# WATER QUALITY ASSESSMENT OF EKULU AND ASATA RIVERS IN ENUGU AREA, SOUTHEASTHERN NIGERIA, USING GEOCHEMICAL AND BACTERIOLOGICAL PARAMETERS

**BY**

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## CERTIFICATION

This is to certify that this research thesis titled "**Water Quality Assessment of Ekulu and Asata Rivers in Enugu Area, Southeastern Nigeria, Using Geochemical and Bacteriological Parameters** was carried out by **Ken-Onukuba, Doris Nkechi** with registration number **20124764194** in partial fulfilment for the award of Master of Science (M. Sc) degree in Environmental Geology in the Department of Geology of the Federal University of Technology Owerri, Imo State.

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# DEDICATION

Dedicated to Almighty Father, Kenny, Precious, Brian & Nicole, Johns' & Moses'.

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I thank God Almighty who in His mercy gives us power to do all things. God is indeed a great God.  My unquantifiable gratitude goes to Head of Department whom also is my supervisor, Dr. O.C Okeke whose kindness, constructive criticism and painstakingly supervision made this work a huge success. I appreciate my Co-Supervisor Prof. C.A. Ahiarakwem and the M.Sc. Cordinator Dr. Sam Onyekuru for their support all through this program.

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## ABSTRACT

Ekulu and Asata Rivers are major sources of water supply for domestic and industrial use in Enugu Southeasthern Nigeria. The Rivers have been exploited and abused over the past decades and henceforth have lost their original status of potability and usage for domestic, recreational and industrial use due to human activities such as mining, industrial and agricultural activities. It is in this light that this work was initiated to comparatively assess the quality of both rivers in terms of geochemical and bacteriological characteristics. Data for the study was generated from the water samples collected from the study area. The pH of the water samples taken from River Ekulu ranged from 4.5 to 6.0 while Asata River recorded a pH range of 5.8 to 7.0. Extremely high turbidity values ranging from 106NTU-294NTU recorded at River Ekulu trends far above standard WHO limit of 5NTU. River Asata has relatively low turbidity (7.88-40NTU) when compared to River Ekulu. Records of River Asata reveal higher electrical conductivities, Total Dissolved Solids, Dissolved Oxygen, Calcium, Magnesium, salinity and total hardness than those of River Ekulu. Higher Iron and Manganese concentrations were recorded at River Ekulu, hence its low acidic content. The heavy metals analysed include Lead, Iron, Copper, Chromium, Manganese and Arsenic most of which had low concentrations as some of them were below detection limits. However, Iron and Chromium are shown to be of high concentrations. At River Ekulu, the recorded values for Lead range from 0.01-0.031, Iron 3.1-7.35, Copper 0.00-0.032, Chromium 0.00 – 0.089, Manganese 0.007-0.079 and Arsenic 0.00-0.00 while at River Asata, the values for lead range from 0.00-0.047, Iron 1.09-2.58, Copper 0.00-0.022, Chromium 0.00-0.429, Manganese 0.00-0.021 and Arsenic 0.00-0.00. River Ekulu and Asata recorded high total faecal count throughout the entire study area (20 to 180) with higher percentages at River Ekulu. The data was statistically analysed using Histograms, Piper Diagram and Stiff Diagram. The Piper Chart Classified the River Ekulu as Calcium Chloride Type and River Asata as Mixed Water Type.



**Keywords:** Assessments, quality, geochemical, bacteriological, potability and Turbidity

# CHAPTER ONE

# INTRODUCTION

## 1.1 Background Information

Water is a vital element on earth; no activity is possible without the presence of water both for human utilization and for industry and agricultural use. In recent times, the development of society through population growth and development of agriculture and various industries have increased water uses. But, used and returned water has not the same quality as that taken prior to use, hence water quality and quantity have become a real problem. Clean, fresh water is critical for meeting basic human needs; from consumption and sanitation to economic activities and agriculture purposes (Bartram and Balance, 1996; UNEP, 2010). Water is a "right" for all human life on earth, and also plays a crucial role in many ecosystems, especially aquatic ones (Moiseenko, 2008).

Water is one of the most common substances known. More than 70% of the Earth's surface is covered with this simple molecule in the form of swamps, lakes, rivers and ocean. Rivers are useful in multiple ways; rivers serve as source of water for man and domestic animals, in fisheries, agriculture, navigation and generation of hydroelectric power. Rivers are essential for other uses such as industrial processes, recreation, religious ceremonies, and aesthetic enjoyment (Forslund, 2009; Hunt, 2004). Many Nigerians rely on water from the Nigeria Rivers; therefore, impacts on the Nigeria Rivers which negatively affect water quality in the country are important. The impact of poor surface water quality is evident worldwide; however, humans need to continue to use available water for consumption and everyday use.

Water quality describes the condition of a water body including chemical, physical and biological characteristics of the water usually with respect to its suitability for a particular purpose such as drinking, recreational, agricultural, industrial etc. (Garg *et al.*, 2009). It is a measure of the condition of water relative to the requirements of one or more biotic species and or to any human need or purpose. Another general perception of water quality is that of a simple property that tells whether water is polluted or not. Water quality depends on the local geology and ecosystem as well as human activities. Poor water quality can pose a health risk for humans and for the ecosystem. A detailed understanding of the causes of poor water quality, how they affect humans, and what can be done to prevent and/or address poor water quality is important. This can be achieved in part by water quality monitoring (i.e. assessing the physical, chemical, and biological characteristics of a water system that are pertinent to human health and ecosystem health) (Fukue *et al.*, 2004). Assessment of water quality can be determined by physical, chemical and biological attributes in relation to standards developed by United States Environmental Protection Agency (USEPA, 1991), American Public Health Association, (2012) and World Health Organization (1993). The national standards includes; National Environmental Standard Regulation Enforcement Agency (NESREA, 2013) and Federal Ministry of Environments Guidelines and Standards for Water Qualityin Nigeria (2011).

Depending on the quality and quantity of waste input, the physical, chemical and biological balance of the receiving water may be significantly modified leading to pollution and its associated consequences (Akpan *et al.*, 2002; Osondu, 2007). Deterioration of water quality can be as a result of heavy metals, acidification, inorganic and organic pollutants, farming practices etc. The physico-chemical and biological composition of surface water and its properties in a particular region is basically governed by natural processes and human activities which can either be point or non-point sources such as urbanization, industrial as well as agricultural activities. In spite of the huge amount of water available on the earth's surface, only a small amount is available as fresh water which can be used for human needs.

Despite the importance of surface water in human life; it is the most poorly managed resources in the world (Fakayode, 2005). The quality of water available at any given site determines to a large extent its usage. On the other hand, the nature of the environment through which the water passes determines the quality of the water (Ezeigbo and Ezeanyim, 1998). Pollution of fresh water which is the introduction of contaminants into a natural water body causes adverse change to the environment. This pollution of freshwater can be as a result of discharge of wastewater from homestead, commercial and industrial effluent or spills and runoff from agricultural farm lands into the surface water. Most of these activities have a negative impact on river ecosystem and human health (Nwachukwu and Otukunefor, 2003).

Current levels of water pollution in cities of developing countries are critical and have led to significant losses in terms of human health, productivity, and damage to ecological resources. Contaminants may also cause stains on clothings and fixtures, objectionable tastes and odours, or corrode pipes and other system components. Contaminated surface water supplies are the causes of variety of water related diseases, including typhoid, hepatitis, cholera, schistosomaiasis and guinea worm (UNESCO, 1994). The water quality of surface waters in Enugu Metropolis has been the subject of numerous investigations. Enugu owes its urban status primarily to the existence of very large deposit of coal (mainly of sub-bituminous grade) (Ezeigbo and Ezeanyim 1988). The drainage from underground coal mine and coal refuse piles is the oldest form of industrial pollution in Enugu area (Gibline, 1994).

## 1.2 Water Sources

Water is one of the most common and most abundant substances known. Water is the major constituent of almost all life forms. Water makes up 55% to 78% of the human body. Clean, fresh drinking water is essential to man and other animals. Pure water is a clear, colourless, practically tasteless and odourless liquid with a boiling point of 100$^0$C, a freezing point of 0 $^0$C, maximum density of 1g/cm$^3$ at 4$^0$C and neutral to litmus. However, water sources in nature are not obtained in its pure state. Thus the following features results; colour, taste, odour, turbidity, solids, hardness, alkalinity, acidity, organic chemicals etc. There are many natural water sources on the earth's surface. These can be broadly classified into; rain water, surface water and ground water.

### 1.2.1 Rain Water

Rain water refers to water sourced from rainfall. In environments where atmospheric pollution is not a major problem, rainwater provides an appropriate high quality source of water. The rain water can be considered as the purest form of natural water because it is formed as a result of the condensation of water vapours in the atmosphere. It is naturally distilled water. Being relatively free from mineral salts, rainwater is usually soft and lathers easily with soap. However, since water is a good solvent, it is inevitable that rainwater will also contain dissolved gasses ($CO_2$, $CO_3$, $SO_2$, $SO_3$, $NO_2$, $NO_3$ etc), dust, airborne bacteria etc depending on the conditions of the environment. Also, rain water is typically collected from roof tops and stored in tanks or cisterns. But because the roof or any collection surface is subject to contamination from nesting and flying birds and air borne dust, no one should assume that this source of water is the most suitable for human consumption (Obasikene et.al 2000). Thus, rainwater still requires treatment and disinfection to be suitable for both domestic and industrial applications.

### 1.2.2 Surface Water

Surface water includes natural water found on the earth's surface, like rivers, lakes, lagoons, oceans, springs and streams. Surface water is usually rain water that collects in surface water bodies. Another source of surface water is groundwater that discharges to the surface from springs. The total land area that contributes surface runoff to a river or lake is called a watershed, drainage basin, or catchment area. Majority of the water used both municipally and industrially are derived from surface water sources. Hazardous substances coming into contact with this surface water, dissolving or mixing physically with the water can be called surface water pollution. The effect of water pollution can be quite damaging. Therefore, individuals have to realize that water pollution can lead to long term effects and sometimes death. The source of the pollution can end but the long term effects for animal, humans and plant life can last years and even centuries, sometime totally destroying a species. The sources of surface water include:

### i. River Water

A river is a natural flowing watercourse, usually freshwater, flowing towards an ocean, a lake, a sea, or another river. Small rivers may be called by several other names, including stream, creek, brook, rivulet, and rill. Water generally collects in a river from precipitation through a drainage basin from surface runoff and other sources such as groundwater recharge, springs, and the release of stored water in natural ice and snowpack (e.g. from glaciers).

A river begins at a ‘source’ (or more often several sources) and ends at a ‘mouth’, following a path called a ‘course’. The water in a river is usually confined to a channel, made up of a stream bed between banks. Normally when there is rainfall, it washes a lot of contaminants into the river which includes human and industrial wastes. The type of mineral salts it contains is largely determined by the nature of the river-bed. Where the riverbed is impervious material like granite, the water may be fairly pure, but in limestone areas the river water tends to be very hard because of the dissolved calcium hydrogen trioxocarbonate (iv). River water may also contain a lot of bacteria and organic remains from sewage and factory wastes. Hence in its raw states, it has little suitable applications unless treated.

### ii. Lake and Sea-Water

The lakes and seas form reservoirs for rivers and other running waters. They contain all sorts of substances including bacteria, organic remains, mineral salts and gases. The percentage of solid matter here is usually very high due to the accumulation of impurities from the various sources of water. Thus, the lake and seawater require purification and treatment to be suitable for use.

### 1.2.3 Ground Water

Ground water is the water located beneath the Earth's surface in soil pore spaces and in the fracture of rock formations. These include; springs, wells, borehole, underground dam etc. Groundwater is recharged from the surface, and eventually flows to the surface naturally. Natural discharge often occurs at springs and seeps, and can form oases or wetlands. This means that the underground water are the surface water sources which sink through the porous soil layers until it collects above an impervious layer or aquifer underneath. As a result, ground water sources are also vulnerable to pollution.

