | 8-11 | 40-55 | 25-35 |
| UL | 2500 | 10 | 45 | 350 | 11 | 40 | ND | ND |
| RDA% | 6.86-8.69 | 3.33 | 12.17-27.38 | 5.17-5.33 | 3.04-4.38 | 2.36-3.25 | 0.11-0.13 | 4.72-3.37 |
| S6 (mg/2L)^x | 53.79 | 0.06 | 1.81 | 28.09 | 0.22 | 0.23 | ND | 0.9 |
| RDA | 1000-1300 | 0.9 | 8 - 18 | 310-320 | 1.6-2.3 | 8 - 11 | 40 – 55 | 25-35 |
| UL | 2500 | 10 | 45 | 350 | 11 | 40 | 0.4 | ND |
| RDA% | 4.14-5.38 | 6.67 | 10.06-22.63 | 8.78-9.06 | 9.57-13.75 | 2.09-2.88 | ND | 3.6-2.57 |

All values are mg/ day, x = Average concentration (mg/2L), RDA (%) = Estimated contribution to diet for each element. ND = Not determinable

Source: Author's analysis 2023

4.7 Antibiotics Health Risk Assessment

Table 4.12 shows the results of the Target Hazard Quotients and Risk Quotients of the antibiotics investigated in Oyo and Ogun states sampling locations.

4.7.1 The Potential Hazard Quotient Assessment, THQ

The Target Hazard Quotient was estimated using equation 1 below:

$$\text{THQ} = \frac{\text{MEC}}{\text{PNEC}_{\text{DW}}} = \frac{\text{MEC} \times \text{EF} \times \text{ED} \times \text{IR}}{\text{Bw} \times \text{AT} \times \text{ADI}} \dots\dots\dots\text{Equation 4}$$

The THQ results obtained showed that in S3 for both adults and children, ciprofloxacin was below one, 0.293 and 0.733 respectively as well as in adults for S9 (0.586). These indicate that the groundwater sample poses no discernible risk for both adult and children's consumers. Other results for adults and children in S4, S5, S8 and S10 all have values above one implying that there are obvious risks of antibiotic resistance via drinking the groundwater.

Similarly, in metronidazole, all results obtained revealed that the groundwater samples have high values for adults and children. Although metronidazole was only detected in S1, S6 and S8, the target hazard quotients were obviously higher than one thereby making the groundwater potentially hazardous for consumption.

4.7.2 Ecological Risk Quotient, RQ

Table 4.12 shows the results of the risks quotient calculated using the formula below in equation 5 for ciprofloxacin and metronidazole in adults and children. The outcome indicates

that there are high risk levels of antibiotic resistance in the groundwater samples investigated. The results range from (S9) 2375 to 17765.6 (S4) in ciprofloxacin and (S8) 9528 to 62768 (S1) in metronidazole. These outrageously high values are likely from anthropogenic and agricultural sources and will possibly increase antibiotic resistance in human and ecological organisms that consume the groundwater.

$$\mathbf{RQ} = \frac{\mathbf{MEC}}{\mathbf{PNEC}} \dots\dots\dots \text{Equation 5}$$

The data in the current study indicates that in the groundwater samples, both ciprofloxacin and metronidazole posed an estimated high ecological risk for development of resistance based on the results obtained. This observation emphasizes the need to validate these risks in further studies to ascertain the real risks.

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Table 4.12: Target Hazard Quotient (THQ) and Ecological Risk Quotients of Antibiotics Investigated in Groundwater samples from Oyo and Ogun States

| Sample Location | CIP (THQ) Adult | CIP (THQ) Children | MET (THQ) Adult | MET (THQ) Children | RQ CIP | RQ MET |
|-----------------|-----------------|--------------------|-----------------|--------------------|---------|---------|
| S1 | < LOD | < LOD | 358.26 | 895.66 | < LOD | 62768.0 |
| S2 | < LOD | < LOD | < LOD | < LOD | < LOD | < LOD |
| S3 | 0.293 | 0.733 | < LOD | < LOD | 1187.5 | < LOD |
| S4 | 4.387 | 10.968 | < LOD | < LOD | 17765.6 | < LOD |
| S5 | 3.638 | 9.097 | < LOD | < LOD | 14734.4 | < LOD |
| S6 | < LOD | < LOD | 129.41 | 323.52 | < LOD | 22672.0 |
| S7 | < LOD | < LOD | < LOD | < LOD | < LOD | < LOD |
| S8 | 1.682 | 4.206 | 54.38 | 135.96 | 6812.5 | 9528.0 |
| S9 | 0.586 | 1.466 | < LOD | < LOD | 2375.0 | < LOD |
| S10 | 3.098 | 7.746 | < LOD | < LOD | 12546.8 | < LOD |

< LOD -Limit of detection. CIP- Ciprofloxacin. MET- Metronidazole

Source: Author's Analysis,2023.

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Chapter Five

Conclusion

5.1 Summary of Findings

In summary, all the physicochemical parameters evaluated for the selected groundwater samples were below the WHO and FEPA permissible limits. The pH ranged from 6.34 to 7.57, TDS ranged from 0.04 to 0.39 $\mu\text{g L}^{-1}$, Temp ranged from 29.6 to 31.7 $^{\circ}\text{C}$, COND was 0.18 to 40.7 $\mu\text{S cm}^{-1}$ and Dissolved Oxygen is from LOD to 0.04 $\mu\text{g L}^{-1}$. Similarly, the average elemental concentrations of all heavy metals in groundwater samples were below the WHO permissible limit for drinking water except for Cr, Ni and Pb at 0.05, 0.02 and 0.10 mg L^{-1} respectively. The concentration of Ca, Mg, Na, and K ranged from 9.14 to 52.8 mg L^{-1} , 2.41 to 27.7 mg L^{-1} , 2.24 to 13.29 mg L^{-1} and 1.29 to 35.8 mg L^{-1} respectively. Furthermore, the average concentration of Ciprofloxacin ranged from 76 to 1137 $\mu\text{g L}^{-1}$ while the average concentration of Metronidazole ranged from 1191 to 7846 $\mu\text{g L}^{-1}$. However, the concentration of Ampicillin and Chloramphenicol concentrations were below the limit of detection. Data from this study indicated Cr, Ni and Pb contamination in groundwater and may pose a potential health risk to the local inhabitants who depend on well water for consumption and other domestic uses.