Ground water contains higher dissolved solids concentrations than surface waters of the same local environment. However the quality of water available from underground aquifers may be superior in many respects to the quality of surface water. Although groundwater is less subject to contamination as compared to surface water, it can still be contaminated by salt intrusion, domestic and industrial effluents, seepage of agricultural chemicals etc ( Ajiwe 1990)

### i. Well Water

Ground water can be extracted by constructing a water supply well. Water well is a hole, shaft, or excavation used for the purpose of extracting ground water from the subsurface. A well should be built so that only water from selected depths may enter and only the best available ground water is obtained. Once a well is built, protection and management of the well and the area around it is necessary to maintain the quality of water supply. Proper well location, high quality construction materials, and protective installation techniques done by professional well contractors are essential to providing a safe supply of drinking water for individual and collective use. Wells can be constructed through various mechanized and manual methods including hand dug wells. Mechanized methods are more efficient and effective. The quality of the aquifer/borehole water is largely dependent on complete control of the entire recharge area as well as the chemical composition of the earth crust within the area.

### ii. Spring Water

A spring is formed in natural situations where water flows from an aquifer to the earth's surface. When there is rainfall, some of the rainwater sinks through the porous soil layers until it collects above an impervious layer. Some of this water may then emerge again on the soil surface as spring. A spring may be the result of karst topography where surface water has infiltrated the Earth's surface (recharge area), becoming part of the area groundwater. The water eventually emerges from below the surface in the form of a **karst spring.** Other springs are formed as a result of pressure from an underground source in the earth, in the form of volcanic activity. The result can be water at elevated temperature such as a **hot spring.**

Spring water is a good source of drinking water. The water quality at the surfacing point is usually excellent as the water has percolated through thick strata of soil. In this process of percolation, the water picks dissolved minerals (such as calcium, magnesium, iron etc) and is purified of biological pathogens, (disease producing organisms) such as bilharzias (Obasikene et al. 2000). The spring will manifest varying quantity and quality determined by the hydro geologic formation in the environment such as the type of aquifer system. Water from springs is usually clear. However some springs may be colored by the minerals that are dissolved in the water. Iron and tannins often give spring water an orange color.

## 1.3 Location and Climate of the Study Area

Enugu is the capital of Enugu State in Southeastern Nigeria. The state shares borders with Abia State and Imo State to the South, Ebonyi State to the East, Benue State to the Northeast, Kogi State to the Northwest and Anambra State to the West. Enugu is located between latitude $6^0$15'N and $6^0$37'N and longitude $7^0$20'E and $7^0$37'E in Southeastern Nigeria (Fig.1). The State occupies much of the highlands of Awgu, Udi and Nsukka.

Enugu State has a total land area of 7,161 square kilometres and a population of 722,664 according to the 2006 Nigerian census (National Population Commission, 2006). The State falls within the tropical climatic region with temperature range of 23-$30^0$C. There are two distinct seasons; dry and wet seasons. Mean annual rainfall ranges between 1500mm and 2400mm with the driest month having at least 27mm of rainfall. The natural vegetation is the tropical rain forest type.

Ekulu and Asata Rivers are surface waters which traverse the Enugu metropolis, (Ezeigbo and Ezeanyim, 1988). The major rivers in the study area include

Emene, Ekulu, Akwata, Nyaba, Asata, Idaw and Iyiukwu. Eyo and Iyiukwu Rivers are tributaries of Emene River which originate from Eastern part of the study area. Emene River captures Ekulu river system which comprises of Asata, Akwata, Aria, and Ogbete Rivers; and they empty into Nyaba River which drains into Cross River Basin. Ekulu river is about 30kilometers in length from its source to its confluence with Nyabariver in the south (Ezenwaji *et al*, 2014)

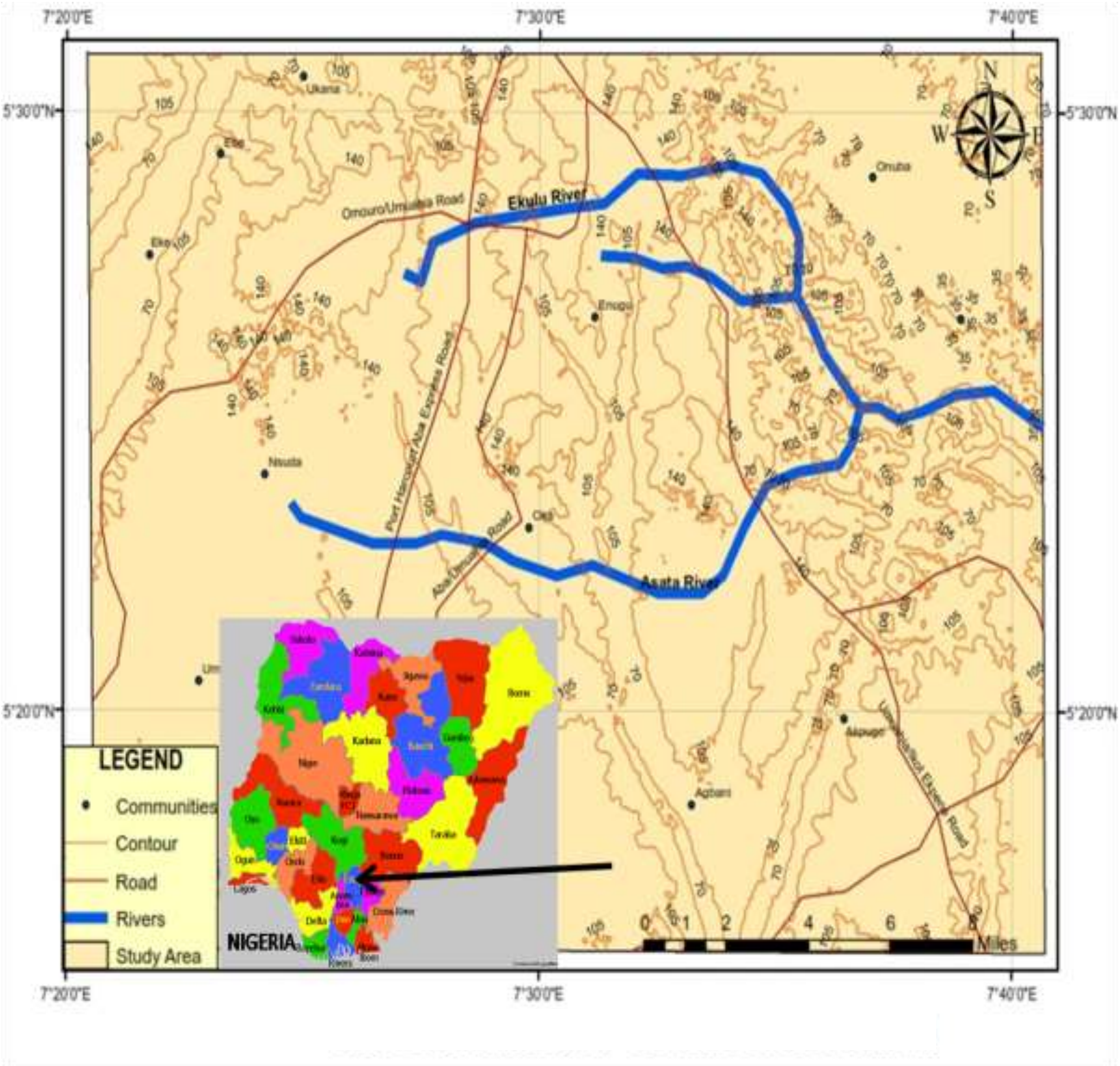


Fig. 1.1: Topographic Map of the Study Area

Source: Nigeria Geological Survey Agency 2004

## 1.4 Statement of the Problem

Water quality is of great concern in rural and urban areas such as those found within Enugu metropolis. The Ekulu and Asata rivers and their tributaries flow through a vast distance traversing abandoned coal mines, companies, factories, farms, hotels, educational and residential areas all of which constitute the Enugu metropolis. Hence, these rivers are prone to human and environmental pollution and therefore require water quality analysis to investigate their usability.

Furthermore, the increase in demand of water for domestic, agricultural, recreational and industrial uses arising from increase in population and fast growth of industries in Enugu has put pressure on the limited water resources available. This is coupled with poor groundwater potential of the area, hence there is need to explore other water sources to augment the existing inadequate supply. To address these issues, water quality studies and monitoring projects are crucial for current and future research.

## 1.5 Aim of the Study

The aim of this work is to establish a water quality baseline and develop a framework for water quality monitoring of Ekulu and Asata Rivers in Enugu metropolis.

## 1.6 Objectives of the Study

The objectives of the study are:

i. To determine the geochemical and bacteriological properties of Ekulu and Asata Rivers within Enugu metropolis.

ii. To compare the geochemical and bacteriological parameters of the two rivers and evaluate their quality against national and international standards.

iii. To interpret the results using histograms, piper charts and stiff diagrams.

iv. To assess sodity of the water samples using SAR

v. To identify various environmental processes/activities that influences the water quality of the two rivers.

vi. To recommend control measures that will improve the quality of the rivers in the study area.

**1.7 Significance of the Study**

Water is fundamental for human life and an essential resource to be protected. Despite of the availability of water everywhere, there is no such thing in nature as "pure" water. Nearly, all water contains contaminants, even in the absence of nearby pollution-causing activities. Many dissolved minerals, organic carbon compounds, and microbes find their way into water bodies. As a result, the only way to ensure that a water source is safe is to have a periodic laboratory analysis such as was carried out in this study.

Although most of the population within Enugu gets their drinking water from groundwater sources, Ekulu and Asata River water still remains an important source for daily activities such as bathing, cooking, livestock watering, recreational activities, agricultural etc. This study is designed to analyse the water quality of the two rivers and to recommend measures to reduce pollution level of the rivers. The findings in this work provide valuable information about the geochemical and bacteriological properties of Ekulu and Asata River and can be incorporated in water quality monitoring programs. The Research will serve as a framework for further studies on water quality of Ekulu and Asata Rivers in Enugu metropolis. It can also aid healthcare workers and other relevant agencies to educate the rural communities; the more people know about the causes and effects of pollution, the more they try to avoid the consequences.

## 1.8 Scope of the study

The scope of the study is to assess the geochemical and bacteriological characteristics of Ekulu and Asata rivers within Enugu metropolis, Enugu State, Southeastern Nigeria.

# CHAPTER TWO
# LITERATURE REVIEW

## 2.1 Geology of the Study Area

Enugu State occupies much of the highlands of Awgu, Udi and Nsukka. Enugu metropolis is within the Anambra basin, which comprises mainly sedimentary rocks of sandstone, siltstone, mudstone and shales in the Lower Benue trough. The geology of Enugu State is part of the geology of Southeastern Nigeria underlain by the following geological formations (Table1), the Asu River Group, Eze Aku Formation, Awgu/Ndeabor Formation, Nkporo /Enugu Shale, Mamu Formation, Ajali Formation, and Nsukka Formations.

The Asu River group is the earliest recorded marine sediments. Deposition of sedimentary rocks in Southeastern Nigeria started with major marine transgression across a large area that led to the deposition of “Asu River Group” sediments. The Asu River Group is characterised by Abakiliki Shale and Awi Formation in Calabar area in the Albian time (Lower Crtaceous) (Rayment 1965). This was followed by transgression and regression activities that led to the deposition of Ezeaku Formation (Ezeaku Shale) with lateral equivalent of Amasiri Sandstone in Afikpo area. The regression activities continued with the deposition of marine Awgu Formation (Awgu Shale). The deposition of Awgu Formation was terminated by Santonian Tectonism characterised by folding, faulting and volcanism which resulted in the formation of Abakiliki ridge/anticlinorium and Anambra Basin/Afikpo Syncline.

The depositional process resumed in the Campanian with the deposition of Nkporo Shale (with lateral equivalent of Enugu Shale); and continued into the Maastrichtian with the deposition of Mamu, Ajali and Nsukka Formations. The Nsukka Formation has the same lithological characteristics as the Mamu

Formation. The two formations are sometimes referred to as the upper coal measures and Lower Coal Measures respectively. The coal-bearing Mamu Formation is one of the sedimentary formations of South-eastern Nigeria and consists of alternating beds of shale, claystone, mudstone, siltstone, sandstone and coal seams. The Mamu Formation was formed by series of transgression and regression that dominated the process of sedimentation during Maastrichtian (Upper Cretaceous) (Reyment, 1965).

The Mamu Formation is the most important geological formation with respect to coal formation, occurrence and mining in Enugu State. The Mamu Formation underlies Ajali Sandstone (aquiferous unit), but both are generally affected by late Cretaceous tectonism leading to fauting, folding and fracturing of the rock materials (Ezeigbo and Ezeanyim, 1988). The Area is richly endowed with sub-bituminous three-coal seams within the Mamu Formation. Enugu state also experiences much groundwater contamination due to coal mining activities. It also lacks prolific and potable groundwater due to the thinning-out of the Ajali sandstone aquifer through Udi town and Ninth- mile into Enugu metropolis.

The rivers (Ekulu and Asata) flows through three geological formations namely the false bedded sandstone (Ajalli formation), the lower Coal measure (Mamu formation) and Enugu shale that constituted the largest formation in terms of area. The table below shows the generalized stratigraphic sequence of Southeasthern Nigeria.

Table1: Generalized Stratigraphic Sequence of Southeasthern Nigeria (Modified from Ofodile 1975 and Okeke 2008)

| AGE | FORMATION | LITHOLOGICAL CHARACTERISTICS |
|---|---|---|
| Recent | Recent Sediments | Alluvium/Deltaic Plains |
| Miocene – Recent | Benin Formation | Unconsolidated sandstone with lenses of clay |
| Oligocene - Miocene | Ogwashi-Asaba Formation | Unconsolidated sandstone, Mudstone, Clay and Lignite Seams |
| Eocene | Ameki Formation | Grey to green argillaceous sandstone, shale and limestone units |
| Paleocene | Imo Formation | Fine textured dark-grey shale with arenaceous sandstone member |
| Maastrichtian | Nsukka Formation<br><br>Ajali Formation<br><br>Mamu Formation | Alternating sequence shale, sandstone and coal seams.<br><br>Friable sandstone with Iron stains<br><br>Alternating sequence of sandstone, claystone and shale with coal seams |
| Campanian | Nkporo Formation/Enugu Shale | Dark grey shale with clayey Mudstone and Shale with thin beds of Sandstone |
| Santonian | Awgu Formation | Bluish grey Shale with intercalations Sandstone and shaly limestone |
| Turonian | Ezeaku Formation (Ezeaku Shale) | Black shale with clay and sandtone lenses |
| Albian | Asu River Group | Black shale and sandstone |
| Precambrian | Basement Complex | Older Granite and Gneiss |

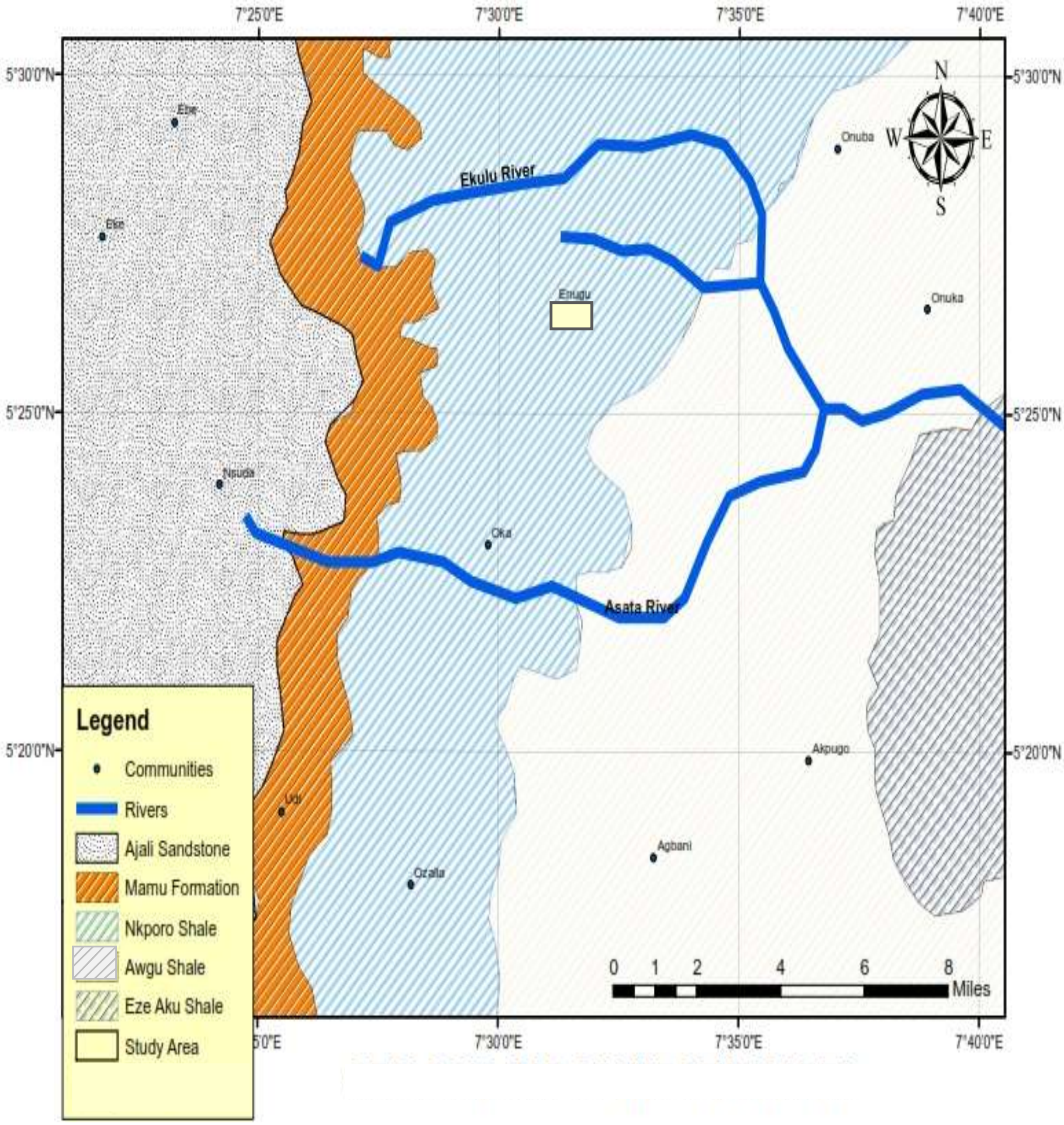


**Fig 2.1: Geologic Map of the Study Area**

**Source: Nigerian Geological Survey, 2004**

## 2.2 Previous Works

Water pollution is a major global problem which requires ongoing evaluation and revision of water resource policy at all levels. River water pollution is very common in most urban rivers in Nigeria. Water pollution is a rapid growing menace in the society and environment. At concentrations where wastes or contaminants become dangerous to human health and ecological balance and are culturally offensive, it is labelled pollution.

In Nigeria, numerous studies on physico–chemical and biological pollution of urban rivers and the implications of polluted water on man and the environment have been carried out by several authors such as Asiwaju-Bello and Akande, (2000), Onipede and Bolaji, (2004), Ufia et al, (2013), Garizi and Saddodin (2011), Okeke and Igboanua, (2003), Butu, (2013), Olofin, (1991), Ibe, (2014), Ubani, (2009), Nwaichi et al, (2013). Similar studies have been carried out in Enugu and its environs by Ezenwaji and Orji, (2010), Udeze, (1988), Ezeigbo and Ezeanyim, (1998), Ezenwaji et al, (2014), and few others particularly studied the pollution level of Ekulu river.

Ezenwaji *et al*, (2014) studied the "Negative Human Impact on the Environment", using River Ekulu as a case study. The aim of the paper was to identify those human activities and land uses that tend to produce wastes and the extent of pollution of the river by these contaminants using geochemical and microbiological parameters. According to the study, the Ekulu river basin is wholly located within the built up areas of Enugu and the result is that a range of human and economic activities produce contaminants that daily pollute the river as the river serve as a receptacle for the discharge of these waste effluents. The result of the analysis shows that the samples from various sites are statistically different while the degree of pollution was highest in the built up areas.

Awalla, (2013) did an appraisal of the water related contaminants as they affect the environment around the Enugu coal mines of Enugu state, Southeastern Nigeria. An Assessment of the Pollution Levels of Rivers in Enugu Urban and their Environmental Implication was also carried out by Ubani et al, (2009). The purpose of the study was to examine the pollution levels of rivers in Enugu urban in relation to the safe limits described by the National Agency for Food and Drug Administration and Control standard. The result of the study shows that the water quality of rivers in Enugu urban has been found to be slightly below the acceptable safe limit set by NAFDAC.

Furthermore, in Enugu, Nnodu and Ilo, (2000) studied aspects of the ground and surface water quality from range of water supply sources including shallow wells, boreholes, rivers, tap water and water vendors. Their conclusion is that all water supply sources in the area are heavily polluted by physical, chemical and biological contaminants. However, none of these authors did comparative analysis of any of the rivers within Enugu metropolis. This study is therefore aimed at comparative assessment of the geochemical and bacteriological characteristics of water samples taken from Ekulu and Asata Rivers.

## 2.3 Water Quality and Human Health

In 1854, water quality was shown to have an impact on human health when Dr. John Snow discovered that a cholera outbreak in London was linked to a public well near the Thames River which was contaminated by sewage infiltration. This led to an increased recognition of the importance of water quality to human health (National Research Council U.S., 1977; Olajire and Imeokparia, 2002). As a result of this growing awareness, water quality testing has become increasingly important over the past number of decades (Niemi et al, 1990; Silva and Sacomani, 2000).

Contaminated water containing pathogenic microorganisms or various chemical contaminants can cause many diseases in humans. Such diseases can be contracted by ingesting affected food or water, or by coming into contact with contaminated water through bathing or washing. As stated by the World Health Organization (WHO), "Water sanitation and hygiene have important impacts on health" (World Health Organization, 2008). Waterborne diseases occur when water transmits diseases such as diarrhoea, typhoid, cholera, dysentery, hepatitis A etc.  Drinking water contaminated by human faecal matter is the main cause of waterborne diseases (Gleick, 2012)

## 2.4 Millennium Development Goals

Over the years, it has become obvious that our world has succumbed to poverty worldwide and this has had social, economic, political, and environmental consequences for human beings. Many initiatives have been put forward, particularly by the United Nations (UN), and they have established a set of targets with timelines for world development projects. Prior to the Millennium Summit in 2000, eight international development goals known as "the Millennium Development Goals (MDGs)" were set to be achieved by the year 2015. These eight goals were further broken down into various subcategories which define specific aspects of each goal. The first seven goals are targeted towards poverty and hunger, education, gender equality and empowerment of women, child mortality, maternal health, combating diseases, and ensuring environmental sustainability. The eighth goal focuses on a global partnership for development.

Water is fundamental for human life and an essential resource to be protected. One of the United Nations eight Millennium Development Goals of particular interest is 7c, which aims 'to half by 2015, the proportion of the population without sustainable access to safe drinking water and basic sanitation' (United Nations, 2011). In Resolution 64/292, the United Nations stresses the importance of equitable access to safe and clean drinking water and sanitation as an integral component of the realization of all human rights. Also, the United Nations recognizes the right to safe and clean drinking water and sanitation as a human right that is essential for the full enjoyment of life and all human rights (General Assembly, 2010)

## 2.5 Water Quality and Ecosystem Health

The focus on water quality is starting to shift from a principal focus on human health to a focus on both human and ecosystem health (Karr, 1992). Most of the earth's surface is covered by water, and most of the human body is composed of water – these are two facts illustrating the critical linkages between water, health and ecosystems (UNEP, 2010). As water resources around the world are being depleted, we are starting to see that water scarcity is leading to degraded ecosystems and contamination (UNEP, 2010).