5.2 Conclusion

In conclusion, data from this study showed that ciprofloxacin and metronidazole were the common antibiotics detected in the studied groundwater samples. The average concentrations

of PTEs such as Cr, Ni, Pb, and Cd in the studied groundwater samples suggest a possible bioaccumulation which may lead to an unhealthy accumulation of these PTEs in people who depend on these groundwater samples for their source of potable water. Furthermore, data from the human health risk assessment revealed that the consumption of water from these groundwater samples is not safe and that the indigenous people of these communities are predisposed to a gradual build-up of the studied contaminants.

5.3 Recommendations

The following are recommended based on the results of this study;

- i. there is a need to develop affordable and available analytical techniques that are able to measure heavy metals and antibiotics.
- ii. suitable strategies for groundwater recharge, controlled groundwater usage, measures to reduce groundwater pollution, and awareness of the importance of water quality for private well-water users are recommended.
- iii. agricultural and domestic wastes should not be discharged without proper treatment

5.4 Contributions to Knowledge

This research serves as a baseline for further work on the eradication of groundwater contamination in Southwest, Nigeria. It has necessitated public sensitization and awareness of the importance of groundwater quality, controlled groundwater usage and measures to reduce groundwater pollution so as to curb the human health and ecological risks associated with consuming polluted water. Solving this problem involves close coordination between researchers at universities and government agencies, as well as the industry and decision-makers at all levels.

5.5 Areas for Further Research

More comprehensive studies are required to determine the fate of antibiotic residues and their ecological risk and potential effects on human health and resistance development. Research works should also be encouraged regarding the removal of heavy metals from water. In addition, the variation of the influence of groundwater contamination in different countries especially Nigeria must be well studied, including the effect on climatic regions and geological features. To study groundwater contamination in the future, groundwater scientists will need to adopt and apply new technologies such as artificial intelligence, “big data” analysis, drone surveys and molecular and stable isotope analysis technologies. Finally, governments, especially those with developing economies need to invest more in groundwater and encourage researchers, training and research in this important, valuable field.

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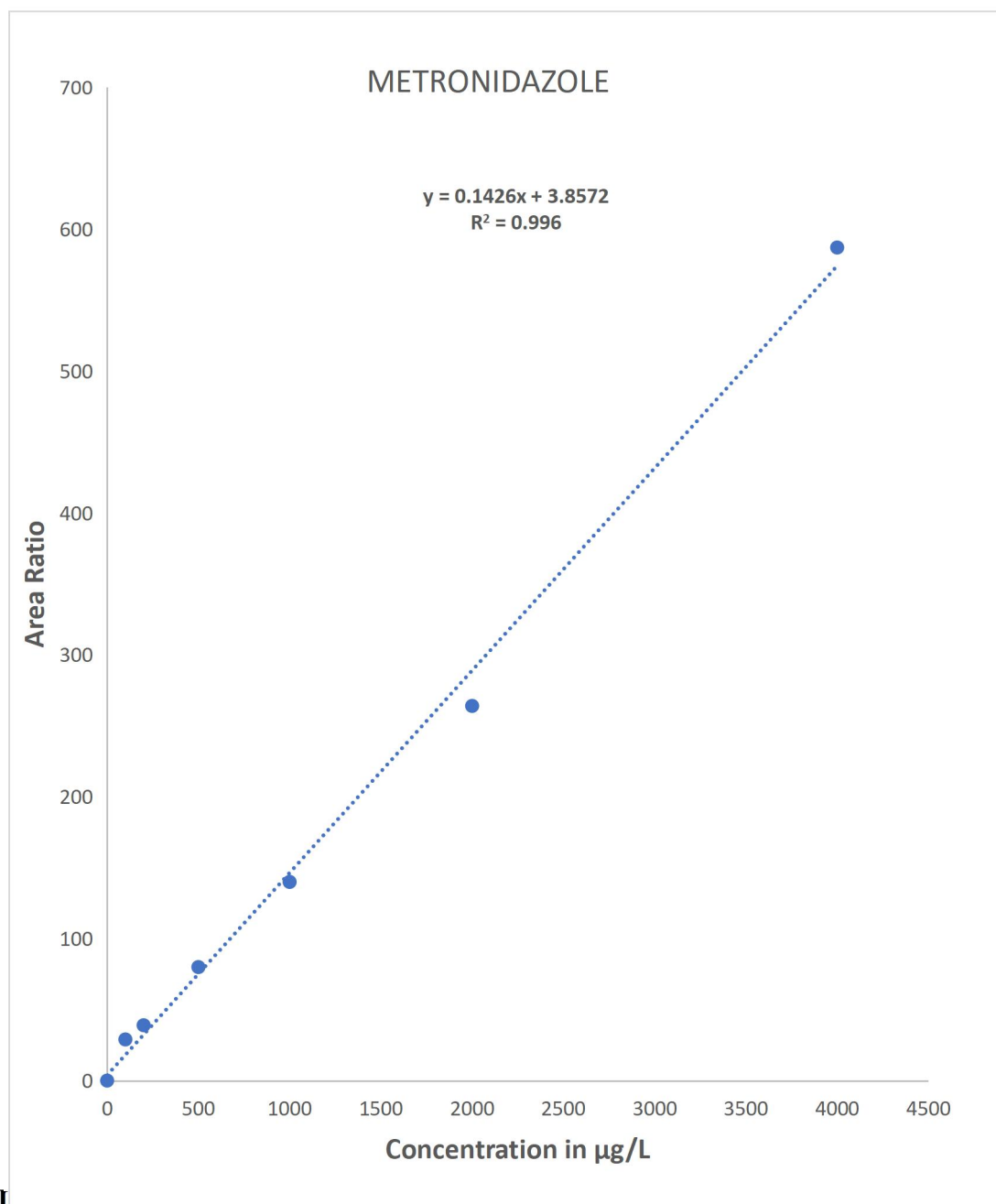
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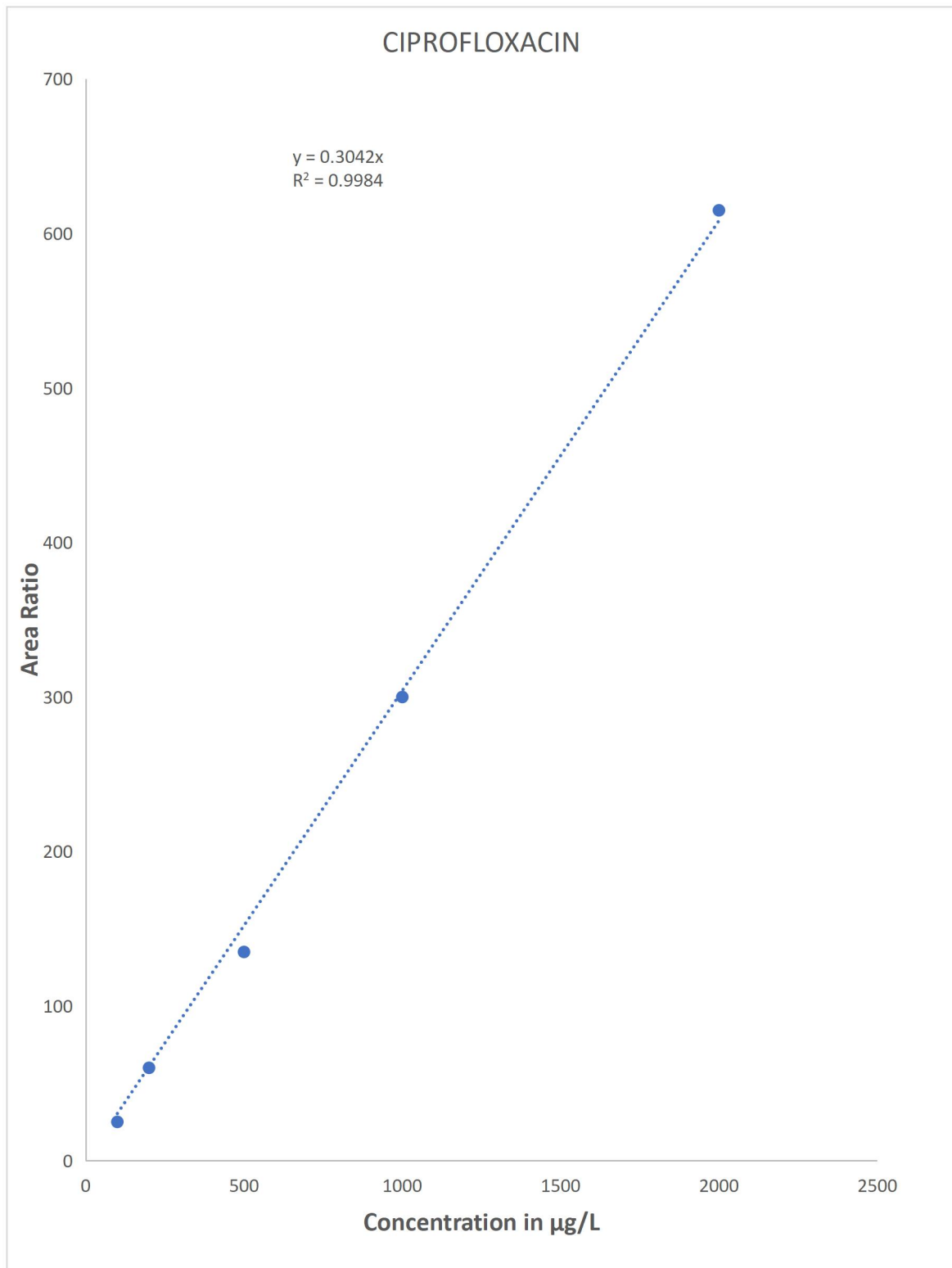
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Appendix



Calibration curve using HPLC-UV for Metronidazole.

Appendix II



Calibration curve using HPLC-UV for Ciprofloxacin

Appendix III

Analysis of Variance of Essential Macro Elements in groundwater samples.

| DESCRIPTION | | | | | Alpha = 0.05 | | | |
|--------------|--------------|------------|-------------|-----------------|--------------|----------------|--------------|--------------|
| <i>Group</i> | <i>Count</i> | <i>Sum</i> | <i>Mean</i> | <i>Variance</i> | <i>SS</i> | <i>Std Err</i> | <i>Lower</i> | <i>Upper</i> |
| Ca | 10 | 266.98 | 26.70 | 237.13 | 2134.13 | 3.25 | 20.11 | 33.29 |
| Mg | 10 | 120.44 | 12.04 | 67.11 | 603.95 | 3.25 | 5.45 | 18.64 |
| K | 10 | 71.14 | 7.11 | 103.74 | 933.66 | 3.25 | 0.52 | 13.71 |
| Na | 10 | 78.50 | 7.85 | 14.75 | 132.75 | 3.25 | 1.26 | 14.44 |

| ANOVA | | | | | | | | |
|-----------------------|-----------|-----------|-----------|----------|----------------|---------------|--------------|-----------------|
| <i>Sources</i> | <i>SS</i> | <i>df</i> | <i>MS</i> | <i>F</i> | <i>P value</i> | <i>Eta-sq</i> | <i>RMSSE</i> | <i>Omega Sq</i> |
| Between Groups | 2490.09 | 3 | 830.03 | 7.85 | 0.00037 | 0.40 | 0.89 | 0.34 |
| Within Groups | 3804.48 | 36 | 105.68 | | | | | |
| Total | 6294.57 | 39 | 161.40 | | | | | |

Appendix IV

Post-hoc Analysis of Essential Macro Elements in samples

| TUKEY HSD/KRAMER | | alpha | 0.05 | | |
|------------------|-------------|----------|-----------|-----------|---------------|
| <i>group</i> | <i>mean</i> | <i>N</i> | <i>ss</i> | <i>Df</i> | <i>q-crit</i> |
| Ca | 26.70 | 10 | 2134.129 | | |
| Mg | 12.04 | 10 | 603.9455 | | |
| K | 7.11 | 10 | 933.6614 | | |
| Na | 7.8495 | 10 | 132.7462 | | |
| | | 40 | 3804.482 | 36 | 3.809 |