Since the 1800s, scientific research related to ecosystem health has been undertaken. Research connecting ecosystem problems related to water date back to the early 1900s when a Swedish chemist, Savante Arrhenius, stated that carbon dioxide levels would increase in the future, and ultimately lead to an increase in global temperatures (Weart, 2011). Decades later, in the 1980s and 1990s, ice cores and computer-generated models supported Arrhenius assertion of increasing global temperatures, which is causing worldwide effects on our water resources. In the 1920s and 1930s, conservationist, Aldo Leopold, played a major role in increasing awareness of the environment, ecology, and forestry. In his book entitled *A Sand County Almanac*, Leopold commented that "land health is the capacity for self-renewal in the soils, waters, plants, and animals that collectively comprise the land." (Quoted in Meine and Knight, 2006, p.148).

In many developing countries, there is lack of significant funding and expertise to implement and maintain water quality monitoring programs on the rivers and streams. On the African continent, eighty percent of all diseases are related to poor water quality and unsanitary conditions (Olajire and Imeokparia, 2002). There is limited research and documentation on African water sources, despite the ongoing concern over water quality and the scarcity the continent is currently facing (Mwanza, 2005). Although most of the population within Enugu get their drinking water from groundwater sources, Ekulu and Asata

River water still remains an important source for daily activities such as bathing, cooking, livestock watering, recreational activities, agricultural purposes, etc.

In order for continued human and ecosystem existence, we must secure enough water to provide for our future needs. Water security is an increasing concern for countries worldwide. The United Nations defines water security as the capacity of a population to safeguard sustainable access to adequate quantities of acceptable quality water for sustaining livelihoods, human well- being, and socio-economic development, for ensuring protection against water-borne pollution and water-related disasters, and for preserving ecosystems in a climate of peace and political stability (UN 2011). This ever increasing concern over water security can be caused by both natural sources and man-made sources. However, it is necessary to make provisions to ensure the sustainability of such a precious resource worldwide.

## 2.6 Review of Geochemical and Bacteriological Parameters

The physical and chemical parameters used for the water quality assessments in the study include temperature, turbidity, colour, conductivity, pH, dissolved oxygen content (DOC), biochemical oxygen demand (BOD), chemical oxygen demand (COD), total dissolved solute (TDS), total suspended solids, total hardness, total alkalinity, nitrate, nitrite, ammonia, silicate, manganese, calcium, phosphate, sulphate and chloride.

**pH** - The pH of a solution is a measure of the molar concentration of hydrogen ions in the solution and as such is a measure of the acidity or basicity of the solution. The letters pH stand for "power of hydrogen" or “potential of Hydrogen” and the numerical value is defined as the negative base 10 logarithm of the molar concentration of hydrogen ions i.e. $pH = -\log_{10}[H^+]$. pH measurements run on a scale from 0 to 14, with 7.0 considered neutral.

Solutions with a pH below 7.0 are considered acids. Solutions with a pH above 7.0, up to 14.0 are considered bases.

The chemical and biological conditions of water play a role in the control of pH concentrations. The pH of a body of water is affected by factors such as the bedrock and soil composition through which the water moves. The amount of plant growth and organic material within a body of water also affects pH e.g. carbon dioxide released when these materials decompose combines with water to form carbonic acid which can lower the pH. Other factors that influence pH include dumping of chemicals into the water, the amount of acid precipitation that falls in the watershed caused by nitrogen oxides (NOx) and sulfur oxide ($SO_x$) in the air combining with water vapor, coal mine drainage etc. pH is a critical factor in determining the health of a waterway. Most organisms have adapted to life in water of a specific pH and may die if it changes even slightly.

**Turbidity** - Turbidity is a measure of water clarity and an indicator of its optical properties. It is a measure of the degree to which water loses its transparency due to the presence of suspended particulates. Turbidity can also be defined as the cloudiness or haziness of a fluid. Turbidity in water is caused by suspended and colloidal materials such as mineral particles, clay, silt, finely-divided organic and inorganic matter, waste discharge, urban runoff, phytoplankton, algae growth and other microscopic organisms. The measurement of turbidity is a key test of water quality. In water bodies such as lakes, rivers and reservoirs, high turbidity levels can reduce the amount of light reaching lower depths. The suspended particles scatter the light, thus decreasing the photosynthetic activity of plants and algae, which contributes to lowering oxygen concentration. The suspended particles also absorb heat from the sunlight, thereby making turbid waters become warmer, and so reducing the concentration of oxygen in the water (oxygen dissolves better in colder water). Some aquatic organisms also can’t survive in warmer water. As a consequence of the particles settling to the bottom of water bodies, fish eggs and insect larvae are being covered and suffocated; gill structures get clogged or damaged thereby affecting the ability of fish gills to absorb dissolved oxygen. The main impact is merely aesthetic: nobody likes the look of dirty water. Higher turbidity levels are often associated with higher levels of disease-causing microorganisms such as viruses, parasites and some bacteria. The suspended particles also help the attachment of heavy metals and many other toxic organic compounds and pesticides.

**Total dissolved solids (TDS) and Total Suspended Solids** - Solids present in water sample can either be suspended or dissolved matter. Total Dissolved Solids are the total weight of all solids that are dissolved in a given volume of water, expressed in units of milligram per unit volume of water (mg/L). It refers only to solids in solution or in other words, the solid remaining in the filtrate after all the suspended solids (total suspended solid) have been removed on the filter.

TDS concentrations are used to evaluate the quality of freshwater systems. Some dissolved solids come from organic sources such as leaves, silt, plankton, and industrial waste and sewage. Also, from inorganic materials such as rocks and air that may contain calcium bicarbonate, nitrogen, iron phosphorous, sulfur, and other minerals. Other sources come from runoff from urban areas, fertilizers and pesticides used on lawns and farms. TDS is not considered primarily as pollutant, high TDS levels typically indicate hard water and may lead to scale build-up in pipes, reduced efficiency of water filters, hot water heaters, etc., and aesthetic problems such as a bitter or salty taste. When TDS levels exceed 1000mg/L it is generally considered unfit for human consumption. Most often, high levels of TDS are caused by the presence of potassium, chlorides and sodium. These ions have little or no short-term effects, but toxic ions such as lead arsenic, cadmium, nitrate and others may also be dissolved in the water. TDS is an indicator of non-point source pollution problems associated with various land use practices (Sridhar, 2002, Imoisi *et al.*, 2012).

**Electrical conductivity -** Electrical conductivity is the measure of the ability of water to conduct an electric current and depends upon the number of ions or charged particles in the water. Electrical conductivity meter is used to determine electrical conductivity. The unit of measurement for electrical conductivity is expressed in either micro Siemens per centimetre (µS/cm) or milli Siemens per centimetre (mS/ conductivity cm). Low values of electrical conductivity are characteristic of high quality water. Very high values are good indicators of possible polluted sites.

A sudden change in electrical conductivity can indicate a direct discharge or other source of pollution into the water. As the number of charged ions in the water increase, so does the electrical conductivity. Significant increase in conductivity may be an indicator that discharges, high nutrients and heavy metals have entered the water (Madu, *et al.,* 1995).

Conductivity in streams and rivers is affected primarily by the geology of the area through which the water flows. Streams that run through areas with granite bedrock tend to have lower conductivity because granite is composed of more inert materials that do not ionize. On the other hand, streams that run through areas with clay soils tend to have higher conductivity because of the presence of materials that ionize when washed into the water.

**Dissolved Oxygen (DO) -** Dissolved oxygen (DO), is a measure of how much oxygen is dissolved in water. Although water molecules contain oxygen atom, this oxygen is not what is needed by aquatic organisms living in natural waters. Some amount of oxygen is actually dissolved in water. This dissolved oxygen is breathed by fish and zooplankton and is needed by them to survive. The oxygen dissolved in lakes, rivers, and oceans is crucial for the organisms and creatures living in it. This gas is an absolute requirement for the metabolism of aerobic organisms and also influences inorganic chemical reactions. Oxygen gets into water by diffusion from the surrounding air, by aeration (rapid movement) and as a waste product of photosynthesis. When transparency increases, photosynthetic activities increase because of sufficient sunlight penetration thereby leading to increase in dissolved oxygen (Adeogun, 2012).

The amount of dissolved oxygen in surface water is highly dependent on temperature and has both a seasonal and a daily cycle. Cold water can hold more dissolved oxygen than warm water. Rapidly moving water such as in a mountain stream or large river tends to contain a lot of dissolved oxygen, whereas stagnant water contains less. Bacteria in water can consume oxygen as organic matter decays. Thus, excess organic material in lakes and rivers can cause eutrophic conditions, which is an oxygen-deficient situation that can have negative impact on the water body. As the amount of dissolved oxygen drops below normal levels in water bodies, the water quality is harmed and creatures begin to die off. Low levels of dissolved oxygen can hinder stream purification processes resulting in negative effects on aquatic life. Adequate dissolved oxygen is necessary for good water quality. Natural stream purification processes require adequate oxygen levels in order to provide for aerobic life forms. As dissolved oxygen levels in water drop below 5.0 mg/l, aquatic life is put under stress.

**Biochemical Oxygen Demand and Chemical Oxygen Demand** - Biochemical oxygen demand (BOD) is the amount of dissolved oxygen needed by aerobic biological organisms in a body of water to break down organic materials present in a given water sample at certain temperature over a specific time period (American Public Health Association, 2012). It is simply a measure of the amount of oxygen required for microbial metabolism of organic compounds in water while Chemical Oxygen Demand (COD) is a measure of the total quantity of oxygen required to oxidize all organic material into carbon dioxide and water. Specifically, COD measures the equivalent amount of oxygen required to chemically oxidize organic compounds in water. COD values are always greater than BOD values. BOD is similar in function to chemical oxygen demand (COD), in that both measure the amount of organic compounds in water.

Most natural waters contain small quantities of organic compounds. Aquatic microorganisms use some of these compounds as food. Microorganisms living in oxygenated waters use dissolved oxygen to oxidatively degrade the organic compounds, releasing energy which is used for growth and reproduction. Populations of these microorganisms tend to increase in proportion to the amount of food available. This microbial metabolism creates an oxygen demand proportional to the amount of organic compounds useful as food. Under some circumstances, microbial metabolism can consume dissolved oxygen faster than atmospheric oxygen can dissolve into the water or the autotrophic community (algae, cyanobacteria and macrophytes) can produce. Oxygen consumed in the decomposition process robs other aquatic organisms of the oxygen they need to live. Fish and aquatic insects may die when oxygen is depleted by microbial metabolism (Goldman and Horne, 1983).

**Hardness -** One of the factors that establish the quality of a water supply is its degree of hardness. Hardness in water is defined as concentration of multivalent cations in water. Multivalent cations are positively charged metal complexes with a charge greater than 1+ e.g. $Ca^{2+}$ and $Mg^{2+}$. These cations in high concentrations causes water hardness. These ions enter a water supply by leaching from minerals such as calcite, gypsum and dolomite  within an aquifer. Thus, the hardness of water is defined in terms of its content of calcium and magnesium ions. Hard drinking water may have moderate health benefits, but can pose serious problems in industrial settings where water hardness is monitored to avoid costly breakdowns in boilers, cooling towers, and other equipment that handles water. In domestic settings, hard water is often indicated by a lack of suds formation when soap is agitated in water, and by the formation of limescale in kettles and water heaters (WHO, 2008). Hardness can thus be defined as the soap-consuming capacity of a water sample.