Q TEST

| <i>Group 1</i> | <i>Group 2</i> | <i>Mean</i> | <i>Std err</i> | <i>q-stat</i> | <i>lower</i> | <i>upper</i> | <i>p-value</i> | <i>Cohen d</i> |
|----------------|----------------|-------------|----------------|---------------|--------------|--------------|----------------|----------------|
| Ca | Mg | 14.65 | 3.25 | 4.51 | 2.27 | 27.04 | 0.015 | 1.43 |
| Ca | K | 19.58 | 3.25 | 6.02 | 7.20 | 31.97 | 0.001 | 1.91 |
| Ca | Na | 18.85 | 3.25 | 5.80 | 6.47 | 31.23 | 0.001 | 1.83 |
| Mg | K | 4.93 | 3.25 | 1.52 | -7.45 | 17.31 | 0.708 | 0.48 |
| Mg | Na | 4.19 | 3.25 | 1.29 | -8.19 | 16.58 | 0.798 | 0.41 |
| K | Na | 0.74 | 3.25 | 0.23 | -11.65 | 13.12 | 0.999 | 0.07 |

Appendix V

Analysis of Variance of Essential Micro Elements in samples.

| DESCRIPTION | | | | | Alpha = 0.05 | | |
|--------------|--------------|------------|-------------|-----------------|--------------|--------------|--------------|
| <i>Group</i> | <i>Count</i> | <i>Sum</i> | <i>Mean</i> | <i>Variance</i> | <i>SS</i> | <i>Lower</i> | <i>Upper</i> |
| Cu | 10 | 0.50 | 0.05 | 0.00 | 0.03 | -0.41 | 0.51 |
| Fe | 10 | 18.94 | 1.89 | 0.82 | 7.38 | 1.44 | 2.35 |
| Zn | 10 | 2.14 | 0.21 | 0.01 | 0.05 | -0.24 | 0.67 |
| Al | 10 | 21.21 | 2.12 | 1.35 | 12.19 | 1.66 | 2.58 |
| B | 10 | 0.96 | 0.10 | 0.01 | 0.08 | -0.36 | 0.55 |
| Se | 10 | 0.06 | 0.01 | 0.00 | 0.00 | -0.45 | 0.46 |
| Co | 10 | 42.96 | 4.30 | 1.96 | 17.63 | 3.84 | 4.75 |
| Mn | 10 | 2.35 | 0.24 | 0.09 | 0.80 | -0.22 | 0.69 |

| ANOVA | | | | | | | | |
|----------------|-----------|-----------|-----------|----------|-----------------|---------------|--------------|-----------------|
| <i>Sources</i> | <i>SS</i> | <i>Df</i> | <i>MS</i> | <i>F</i> | <i>P value</i> | <i>Eta-sq</i> | <i>RMSSE</i> | <i>Omega Sq</i> |
| Between Groups | 167.26 | 7 | 23.89 | 45.09 | 7.65E-24 | 0.81 | 2.12 | 0.79 |
| Within Groups | 38.15 | 72 | 0.53 | | | | | |
| Total | 205.42 | 79 | 2.60 | | | | | |

Appendix VI

Post-hoc Analysis of Essential Micro Elements in samples

| TUKEY HSD/KRAMER | | Alpha | 0.05 | | |
|------------------|-------------|----------|-----------|-----------|---------------|
| <i>group</i> | <i>mean</i> | <i>n</i> | <i>ss</i> | <i>Df</i> | <i>q-crit</i> |
| Cu | 0.05 | 10 | 0.035 | | |
| Fe | 1.89 | 10 | 7.381 | | |
| Zn | 0.21 | 10 | 0.054 | | |
| Al | 2.121 | 10 | 12.186 | | |
| B | 0.096 | 10 | 0.076 | | |
| Se | 0.01 | 10 | 0.001 | | |
| Co | 4.296 | 10 | 17.626 | | |
| Mn | 0.24 | 10 | 0.799 | | |
| | | 80 | 38.151 | 72 | 4.415 |

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Q TEST

| <i>group 1</i> | <i>group 2</i> | <i>mean</i> | <i>std err</i> | <i>q-stat</i> | <i>lower</i> | <i>upper</i> | <i>p-value</i> | <i>Cohen d</i> |
|----------------|----------------|-------------|----------------|---------------|--------------|--------------|------------------------|----------------|
| Cu | Fe | 1.84 | 0.23 | 8.01 | 0.83 | 2.86 | 7.6 x10 ⁻⁶ | 2.53 |
| Cu | Zn | 0.16 | 0.23 | 0.71 | -0.85 | 1.18 | 1.00 | 0.23 |
| Cu | Al | 2.07 | 0.23 | 9.00 | 1.05 | 3.09 | 4.5 x10 ⁻⁷ | 2.85 |
| Cu | B | 0.05 | 0.23 | 0.20 | -0.97 | 1.06 | 1.00 | 0.06 |
| Cu | Se | 0.04 | 0.23 | 0.19 | -0.97 | 1.06 | 1.00 | 0.06 |
| Cu | Co | 4.25 | 0.23 | 18.45 | 3.23 | 5.26 | 6.7 x10 ⁻¹⁵ | 5.83 |
| Cu | Mn | 0.19 | 0.23 | 0.80 | -0.83 | 1.20 | 1.00 | 0.25 |
| Fe | Zn | 1.68 | 0.23 | 7.30 | 0.66 | 2.70 | 5.5 x10 ⁻⁵ | 2.31 |
| Fe | Al | 0.23 | 0.23 | 0.98 | -0.79 | 1.24 | 1.00 | 0.31 |
| Fe | B | 1.80 | 0.23 | 7.81 | 0.78 | 2.81 | 1.3 x10 ⁻⁵ | 2.47 |
| Fe | Se | 1.89 | 0.23 | 8.20 | 0.87 | 2.90 | 4.4 x10 ⁻⁶ | 2.59 |
| Fe | Co | 2.40 | 0.23 | 10.43 | 1.39 | 3.42 | 6.1 x10 ⁻⁹ | 3.30 |
| Fe | Mn | 1.66 | 0.23 | 7.21 | 0.64 | 2.68 | 7.1 x10 ⁻⁵ | 2.28 |
| Zn | Al | 1.91 | 0.23 | 8.28 | 0.89 | 2.92 | 3.5 x10 ⁻⁶ | 2.62 |
| Zn | B | 0.12 | 0.23 | 0.51 | -0.90 | 1.13 | 1.00 | 0.16 |
| Zn | Se | 0.21 | 0.23 | 0.90 | -0.81 | 1.22 | 1.00 | 0.29 |
| Zn | Co | 4.08 | 0.23 | 17.73 | 3.07 | 5.10 | 6.8 x10 ⁻¹⁵ | 5.61 |
| Zn | Mn | 0.02 | 0.23 | 0.09 | -1.00 | 1.04 | 1.00 | 0.03 |
| Al | B | 2.03 | 0.23 | 8.80 | 1.01 | 3.04 | 8.0 x10 ⁻⁷ | 2.78 |
| Al | Se | 2.12 | 0.23 | 9.19 | 1.10 | 3.13 | 2.5 x10 ⁻⁷ | 2.91 |
| Al | Co | 2.18 | 0.23 | 9.45 | 1.16 | 3.19 | 1.2 x10 ⁻⁷ | 2.99 |
| Al | Mn | 1.89 | 0.23 | 8.19 | 0.87 | 2.90 | 4.6 x10 ⁻⁶ | 2.59 |
| B | Se | 0.09 | 0.23 | 0.39 | -0.93 | 1.11 | 1.00 | 0.12 |
| B | Co | 4.20 | 0.23 | 18.25 | 3.18 | 5.22 | 6.8 x10 ⁻¹⁵ | 5.77 |
| B | Mn | 0.14 | 0.23 | 0.60 | -0.88 | 1.16 | 1.00 | 0.19 |
| Se | Co | 4.29 | 0.23 | 18.64 | 3.27 | 5.31 | 6.6 x10 ⁻¹⁵ | 5.89 |
| Se | Mn | 0.23 | 0.23 | 1.00 | -0.79 | 1.25 | 1.00 | 0.31 |

| | | | | | | | | |
|----|----|------|------|--------------|------|------|------------------------|------|
| Co | Mn | 4.06 | 0.23 | 17.64 | 3.04 | 5.08 | 6.9 x10 ⁻¹⁵ | 5.58 |
|----|----|------|------|--------------|------|------|------------------------|------|

Appendix VII

ANOVA of Potentially Toxic Elements in samples

| DESCRIPTION | | | | | Alpha = 0.05 | | | |
|--------------|--------------|------------|-------------|-----------------|--------------|----------------|--------------|--------------|
| <i>Group</i> | <i>Count</i> | <i>Sum</i> | <i>Mean</i> | <i>Variance</i> | <i>SS</i> | <i>Std Err</i> | <i>Lower</i> | <i>Upper</i> |
| Cd | 10 | 2 | 0.2 | 0.400 | 3.600 | 0.113 | -0.030 | 0.430 |
| Cr | 10 | 8.35 | 0.84 | 0.107 | 0.962 | 0.113 | 0.605 | 1.065 |
| Ni | 10 | 1.36 | 0.14 | 0.004 | 0.039 | 0.113 | -0.094 | 0.366 |
| Pb | 10 | 1.12 | 0.11 | 0.001 | 0.012 | 0.113 | -0.118 | 0.342 |

ANOVA

| <i>Sources</i> | <i>SS</i> | <i>df</i> | <i>MS</i> | <i>F</i> | <i>P value</i> | <i>Eta-sq</i> | <i>RMSSE</i> | <i>Omega Sq</i> |
|----------------|-----------|-----------|-----------|----------|-----------------|---------------|--------------|-----------------|
| Between Groups | 3.567 | 3 | 1.189 | 9.280 | 0.000111 | 0.436 | 0.963 | 0.383 |
| Within Groups | 4.613 | 36 | 0.128 | | | | | |
| Total | 8.180 | 39 | 0.210 | | | | | |

Appendix VIII

Post-hoc Analysis of Potentially Toxic Elements in Samples

| TUKEY HSD/KRAMER | | alpha | 0.05 | | |
|------------------|-------------|----------|-----------|-----------|---------------|
| <i>Group</i> | <i>Mean</i> | <i>N</i> | <i>SS</i> | <i>df</i> | <i>q-crit</i> |
| Cd | 0.2 | 10 | 3.60 | | |
| Cr | 0.84 | 10 | 0.96 | | |
| Ni | 0.14 | 10 | 0.04 | | |
| Pb | 0.11 | 10 | 0.01 | | |
| | | 40 | 4.61285 | 36 | 3.809 |

| Q TEST | | | | | | | | |
|----------------|----------------|-------------|----------------|---------------|--------------|--------------|----------------|----------------|
| <i>Group 1</i> | <i>Group 2</i> | <i>mean</i> | <i>std err</i> | <i>q-stat</i> | <i>lower</i> | <i>upper</i> | <i>p-value</i> | <i>Cohen d</i> |
| Cd | Cr | 0.64 | 0.11 | 5.61 | 0.20 | 1.07 | 0.0018 | 1.77 |
| Cd | Ni | 0.06 | 0.11 | 0.57 | -0.37 | 0.50 | 0.9780 | 0.18 |
| Cd | Pb | 0.09 | 0.11 | 0.78 | -0.34 | 0.52 | 0.9460 | 0.25 |
| Cr | Ni | 0.70 | 0.11 | 6.18 | 0.27 | 1.13 | 0.0006 | 1.95 |
| Cr | Pb | 0.72 | 0.11 | 6.39 | 0.29 | 1.15 | 0.0004 | 2.02 |
| Ni | Pb | 0.02 | 0.11 | 0.21 | -0.41 | 0.46 | 0.9988 | 0.07 |

Appendix IX

Analysis of Variance of Antibiotics in Groundwater samples

| DESCRIPTION | | | | | Alpha | 0.05 | | |
|--------------|--------------|------------|-------------|-----------------|-----------|----------------|--------------|--------------|
| <i>Group</i> | <i>Count</i> | <i>Sum</i> | <i>Mean</i> | <i>Variance</i> | <i>SS</i> | <i>Std Err</i> | <i>Lower</i> | <i>Upper</i> |
| MET | 10 | 11871 | 1187.1 | 6324188 | 56917689 | 403.8199 | 368.12 | 2006.08 |
| CIP | 10 | 3547 | 354.7 | 198631.3 | 1787682 | 403.8199 | -464.28 | 1173.68 |
| AMP | 10 | 0 | 0 | 0 | 0 | 403.8199 | -818.98 | 818.98 |
| CHL | 10 | 0 | 0 | 0 | 0 | 403.8199 | -818.98 | 818.98 |