The World Health Organization says that "there does not appear to be any convincing evidence that water hardness causes adverse health effects in humans"(WHO, 2006). In fact, the United States National Research Council has found that hard water can actually serve as a dietary supplement for calcium and magnesium. Though, some studies correlate domestic hard water usage with increased eczema in children (Miyake et al 2004, Arnedo-Pena et al, 2007). Several scales are used to describe the hardness of water in different contexts. The precise mixture of minerals dissolved in water, together with the water's pH and temperature, determine the behaviour of the hardness. Hence, a single-number scale does not adequately describe hardness. However, the United States Geological Survey uses the following classification; water can be said to be soft, moderately hard, hard or very hard when the level of hardness are in the following ranges:

| | |
|---|---|
| Soft: | 0–60 mg/L |
| Moderately hard | 61–120 mg/L |
| Hard: | 121–180 mg/L |
| Very hard: | >181 mg/L |

**Nitrate and Nitrite** - Nitrogen is essential for all living things as it is a component of protein. Nitrogen exists in the environment in many forms and changes forms as it moves through the nitrogen cycle. Nitrate ($NO_3^-$) and Nitrite ($NO_2^-$) are naturally occurring inorganic ions that are part of the nitrogen cycle. Microbial action in soil or water decomposes wastes containing organic nitrogen into ammonia, which is then oxidized to nitrate and nitrite. Contamination with nitrogen containing fertilizers (e.g. potassium nitrate and ammonium nitrate), or animal or human organic wastes, can raise the concentration of nitrate in water. Nitrates ($NO_3$) are formed by conversion of nitrogen ($N_2$) gas by blue green algae and legumes (nitrification). These nitrates enter streams and rivers from natural sources like decomposing plants and animals waste as well as human sources like sewage and fertilizers (Wetzel, 2001).

Excessive concentrations of nitrate-nitrogen or nitrite-nitrogen in drinking water can be hazardous to health, especially for infants and pregnant women. The primary health hazard from drinking water with nitrate-nitrogen occurs when nitrate is transformed to nitrite in the digestive system. The nitrite oxidizes the iron in the haemoglobin of the red blood cells to form met haemoglobin, which lacks the oxygen-carrying ability of haemoglobin. This creates the condition known as methemoglobinemia (sometimes referred to as "blue baby syndrome"), in which blood lacks the ability to carry sufficient oxygen to the individual body cells causing the veins and skin to appear blue. This health concern is primarily related to potential exposure through consumptions by infants. In addition, there are reports of potential birth defects associated with pregnant women drinking water high in nitrogen. Also a possibility exists that nitrate can react with amines or amides in the body to form nitrosamine which is known to cause cancer.

**Chloride, $Cl^-$** - Chlorides are present in both fresh and salt water, and are essential elements of life. Chloride ions in the environment can come from sodium chloride or from other chloride salts such as potassium chloride, calcium chloride and magnesium chloride. Natural Chlorides constitute approximately 0.05% of the earth's crust. Chloride may get into surface water from several sources including wastewater from industries and municipalities, wastewater from water softening, road salting, agricultural runoff, produced water from gas and oil wells etc. In coastal areas, chloride from saltwater aquifers, sea spray, and coastal flooding can also find its way into freshwater waters.

High chloride concentrations in freshwater can harm aquatic organisms by interfering with osmoregulation; the biological process by which they maintain the proper concentration of salt and other solutes in their bodily fluids (IOS, 2014). Chloride increases the electrical conductivity of water and thus increases its corrosivity. In metal pipes, chloride reacts with metal ions to form soluble salts, thus increasing levels of metals in drinking water (Gregory, 1990). Chloride concentrations in excess of about 250 mg/litre can give rise to detectable taste in water.

**Heavy Metals -** Heavy metals refers to any metallic chemical element that has relatively high density and is toxic or poisonous at low concentrations e.g. Mercury, Cadmium, Arsenic, Chromium, Thallium, Lead etc. Though living organisms require trace amounts of some heavy metals such as cobalt, copper, manganese, molybdenum, vanadium, strontium, and zinc, excessive levels can be detrimental to the organism. Other heavy metals such as mercury, lead and cadmium have no known vital or beneficial effect on organisms, they are toxic and their accumulation over time in the bodies of mammals can cause serious illness. A feature that heavy metals have in common is that they tend to accumulate in the bodies of organism that ingest them and become a significant health hazard. The heavy metals analysed include Lead, Iron, Copper, Chromium, Manganese Arsenic and Cadmium

**Lead** is a metal with no known biological benefit to humans. Exposure to lead through water is generally low in comparison with exposure through air or food. The amount of lead that may dissolve in water depends on acidity (pH), temperature, water hardness and standing time of the water. The major sources of lead include lead piping used in water distribution systems, industrial sources such as smelters and lead manufacturing and recycling industries, cottage industries and waste sites (e.g. contaminated landfills), automobiles' exhausts, paints, chemical and pesticide industries, etc. Other sources include use of lead-containing ceramics for cooking, eating or drinking

Lead in drinking water can cause a variety of adverse health effects. In babies and children, exposure to lead can cause consequences which may be irreversible including learning disabilities, behavioural problems, and mental retardation.  At very high levels, lead can cause convulsions, coma and death. In adults, it can cause damage to various systems of the body including the nervous and reproductive systems and the kidneys, and it can cause high blood pressure and anaemia (US EPA, 1991).

**Iron** is one of the essential mineral for humans and animals. Iron is one of the earth's most plentiful resources, making up at least five percent of the earth's crust. Iron is mainly present in water in two forms: either the soluble ferrous iron or the insoluble ferric iron. Iron is essential to health; it is a component of blood cells and liver metalloenzymes. The most well known role that iron plays in human nutrition is in the formation of the protein haemoglobin, which transports oxygen to all cells of the body. Low iron stores in the body can lead to iron deficiency, anaemia and fatigue and can make one more susceptible to infections.

Ingesting large amounts of iron can lead to a condition known as iron overload; this condition usually results in gene mutation. If left untreated, iron overload can lead to hemochromatosis (a severe disease that can damage the body's organs). Early symptoms include fatigue, weight loss, and joint pain. Also, if hemochromatosis is not treated, it can lead to heart disease, liver problems and diabetes.  Iron is not hazardous to health, but it is considered a secondary or aesthetic contaminant. Dissolved ferrous iron gives water a disagreeable metallic taste. Concentrations of iron as low as 0.3 mg/l will leave reddish brown stains on fixtures, table wares and laundry, and the stain are very hard to remove.

**Manganese** occurs naturally in many surface water and groundwater sources and in soils that may erode into these waters. Manganese is present in ground waters primarily as the divalent ion ($Mn^{2+}$), due to lack of subsurface oxygen. Surface waters may contain combinations of manganese in various oxidation states as soluble complexes, or as suspended particles. Natural sources manganese is more common in deeper wells where the water has been in contact with rock for a longer time. It may also occur from both deep and surface mining activities. However, human activities are also responsible for much of the manganese contamination in water in some areas.

The occurrence of manganese in public water supplies presents more of an economic problem than a potential health hazard. Manganese causes dark stains in laundry and on plumbing fixtures, it tends to deposit in water lines, and imparts a strong objectionable metallic taste to water. Manganese levels in natural waters rarely exceed 1 mg/l, but levels of 0.1 mg/L are sufficient to cause taste and staining problems. At excessive concentrations, manganese can be detrimental to health. Evidence from occupational exposure indicates that manganese can affect neurological function. Manganese has also been linked with liver, kidney and lung damage.

**Copper** is a metal found in natural deposits such as ores containing other elements. Copper is found in surface water, groundwater, seawater and drinking-water, but it is primarily present in complexes or as particulate matter (ATSDR, 2002). The major sources of copper in drinking water are corrosion of household plumbing systems and erosion of natural deposits. Copper concentrations in drinking-water vary widely as a result of variations in water characteristics, such as pH, hardness and copper availability in the distribution system. Results from a number of studies from Europe, Canada and the USA indicate that copper levels in drinking-water can range from ≤0.005 to >30 mg/litre, with the primary source most often being the corrosion of interior copper plumbing (US EPA, 1991). Even though we require 1,000 micrograms of copper daily in our diet, elevated levels of ingested copper can be harmful. Elevated levels of Copper for 14 days or more can lead to health problems such as permanent kidney and liver damage in infants under the age of one year. In adults, high levels of copper can cause digestive disorders such as nausea, vomiting, diarrhoea and stomach cramps. (Monty and Mark, 2005).

**Chromium** is complex in its behavior in drinking water systems as it may occur in both the trivalent (chromium-3) and hexavalent (chromium-6) forms. If there are oxidants (including disinfectants) in the distribution system, chromium-3 can be partially or completely oxidized to chromium-6. Hexavalent compounds have been shown to be carcinogenic by inhalation and are corrosive to tissues. Hexavalent chromium (Cr(VI)) compounds are a group of chemical substances that contain the metallic element chromium in its positive-6 valence (hexavalent) state. According to U.S. Department of Health and Human Services (2008), Chromium is a naturally occurring heavy metal that is commonly used in industrial processes and can cause severe health effects in humans. Although it can be released through natural forces, the majority of the environmental releases of chromium are from industrial sources. The industries with the largest contribution to chromium levels include leather tanning operations, metal processing, stainless steel welding, chromate production, and chrome pigment production. Chromium can be found in many consumer products, including wood treated with copper dichromate, leather tanned with chromic sulphate, and stainless steel cookware, chrome plating, painting, and coating processes. Calcium Chromate, Lead Chromate, Strontium Chromate and Zinc Chromate are known human caseinogens.

**Arsenic** occurs naturally in the environment as elements of the earth's crust. High concentrations of arsenic in water can have an adverse effect on health Arsenic is combined with other elements such as Oxygen, Chlorine and Sulphur to form inorganic Arsenic compounds. Exposure to higher-than-average levels Arsenic occurs mainly in workplaces, near or in hazardous waste sites. Areas with high levels of Arsenic naturally occur in soils, rocks and water. Exposure to high levels of Arsenic can cause death. Arsenic poisoning through water can cause liver and nervous system damage, vascular diseases and also skin cancer.

**Cadmium** is an extremely toxic metal commonly found in industrial workplaces. Due to its low permissible exposure limit, overexposures may occur even in situations where trace quantities of cadmium are found. Sources of cadmium include hazardous waste sites, cigarette smoking, battery manufacturing, electroplating, industrial paints, smelting and refining of metals. Buildup of cadmium levels in the water, air, and soil has been occurring particularly in industrial areas.

Cadmium is an extremely toxic industrial and environmental pollutant classified as human casinogen. Cadmium gets deposited in visceral organs like liver, pancreas, kidney, intestinal mucosa etc. Acute exposure to Cadmium may cause tracheobronchitis, pulmonary edema, respiratory and kidney problems, bronchial pneumonia, kidney necrosis, vomiting, headache, weakness, chest pain, soft bones (osteomalacia) etc.

**Faecal Coliform** - Biological pollutants of water include dissolved organic constituents and microorganisms. Microorganisms may contribute to pollution in many ways; they may themselves be pathogenic, aesthetically they may produce undesirable biomass. Bacteriological water analysis is a microbiological analytical procedure used to determine the concentration of bacteria present in water, and if needed, to find out what sort of bacteria they are. It is then possible to draw inferences about the suitability of the water for use from these concentrations. This process is used, for example, to routinely confirm that water is safe for human consumption or that bathing and recreational waters are safe to use.

The common feature of all these routine screening procedures is that the primary analysis is for indicator organisms rather than the pathogens that might cause concern. Indicator organisms are bacteria such as coliforms, Escherichia coli and Pseuomonas Aeruginosa. Coliform bacteria include genera that originate in feces (e.g. Escherichia) as well as genera not of faecal origin e.g. Enterobacter, Klebsiella, Citrobacter. These bacteria are commonly found in the human or animal gut and which, if detected, may suggest the presence of faecal contamination; more specifically of E. coli which is an indicator microorganism for other pathogens that may be present in faeces. Faecal coliform bacteria can enter rivers through direct discharge of waste from mammals and birds, from agricultural and storm runoff, and from human sewage.