ANOVA

| <i>Sources</i> | <i>SS</i> | <i>Df</i> | <i>MS</i> | <i>F</i> | <i>P value</i> | <i>Eta-sq</i> | <i>RMSSE</i> | <i>Omega Sq</i> |
|----------------|-----------|-----------|-----------|----------|-----------------|---------------|--------------|-----------------|
| Between Groups | 9407317 | 3 | 3135772 | 1.92 | 0.143298 | 0.138114 | 0.438515 | 0.06474 |
| Within Groups | 58705371 | 36 | 1630705 | | | | | |
| Total | 68112688 | 39 | 1746479 | | | | | |

Appendix X

Post-hoc Analysis of Antibiotics in Samples

| TUKEY HSD/KRAMER | | | Alpha | 0.05 | |
|------------------|-------------|----------|-----------|-----------|---------------|
| <i>group</i> | <i>Mean</i> | <i>n</i> | <i>ss</i> | <i>Df</i> | <i>q-crit</i> |
| MET | 1187.1 | 10 | 56917689 | | |
| CIP | 354.7 | 10 | 1787682 | | |
| AMP | 0 | 10 | 0 | | |
| CHL | 0 | 10 | 0 | | |
| | | 40 | 58705371 | 36 | 3.809 |

Q TEST

| <i>group 1</i> | <i>group 2</i> | <i>mean</i> | <i>std err</i> | <i>q-stat</i> | <i>lower</i> | <i>upper</i> | <i>p-value</i> | <i>Cohen d</i> |
|----------------|----------------|-------------|----------------|---------------|--------------|--------------|----------------|----------------|
| MET | CIP | 832.4 | 403.82 | 2.06 | -705.75 | 2370.55 | 0.47299 | 0.7 |
| MET | AMP | 1187.1 | 403.82 | 2.94 | -351.05 | 2725.25 | 0.179439 | 0.9 |
| MET | CHL | 1187.1 | 403.82 | 2.94 | -351.05 | 2725.25 | 0.179439 | 0.9 |
| CIP | AMP | 354.7 | 403.82 | 0.88 | -1183.45 | 1892.85 | 0.924654 | 0.3 |
| CIP | CHL | 354.7 | 403.82 | 0.88 | -1183.45 | 1892.85 | 0.924654 | 0.3 |
| AMP | CHL | 0 | 403.82 | 0.00 | -1538.15 | 1538.15 | 1 | 0.0 |

Appendix XI

Correlation matrix of Essential Macro Elements in Groundwater samples

| | Ca | Mg | Na | K |
|----|--------------|--------------|-------|-------|
| Ca | 1.000 | | | |
| Mg | 0.529 | 1.000 | | |
| Na | 0.737 | 0.930 | 1.000 | |
| K | 0.628 | 0.001 | 0.243 | 1.000 |

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Appendix XII

Correlation Matrix of Essential Micro Elements in selected Groundwater samples

| | Mn | Fe | Cu | Zn | Al | B | Co | Se |
|----|--------------|--------------|--------|-------|--------|--------|--------|-------|
| Mn | 1.000 | | | | | | | |
| Fe | 0.616 | 1.000 | | | | | | |
| Cu | -0.180 | 0.494 | 1.000 | | | | | |
| Zn | 0.153 | 0.136 | 0.008 | 1.000 | | | | |
| Al | 0.701 | 0.960 | 0.310 | 0.019 | 1.000 | | | |
| B | -0.089 | -0.340 | -0.289 | 0.168 | -0.335 | 1.000 | | |
| Co | 0.170 | 0.238 | 0.383 | 0.431 | 0.182 | -0.014 | 1.000 | |
| Se | -0.303 | -0.381 | -0.260 | 0.033 | -0.438 | -0.378 | -0.612 | 1.000 |

Appendix XIII

Correlation Matrix of Potentially Toxic Elements in Selected Groundwater Samples

| | Cr | Ni | Pb | Cd |
|----|-------|--------|-------|-------|
| Cr | 1.000 | | | |
| Ni | 0.134 | 1.000 | | |
| Pb | 0.197 | -0.314 | 1.000 | |
| Cd | 0.048 | 0.128 | 0.272 | 1.000 |