Generally, increased levels of faecal coliforms provide a warning of failure in water treatment, a break in the integrity of the distribution system, possible contamination with pathogens. When levels are high there may be an elevated risk of waterborne gastroenteritis**.** Some waterborne pathogenic diseases that may coincide with faecal coliform contamination include ear infection, dysentery, typhoid fever, diarrhoea, nausea, cholera, yellow fever and other water borne diseases. Bacteria reproduce rapidly if conditions are right for growth. Most bacteria grow best in dark, warm, moist environments with food. Some bacteria form colonies as they multiply which may grow large enough to be seen. By growing and counting colonies of faecal coliform bacteria from a sample of water, the amount of bacteria originally present can be determined.

# CHAPTER THREE

# MATERIALS AND METHODS

## 3.1 Field Study and Sample Collection

The study was conducted within Enugu metropolis during the rainy season, June 2015. Data used for this work was sourced from the study environment. New clean plastic bottles were used in collecting the samples. The samples collected were labeled for ease of identification with information such as date, time of sampling, study area and station number. This was written with a permanent maker and pasted on the container with a masking tape. Samples to be analyzed for Dissolved Oxygen and BOD were collected in special air tight 60ml BOD glass bottle to prevent loss or gain of oxygen. In other to prevent natural interference such as organic growth and unnecessary reactions, analyses of PH and Dissolved Oxygen were done immediately. The methods described by American Public Health Association, (1998) were adopted in the analysis unless otherwise stated. The water quality analysis was carried out at Enugu State Water Corporation Water Laboratory, Enugu. The World Health Organisation and Federal Ministry of Environment safety limit standards were used as control water quality standards. The samples were analysed using Histograms, Piper Charts and Stiff diagrams. The softwares used include Grapha-8 Microsoft Excel, Aqachem and Arc GIS 10.1

Water samples were collected at twelve locations, six samples for each of the rivers. The samples were analyse.d for their geochemical and bacteriological contents. These points ware designated $E_1$, $E_2$, $E_3$, $E_{4,}$ $E_5$, $E_6$ and $A_1$, $A_2$, $A_3$, $A_{4,}$ $A_5$, $A_6$ respectively for Ekulu and Asata Rivers ( Table 1). For River Ekulu, a control sample $E_1$ was collected from the river before the mine. $E_2$ is run off from Onyeama underground mine. Sample $E_3$ was collected from Iva Bridge, $E_{4,}$ was from Trans Ekuku brigde, $E_5$ was collected from Air Force Bridge along Abakpa and sample $E_6$ was collected from Emene bridge.

For Asata River, the control sample $A_1$, was collected at Udi / Ngwo, $A_2$ was taken from Akwata/Ogboete coal camp area, $A_3$ was taken at Asata river Agangwu (CIC Road). Sample $A_4$ was taken at Asata river O'Connor Street along Presidential Road Enugu. Sample $A_5$ was collected from Asata River Nwafor Orizu Asata Layout and $A_6$ at Asata River New Artisan Market Independence Layout. The sample locations and their coordinates are shown in the table (Table 2) and the drainage map (Fig 3.1) below.

## Table 2: Sample Locations and Coordinates

| Sample Points | Sample Location | Coordinate |
|---|---|---|
| E1 | Ekulu River at source in Ngwo before Onyama mine Ngwo, Udi L.G.A | $06^{o}$ $26^{'}$ $12^{''}$ N,<br>$007^{o}$ $27^{'}$ $57^{''}$ E |
| E2 | Ekulu River at Onyeama Mine, Ngwo, Udi L.G.A | $06^{o}$ $28^{'}$ $20^{''}$ N,<br>$007^{o}$ $26^{'}$ $47^{''}$ E |
| E3 | Ekulu River at Agu-Abor Bridge, G.R.A, Enugu East L.G.A | $06^{o}$ $28^{'}$ $02^{''}$ N,<br>$007^{o}$ $28^{'}$ $21^{''}$ E |
| E4 | Ekulu River at Trans-Ekulu, Trans-Ekulu Enugu East L.G.A | $06^{o}$ $28^{'}$ $08^{''}$ N,<br>$007^{o}$ $29^{'}$ $46^{''}$ E |
| E5 | Ekulu River at Air Force Bridge, Abakpa Nike, Enugu East L.G.A | $06^{o}$ $28^{'}$ $27^{''}$ N,<br>$007^{o}$ $30^{'}$ $47^{''}$ E |
| E6 | Ekulu River at Emene Bridge near Orie Emene Market, Enugu East L.G.A | $06^{o}$ $28^{'}$ $34^{''}$<br>N,$007^{o}$ $34^{'}$ $46.4^{''}$ E |
| A1 | Asata River at a Source in Ngwo Udi L.G.A | $06^{o}$ $26^{'}$ $12^{''}$ N,<br>$007^{o}$ $27^{'}$ $57^{''}$ E |
| A2 | Asata River at Akwata Bridge near Akwata Market Ogbete, Enugu North L.G.A | $06^{o}$ $26^{'}$ $11^{''}$ N,<br>$007^{o}$ $29^{'}$ $42^{''}$ E |
| A3 | Asata River at Zik Ave Bridge, Ogui Enugu North L.G.A | $06^{o}$ $26^{'}$ $11^{''}$ N,<br>$007^{o}$ $29^{'}$ $42^{''}$ E |
| A4 | Asata River at O' Connor St. Bridge, Asata Enugu North L.G.A | $06^{o}$ $26^{'}$ $34^{''}$ N,<br>$007^{o}$ $30^{'}$ $04^{''}$ E |
| A5 | Asata River at Bissalla Road, Opp. Golden Royale, Asata River Layout Enugu North L.G.A | $06^{o}$ $27^{'}$ $18^{''}$ N,<br>$007^{o}$ $30^{'}$ $47^{''}$ E |
| A6 | Asata River @ New Artesan Bridge, Enugu/Port Harcourt Express Way Independence Layout, Enugu North L.G.A | $06^{o}$ $27^{'}$ $17^{''}$ N,<br>$007^{o}$ $32^{'}$ $23.3^{''}$ E |

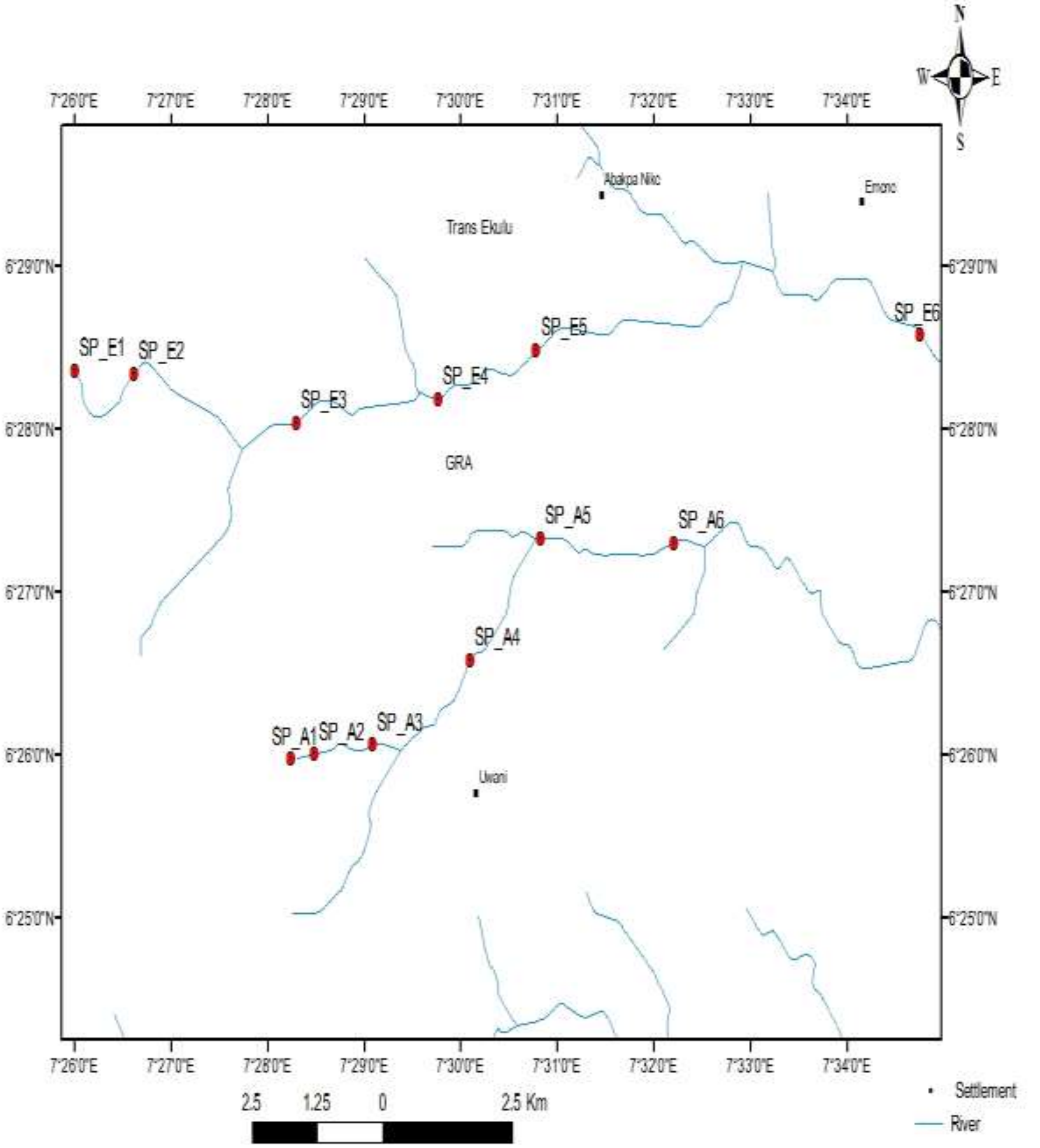


Fig 3.1 Drainage Map of the Study Area Showing Sample Points

Source: Geological Survey Enugu State

### 3.2 Laboratory Analysis of Water Samples

The laboratory analysis of the water samples were carried out at Enugu State Water Corporation Water Analysis Laboratory. The physical and chemical parameters used for the water quality assessments in the study include temperature, turbidity, colour, conductivity, pH, dissolved oxygen content (DOC), biochemical oxygen demand (BOD), chemical oxygen demand (COD), total dissolved solute (TDS), total suspended solids, total hardness, total alkalinity, nitrate, nitrite, ammonia, silicate, manganese, calcium, phosphate, sulphate and chloride.

**pH** concentrations of the water were determined in situ using a portable pH digital meter, HANNA 211 model. The electrodes were rinsed with distilled water. The instrument was standardized against a buffer solution with pH 4 and 7. The electrode (sensor) sends signal to the digital meter, the meter converts the signal to pH and dispays the result. pH measurements run on a scale from 0 to 14, with 7.0 considered neutral. Solutions with a pH below 7.0 are considered acids. Solutions with a pH above 7.0, up to 14.0 are considered bases. After each measurement, hydrochloric acid was added to neutralize alkaline solutions while sodium hydroxide was used for acidic solutions followed by rinsing with distilled water.

**Turbidity** was measured by the use of Hack Turbidimeter. The Turbidimeter measures the light scattered and absorbed by particles present in the water sample as light travels in a straight line through the water sample. It is measured in nepheloturbidimetric units (NTU). Turbidimeters have scattered-light detectors located at $90^o$ to the incident beam called nephelometers. For each range of NTU, calibration was done using silicon oil after which verification was done,

**Total dissolved solids (TDS)** was measured by gravimetric method. The two principal methods of measuring total dissolved solids are gravimetry and conductivity methods. The gravimetary method involves weighing the residue that remains after evaporation and drying the liquid solvent. **The Total Suspended Solids**, **TSS** was determined by filtering a well mixed sample through a weighted glass-fibre filter and the residue retained in the filter was dried to a constant weight at 103 to 110$^0$C. Increase in weight of the filter represents the total suspended solids

**Electrical conductivity** was determined by Electrical conductivity meter. **Dissolved Oxygen (DO)** was measured with DO meter. **Biochemical Oxygen Demand (BOD)** was determined following the procedure of American Public Health Association, (1998). The BOD test involves taking an initial dissolved oxygen (DO) reading and a second reading after five days of incubation at 20$^o$C. **Chemical Oxygen Demand COD** was determined titrimetrically using open reflux method according to American Public Health Association, (1998). This involves a two hour digestion at high heat under acidic conditions in which potassium dichromate acts as the oxidant for any organic material present in a water sample.