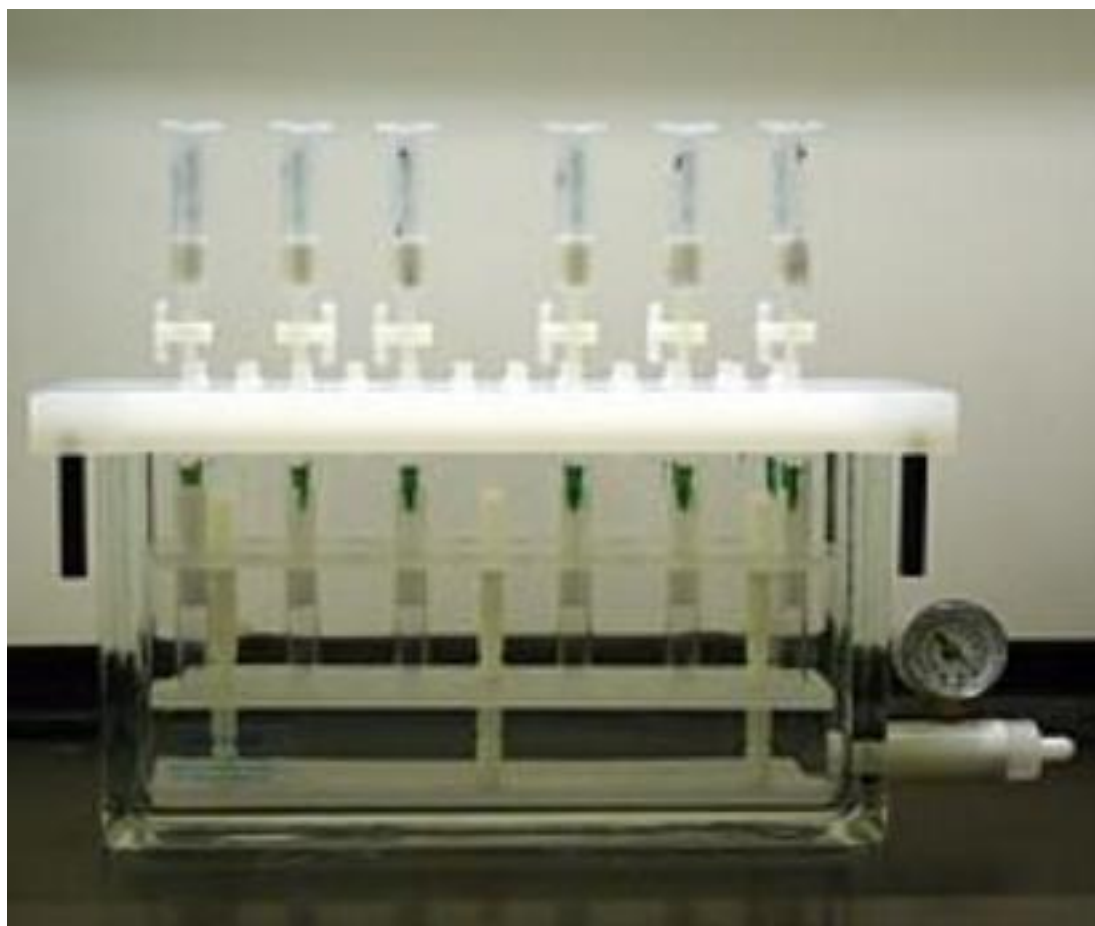
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Appendix XIV

Results of all the physicochemical, elemental and antibiotics analysis in the groundwater samples

| Parameters | S1 | S2 | S3 | S4 | S5 | S6 | S7 | S8 | S9 | S10 | WHO Limit |
|------------|-------|--------|-------|--------|--------|--------|--------|--------|--------|--------|-----------|
| Ca | 9.141 | 52.844 | 15.28 | 36.475 | 43.429 | 26.894 | 10.887 | 13.518 | 39.246 | 19.269 | 75 |
| Mg | 2.411 | 11.936 | 3.89 | 23.483 | 8.263 | 14.044 | 5.766 | 13.952 | 27.648 | 9.049 | 75 |
| K | 4.394 | 35.812 | 1.285 | 3.258 | 6.397 | 4.109 | 2.41 | 5.25 | 3.541 | 4.679 | 12 |
| Na | 2.238 | 10.173 | 3.611 | 13.297 | 8.389 | 8.066 | 3.769 | 9.198 | 13.132 | 6.622 | 200 |
| Mn | 0.073 | 0.989 | 0.093 | 0.073 | 0.035 | 0.112 | 0.112 | 0.465 | 0.073 | 0.327 | 0.5 |
| Fe | 1.675 | 2.856 | 1.385 | 0.842 | 1.096 | 0.905 | 3.156 | 3.19 | 1.642 | 2.196 | 0.3 |
| Cu | 0.028 | 0.017 | 0.028 | 0.028 | 0.017 | 0.028 | 0.2 | 0.028 | 0.051 | 0.074 | 2.0 |
| Zn | 0.296 | 0.237 | 0.289 | 0.16 | 0.128 | 0.116 | 0.179 | 0.141 | 0.198 | 0.296 | 3.0 |
| Al | 1.53 | 3.52 | 1.23 | 0.99 | 1.08 | 0.98 | 3.11 | 4.21 | 2.16 | 2.4 | 0.2 |
| B | 0.21 | 0.05 | 0.06 | 0.13 | 0.0 | 0.25 | 0.0 | 0.08 | 0.00 | 0.18 | 0.3 |
| Cd | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 2.00 | 0.003 |
| Co | 5.38 | 5.38 | 2.67 | 5.38 | 2.67 | 2.67 | 5.38 | 2.67 | 5.38 | 5.38 | 0.01 |
| Cr | 0.72 | 1.18 | 0.60 | 0.45 | 0.59 | 0.45 | 1.12 | 1.40 | 0.96 | 0.88 | 0.05 |
| Ni | 0.08 | 0.08 | 0.24 | 0.08 | 0.08 | 0.16 | 0.24 | 0.16 | 0.08 | 0.16 | 0.02 |
| Pb | 0.14 | 0.14 | 0.07 | 0.14 | 0.07 | 0.07 | 0.14 | 0.07 | 0.14 | 0.14 | 0.10 |
| Se | 0.00 | 0.00 | 0.03 | 0.00 | 0.03 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.01 |
| DO | 0.04 | 0.00 | 0.00 | 0.00 | 0.01 | 0.00 | 0.00 | 0.00 | 0.00 | 0.01 | ≥ 6 |
| Temp | 30.3 | 30.1 | 29.6 | 30.5 | 31.7 | 31.7 | 30.2 | 30.6 | 31.1 | 31.5 | 40 |
| pH | 6.53 | 7.28 | 6.34 | 6.99 | 7.21 | 6.92 | 6.72 | 6.96 | 7.57 | 7.07 | 6.5-8.5 |
| TDS | 0.04 | 0.37 | 0.1 | 0.39 | 0.27 | 0.21 | 0.09 | 0.24 | 0.39 | 0.20 | 500 |
| COND | 0.08 | 0.74 | 0.18 | 0.77 | 0.56 | 0.42 | 0.19 | 0.49 | 0.78 | 40.70 | 300 |
| MET | 7846 | < LOD | < LOD | < LOD | 2834 | < LOD | 1191 | < LOD | < LOD | < LOD | - |
| CIP | < LOD | < LOD | 76 | 1137 | 943 | < LOD | < LOD | 436 | 152 | 803.00 | - |
| AMP | < LOD | < LOD | < LOD | < LOD | < LOD | < LOD | < LOD | < LOD | < LOD | < LOD | - |
| CHL | < LOD | < LOD | < LOD | < LOD | < LOD | < LOD | < LOD | < LOD | < LOD | < LOD | - |