**Hardness** was determined using the Ethylene diaminetetra acetate (EDTA) titrimetric method. The apparatus include Burette, Graduated cylinder, Erlenmer Flask, Pipette. The buffer solution was prepared using HCI and distilled water. While shaking well and carefully the solution is titrated with standardized 0.0Im EDTA solution until the red colour changes to clear blue colour and the burette reading is recorded. The concentration of **Nitrate and Nitrite** in the study area was determined using the Phenoldisulporic acid method. **Chloride** analysis was carried out according to the methods of American Public Health Association, (1998) which involves silver nitrate ($AgNO_3$) titration with chromate indicator ($K_2CrO_4$).

## 3.3 Laboratory Measurement of Heavy Metals

Heavy metal analysis was conducted using Varian AA220 Atomic Absorption Spectrometer according to the method of American Public Health Association, (1998). Atomic absorption spectroscopy (AAS) is a spectroanalytical procedure for the quantitative determination of chemical elements using the absorption of optical radiation (light) by free atoms in the gaseous state. The electrons of the atoms in the atomizer can be promoted to higher orbital (excited state) for a short period of time (nanoseconds) by absorbing a defined quantity of energy (radiation of a given wavelength). This amount of energy, i.e., wavelength, is specific to a particular electron transition in a particular element.

Atomic absorption spectrometer working principle is based on the sample being aspirated into the flame and atomised when the AAS's light beam is directed through the flame into the monochromator, and unto the detector that measures the amount of light absorbed by the atomised element in the flame. Since the metals have their own characteristic absorption wavelength, a source lamp composed of that element is used, making the method relatively free from spectral or radiation interferences. The amount of energy at the characteristic wavelength absorbed in the flame is proportional to the concentration of the element in the sample over a limited concentration range.

## 3.4 Measurement of Bacteriological Parameters (Microbial Analysis)

There are two basic methods for analyzing water samples for bacteria; the membrane filtration method and the multiple-tube fermentation method. The material required for membrane filter coliform tests include filtration units, filter membrane, absorbent pads, forceps and culture dishes. The membrane filtration method was used for bacteriological analysis. In the membrane filteration method, samples to be tested are passed through a filter. 100 ml of a water sample is drawn through a membrane filter (0.45 µm pore size) through the use of a vacuum pump. The microorganisms present in the water remain on the filter surface. When the filter is placed in a sterile petri dish and saturated with an appropriate medium, incubating the plates at a specified temperature (44.5°C or 112.1$^0$F) for a specified time period (24 hours). This elevated temperature heat shocks non-faecal bacteria and suppresses their growth. Hence, growth of the desired organisms is encouraged, while that of other organisms is suppressed. Each cell develops into a separate colony, which can be counted directly, and the results calculated as microbial density. This method varies for different bacteria types (variations might include, for example, the nutrient medium type, the number and types of incubations, etc.).

Discrete bacterial colonies were isolated immediately after counting. The isolates were characterized by Indole Production Test. This test is important in the identification of enterobacteria. Most strains of *E. coli*, *P. vulgaris*, *P. rettegeri*, *M. morgani and Providenca* species break down the amino acid tryptophan with the release of indole. The test organism was inoculated in a bijou bottle containing 3 ml of sterile tryptone water and incubated at 35-37°C for up to 48 hours. Kovac's reagent (0.5 ml) was added to the test solution, shaken gently and examined for red colour at the surface layer within 10 minutes. The red surface layer indicates positive test while no red colour indicates negative test for *E. coli*

# CHAPTER FOUR

# RESULTS AND DISCUSSION

## 4.1 Results

Comprehensive results of measured parameters are shown in the tables below

### Table 3: Geochemical and Bacteriological Data for Ekulu River

| PARAMETERS | UNITS | SAMPLE RESULT FOR RIVER EKULU | | | | | | WHO STD | FMENV |
|---|---|---|---|---|---|---|---|---|---|
| | | E1 | E2 | E3 | E4 | E5 | E6 | | |
| Appearance | | Clear | Cloudy | Cloudy | Cloudy | Muddy | Muddy | | |
| Temperature | $^{o}$Celsius | 30 | 30 | 31 | 29 | 29 | 28 | 25 | 25 |
| Ph | | 5.5 | 4.5 | 5.6 | 5.5 | 5.9 | 6 | 6.5- 8.5 | 6.5 -8.5 |
| E. Conductivity | MicrohmS/cm | 10.4 | 58.4 | 57 | 90.4 | 108 | 122 | 1000 | 1000 |
| Total Solids | mg/l | 6.78 | 37.98 | 37.07 | 58.78 | 70.22 | 79.32 | 1000 | 1500 |
| Turbidity | NTU | 154 | 106 | 294 | 217 | 156 | 105 | 5 | 5 |
| T D S | mg/l | 6.76 | 37.96 | 37.05 | 58.76 | 70.2 | 79.3 | 500 | 500 |
| T S S | mg/l | 0.02 | 0.02 | 0.02 | 0.02 | 0.02 | 0.02 | | 0.25 |
| Total Hardness | mg/l$CaCO_3$ | 2 | 8 | 18 | 26 | 26 | 28 | 200 | 150 |
| Chlorides | mg/l | 167 | 120 | 84 | 91 | 118 | 133 | 200 | 250 |
| Sodium Chlorides | mg/l | 275.55 | 198 | 138.6 | 150.15 | 194.7 | 219.45 | 250 | |
| Sulphates | mg/l | 3.6 | 2.8 | 11.2 | 11.9 | 13.6 | 12.8 | 200 | 100 |
| Nitrate | mg/l | 1.2 | 3.8 | 1.8 | 4.9 | 3.6 | 2.3 | 50 | 50 |
| Nitrite | mg/l | BDL | 0.01 | BDL | 0.09 | 0.26 | 0.23 | 1.00 | 0.02 |
| DO | mg/l | 7.71 | 4.81 | 7.43 | 7.67 | 7.44 | 7.47 | 5 | 6 |
| Ammonia | mg/l | BDL | 0.44 | 0.5 | 0.3 | BDL | 0.4 | | 0.05 |
| Sodium | mg/l | BDL | BDL | 0.4 | 2.7 | 3.7 | 5.9 | 200 | 120 |
| Phosphate | mg/l | BDL | 0.02 | BDL | BDL | BDL | 0.03 | 10 | 3.5 |
| Potassium | mg/l | BDL | 0.9 | 1.3 | 1.8 | 2 | 3.2 | 50 | 50 |
| Manganese | mg/l | 0.014 | 0.079 | 0.016 | 0.007 | 0.026 | 0.022 | 0.5 | 0.5 |
| Iron | mg/l | 3.1 | 6.28 | 7.35 | 5.98 | 7.25 | 4.1 | 0.3-1.0 | 0.5 |
| Lead | mg/l | 0.01 | 0.016 | 0.015 | 0.016 | 0.031 | 0.013 | 0.05 | 0.01 |
| Arsenic | mg/l | 0 | 0 | 0 | 0 | 0 | 0 | 0.01 | 0.05 |
| Chromium | mg/l | 0 | 0 | 0.006 | 0 | 0.089 | 0 | 0.1 | 0.001 |
| Copper | mg/l | 0 | 0.02 | 0.032 | 0.005 | 0.003 | 0.032 | 1.00 | 0.5 |
| Cadmium | mg/l | 0 | 0.076 | 0 | 0.021 | 0.032 | 0.055 | 0.01 | 0.005 |
| Total Alkalinity | mg/l$CaCO_3$ | 2 | BDL | 13 | 38 | 22 | 26 | 100 | |
| Calcium Hardness | mg/l$CaCO_3$ | 2 | 7 | 16 | 23 | 26 | 25 | 200 | 180 |
| Magnesium Hardness | mg/l$CaCO_3$ | 0 | 1 | 2 | 3 | 3 | 3 | 1.00 | |
| Calcium Ion | mg/l | 0.8 | 2.8 | 6.4 | 9.2 | 9.2 | 9.6 | 50 | |
| Magnesium Ion | mg/l | 0 | 0.3 | 0.6 | 0.9 | 0.9 | 1.2 | 30 | 20 |
| Carbonate | mg/l | BDL | BDL | 0.003 | 0.001 | 0.001 | 0.001 | 500 | |
| Biocarbonate | mg/l | 2 | BDL | 13 | 38 | 22 | 26 | 500 | |
| BOD | mg/l | 3 | 1.2 | 1.8 | 1.6 | 1.8 | 1.4 | 5 | 3 |
| COD | mg/l | 30 | 5 | 10 | 12 | 10 | 12 | | 30 |
| Total Coliform | Per 100ml | 30 | 160 | 180 | 160 | 180 | 180 | 3 | 10 |
| E.coli | Per100ml | -Ve | +Ve | +Ve | +Ve | +Ve | +Ve | 0 | 0 |

## Table 4: Geochemical and Bacteriological Data for River Asata

| PARAMETERS | UNITS | SAMPLE RESULT FOR RIVER ASATA | | | | | | WHO STD | FMENV |
|---|---|---|---|---|---|---|---|---|---|
| | | A1 | A2 | A3 | A4 | A5 | A6 | | |
| Appearance | | Clear | Muddy | Cloudy | Cloudy | Clear | Cloudy | | |
| Temperature | $^{o}$Celsius | 29 | 27 | 27 | 28 | 29 | 29 | 25 | 25 |
| Ph | | 7 | 5.8 | 6.4 | 6.4 | 6.5 | 6.5 | 6.5 -8.5 | 6.5 -8.5 |
| E. Conductivity | MicrohmS/cm | 36.5 | 330 | 413 | 435 | 333 | 292 | 1000 | 1000 |
| Total Solids | mg/l | 23.75 | 214.52 | 268.48 | 282.78 | 216.47 | 189.82 | 1000 | 1500 |
| Turbidity | NTU | 29.9 | 40 | 40.1 | 23.9 | 7.88 | 20.1 | 5 | 5 |
| TDS | mg/l | 23.73 | 214.5 | 268.45 | 282.75 | 216.45 | 189.8 | 500 | 500 |
| TSS | mg/l | 0.02 | 0.02 | 0.03 | 0.03 | 0.02 | 0.02 | | 0.25 |
| T. Hardness | mg/l$CaCO_3$ | 20 | 76 | 88 | 70 | 66 | 68 | 200 | 150 |
| Chlorides | mg/l | 150 | 202 | 243 | 245 | 195 | 191 | 200 | 250 |
| Sodium Chlorides | mg/l | 247.5 | 333.3 | 400.95 | 404.25 | 321.75 | 315.15 | 250 | |
| Sulphates | mg/l | 7.78 | 68 | 28.7 | 28.4 | 18.7 | 13.3 | 200 | 100 |
| Nitrate | mg/l | BDL | 8.9 | 20.3 | 24.9 | 25.6 | 25.9 | 50 | 50 |
| Nitrite | mg/l | BDL | 0.21 | 1.18 | 2.28 | 1.69 | 4.53 | 1.00 | 0.02 |
| Dissolved oxygen | mg/l | 7.81 | 6.73 | 5.93 | 7.44 | 6.53 | 7.11 | 5 | 6 |
| Ammonia | mg/l | 0.47 | 3.19 | 4.42 | 4.87 | 0.29 | 0.28 | | 0.05 |
| Sodium | mg/l | BDL | 19 | 26 | 30 | 23 | 20 | 200 | 120 |
| Phosphate | mg/l | 0.02 | 0.1 | 0.09 | 0.1 | 0.1 | 0.09 | 10 | 3.5 |
| Potassium | mg/l | 0.8 | 9.8 | 9 | 12 | 9 | 7.3 | 50 | 50 |
| Manganese | mg/l | 0.021 | 0.009 | 0.007 | 0.006 | 0 | 0 | 0.5 | 0.5 |
| Iron | mg/l | 1.97 | 2.58 | 2.1 | 1.55 | 1.09 | 1.18 | 0.3-1.0 | 0.5 |
| Lead | mg/l | 0.014 | 0.013 | 0.024 | 0.024 | 0 | 0.047 | 0.05 | 0.01 |
| Arsenic | mg/l | 0 | 0 | 0 | 0 | 0 | 0 | 0.01 | 0.05 |
| Chromium | mg/l | 0 | 0.429 | 0.254 | 0.384 | 0.199 | 0.212 | 0.1 | 0.001 |
| Copper | mg/l | 0.01 | 0.009 | 0.022 | 0.005 | 0.004 | 0 | 1.00 | 0.5 |
| Cadmium | mg/l | 0 | 0.078 | 0.034 | 0.011 | 0.045 | 0.034 | 0.01 | 0.005 |
| Total Alkalinity | mg/l$CaCO_3$ | 2 | 24 | 72 | 82 | 80 | 58 | 100 | |
| Calcium Hardness | mg/l$CaCO_3$ | 17 | 70 | 81 | 65 | 61 | 62 | 200 | 180 |
| Mg Hardness | mg/l $CaCO_3$ | 2 | 6 | 7 | 5 | 4 | 6 | 1 | |
| Calcium Ion | mg/l | 6.8 | 28 | 32.4 | 26 | 24.4 | 24.8 | 50 | |
| Magnesium Ion | mg/l | 0.6 | 1.8 | 2.1 | 1.5 | 1.2 | 1.8 | 30 | 20 |
| Carbonate | mg/l | 0.001 | 0.001 | 0.01 | 0.011 | 0.013 | 0.01 | 500 | |
| Biocarbonate | mg/l | 2 | 24 | 72 | 82 | 80 | 58 | 500 | |
| BOD | mg/l | 0.6 | 4.5 | 5.8 | 4.8 | 2.6 | 1.4 | 5 | 3 |
| COD | mg/l | 1 | 18 | 20 | 22 | 12 | 8 | | 30 |
| Total Coliform | Per 100ml | 20 | 30 | 160 | 180 | 180 | 180 | 3 | 10 |
| E.coli | Per100ml | -Ve | -Ve | +Ve | +Ve | +Ve | +Ve | 0 | 0 |