Appendix XV



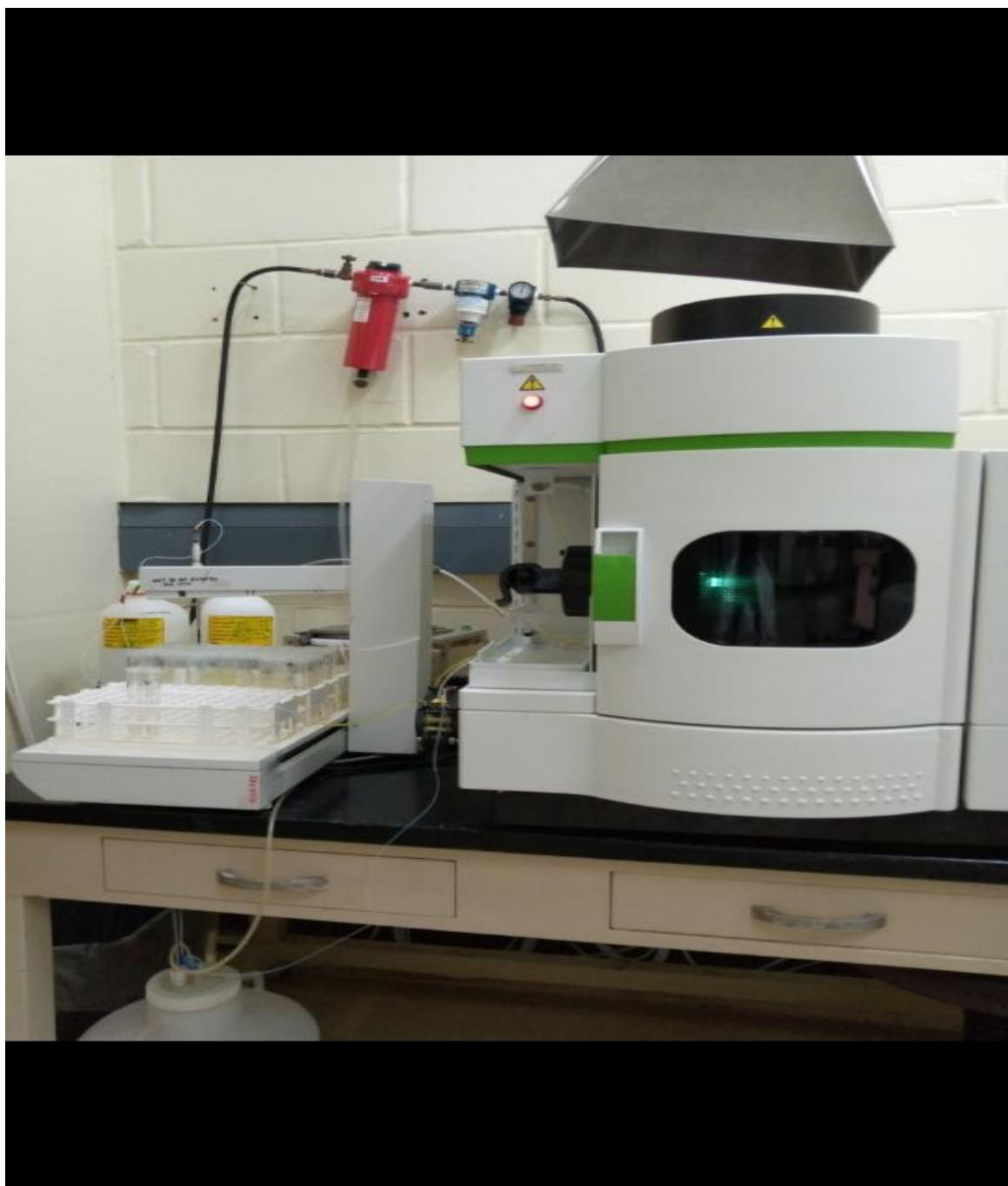
Solid Phase Extraction Process carried out in the laboratory (source: author, 2023)

Appendix XVI



High-Performance Liquid Chromatography–Ultra Violet (source: author, 2023)

Appendix XVIII



Perkin Elmer®Optima™ 8000V Inductively Coupled Plasma Optical Emission Spectrometry (source: author, 2023)

Bio-data

A. PERSONAL DATA

| | |
|-------------------------------|--|
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| Place of Birth | Lagos |
| Nationality | Nigerian |
| Next Of Kin | Mr Adedeji Oluwaseun |
| Address | House 6 Road 4 Ogidi Estate Akobo-Ojurin, Ibadan. |

B. EDUCATION BACKGROUND

Educational Institutions Attended with Dates and Qualifications

- Lead City University, {**MSc. Environmental /Analytical Chemistry**} 2021- till date
- National Open University of Nigeria {**BSc. (Hons) Chemistry**} 2015-2020
- University of Ibadan (**PGDE**) 2007 – 2008
- University of Lagos {**Final Diploma in SLT (Chemistry Option)**} 1997-2002
- Abeokuta Grammar School, Abeokuta, Ogun State
(**Senior Secondary School Certificate**) 1990 - 1995
- Ogun International Montessori Nursery and Primary School,
Abeokuta, Ogun State (**Primary School Leaving Certificate**) 1983 - 1989

C. WORK EXPERIENCE WITH DATES

- Institute For Advanced Medical Research and Training,
College Of Medicine, UCH, Ibadan 2015 - till date
- Ashmina Limited, Ibadan (DANA PHARMA), Ibadan 2004-2005

D. MEMBERSHIP OF ACADEMIC PROFESSIONAL BODIES

- Nigeria Institute of Science Laboratory Technology {AISLT} 2007-till date

E. PUBLICATIONS: Thesis and Dissertation

1. Assay of Vitamin C in Fruit Juice and Fruit Juice Beverages
2. Concentration-Dependent Effects of Metformin on Human Cervical Cancer Cell.

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.....

Signature

.....

Date

The University Compliance Certification

This is to certify that, this Thesis was written by **Adesola Olubunmi, ADEDEJI with Matric Number LCU/PG/002183** of the Department of Chemical Sciences, Faculty of Natural and Applied Sciences, Lead City University, Ibadan and it is in full compliance with the approved University format and style.

.....
Signature

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Date

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