## 4.2 Discussion

Twelve sample points were identified; six points each for River Ekulu and Asata. The samples were analysed in terms of their geochemical and bacteriological parameters (Table 3 and 4). The water appears cloudy and muddy at most of the locations except for A1 (River Asata at source) which was colourless. The Cloudy appearance is reflected in the increasing turbidity values recorded in the study area. Temperature values range between 27$^{o}$C and 31$^{o}$C with highest temperature value recorded at Ekulu River Agu-Abor Bridge (31$^{o}$C).

The result shows that surface water samples taken from River Ekulu and Asata recorded pH values ranging from 4.5 to 7.0. The pH of the water samples taken from River Ekulu ranges from 4.5 to 6.0. These values fall below permissible limits with gradual tendencies towards acidity. A pH value of 4.50 was recorded at E2-Onyeama coal mine. This is a clear indication that the water has strong acidic content and therefore cannot be considered for consumption. The Onyeama abandoned coal mine, agricultural activities, block industry, car wash, hotels and other activities around Ekulu contributes to the pollution of River Ekulu. A pH of 5.8 was recorded at Akwata bridge Asata River. Akwata bridge is very close to Ogboete Market; waste generated from commercial activities, car parks and other activities are dumped at the river bank. Generally, Ekulu River has more acidic content than Asata River, this can be attributed to the presence of Iron Sulphide (Pyrite) associated with coal deposits.

The surface water turbidity of the study area was within 7.8NTU to 294NTU with highest values recorded around River Ekulu indicating a high level of physical disturbance. River Ekulu recorded extremely high turbidity values (105-294NTU) compared to River Asata (7.88-40.1NTU). These values exceed the 5NTU recommended limit by WHO and FMEN. The values recorded at

River Asata are quite minimal but above recommended limits too. This indicates a high extent of pollution in line with the cloudy appearance of the river. River Ekulu at Agu Abor Bridge (E2) had the highest turbidity value of 294 NTU. This is evident from series of house construction activities, block industries and other human activities going on very close to the river in this environment. The water from the river is being utilized for this purpose (See Appendix 1). River Asata has relatively low turbidity when compared to River Ekulu.

Records of River Asata reveal higher Electrical conductivities, Total Dissolved Solids and Total Solids values than those of River Ekulu. The electrical conductivity values measured in the study area ranges from 10.4 to 435.0µS/cm, TDS values between 6.76mg/l to 282.75mg/l, and total solids between 6.78mg/l to 282.78mg/l. Generally, the values obtained from all locations are within WHO and FMENV permissible limit indicating low level of pollution by dissolved contaminants. Dissolved oxygen level in the surface water of the study area was found to have concentration ranging from of 4.81 to 7.81mg/l, with highest values around Asata Rivers. The DO levels in both rivers are high enough to support aquatic life with concentrations above 5.0 mg/l except that of River Asata at Akwata/ Ogbete area which is below 5.0g/ml. The Biochemical Oxygen Demand (BOD) of the sampled Ekulu and Asata River ranges from 0.30 to 5.8mg/l with highest concentration around Asata River at Zik Avenue Bridge, Ogui. The BOD level in all the locations was lower than the WHO standard value of 5.0mg/l except for A3 – Asata River at Zik Avenue Bridge (5.8mg/l). This can be attributed to the presence of a waste dump at this location. High BOD is an indication of significant bacteriological activity on the river.

The values of hardness for the two rivers ranges from 2 to 88 mg/l, with the highest values occurring around River Asata. This is evident from higher concentrations of Calcium (17-81mg/l) and Magnesium (2-7mg/l) in River Asata than River Ekulu (Calcium 2-26mg/l; Magnesium 0-3mg/l). The results are tolerable for Calcium (WHO limit of 200mg/l and FMENV limit of 180mg/L) and beyond limit for Magnesium WHO permissible limit of 1mg/l. Total hardness for the two rivers are within limits, the result shows that the River Ekulu is soft while River Asata is moderately hard.

Salinity level observed in the study samples ranged from 138.00mg/l to 404.25mg/l with the highest concentration around River Asata. High Sodium Chloride content in water may be as a result of the fact that Sodium Chloride constitutes the bulk of amount of wastes deposited in the river by households. Also, River Asata has highest concentrations of Calcium (81mg/l), Magnesium (7mg/l) and Carbonate (80mg/l) than River Ekulu (26mg/l, 3.0mg/l, 0.003mg/l respectively), though all the values are within permissible limits. The presence of a considerable content of Calcium, Magnesium and Carbonate increases the pH value of water, and raises the alkalinity as seen in River Asata.

The recorded value for Phosphate in the study area ranges from (0.0 -0.09mg/l), Ammonia (0.29 - 4.87mg/l), Nitrate (1.2 - 25.90mg/l) and Nitrite (0.0 - 4.53mg/l). The concentrations of these parameters are higher in River Asata when compared to River Ekulu. The values fall within the set limits by World Health Organization (WHO) drinking water standard except for Ammonia and Nitrite. The value for Ammonia at River Asata ranges from 0.28mg/l to 4.87mg/l which is above the set limit of 0.05mg/l by FMENV. This concentration was highest (4.87mg/l) at A4 (O’Connor Bridge Asata). This could be due to the activities of a nearby car, agricultural activities taking place along the river bed, and other uses such as bathing and washing in the river. Highest concentration of Nitrite was at Asata River New Artisan Bridge. This can be attributed to the waste materials generated from a piggery farm located close to the river at this point. Generally, Phosphate, Ammonia and Nitrate in surface waters may result from discharge of domestic, industrial and agricultural runoff that contains excess Phosphate, Ammonia and Nitrates introduced into the soil as fertilizers.

The heavy metals analysed include Lead, Iron, Copper, Chromium, Manganese Arsenic and Cadmium. Some of the Heavy Metals had very low concentrations as some of them were below detection limits at almost negligible concentrations. Iron, Chromium and Cadmium are shown to be of significant concentrations, and above the set limit. The concentration of Iron (3.1-7.35mg/l) and Manganese (0.07- 0.079mg/l) in River Ekulu was higher than that of River Asata (1.09-2.58) and (0.00-0.021) respectively. These figures are within limits for Manganese (0.5mg/l) but far above WHO limit of 0.3mg/l and FMENV 0.5mg/l for Iron. The highest concentration of Manganese (0.079mg/l) was recorded at E2 (Onyeama Mine). High Iron and Manganese concentrations are associated with acidic water as shown by high acidic content of Ekulu River. The Onyeama abandoned coal mine and other activities around River Ekulu accounts for very high concentration of Iron recorded within the area evident from high concentration of Iron (6.28mg/l) recorded at location E2; the Onyama Coal Mine. Sample taken at all twelve sample locations exceed the WHO standard of 0.3mg/l and FMENR 0.5 standards for Iron, though Asata River had lower values compared to Ekulu River.

The sampled water in the study area shows that Lead concentrations ranges from 0.010 to 0.047 mg/l with the highest concentration around Asata River. This range is below WHO Standard of 0.05mg/l indicating that the communities around the study area do not have any threat of Lead toxicity. The concentration of copper within the study area ranges from 0.00 to 0.032, with the highest values around River Ekulu . Copper concentration within the study area fall within WHO and FMENV standards of 1.00 and 0.5 respectively. Arsenic was completely not detected in any of the locations; therefore there is no threat of Arsenic toxicity in the area.

The concentrations of Chromium in the study area was quite alarming, above the set limit of 0.01mg/l. Seven points out of the twelve sample points had high concentrations of Chromium ranging from 0.06 to 0.429mg/l with highest concentrations at River Asata. Chromium is a naturally occurring heavy metal that is commonly used in industrial processes and can cause severe health effects in humans. Although it can be released through natural forces, the majority of the environmental releases of chromium are from industrial sources.

Total Coliform values rank above comparing standards. From the table, the Total Coliform count in the study area ranges from 20 to 180mg/l with River Ekulu accounting for the highest concentrations. Also, the presence of E-Coli at most of the locations indicates faecal pollution. The values show high level of human activities that result in faecal pollution of the surface water bodies. The concentration of coliform bacteria was observed in all the sampling locations with River Ekulu being seriously faecally polluted. This is not surprising as the neighbourhood where the river runs through is highly populated when compared to Asata neighbourhood. E3 - Agu-Abor Bridge, E5-Air Force Bridge Abakpa Nike and Emene Bridge (near Orie Emene Market) had the highest records and these are all high population density areas, majorly lower to medium class. The presence of coliform bacteria in water usually indicates that the water is unsuitable for drinking. Microbes in water can cause water-borne diseases such as dysentery, cholera, and typhoid fever if the water is consumed untreated. However, water at Ngwo source has the lowest concentration of Total Coliform. It also shows that settlement receiving supply from the aforementioned will be potable.

The table below shows a comparative assessment of the average concentrations of each parameter as analysed for each river.

**Table 5: Comparative Assessment of the Average Concentrations of each Parameter in River Ekulu and Asata**

| | | EKULU | ASATA | | |
|---|---|---|---|---|---|
| **PARAMETERS** | **UNIT** | **AVERAGE VALUE** | **AVRRAGE VALUE** | **WHO STANDARD** | **FMENV STANDARD** |
| Temperature | $^{o}$Celsius | 29.5 | 28.16 | $^{o}$Celsius | $^{o}$Celsius |
| Ph | | 5.5 | 6.43 | 06.50 -08.50 | 6.50 -8.50 |
| Electrical Conductivity | Microhms/m | 74,34 | 306.58 | 1000 | 1000 |
| Total Solids | mg/l | 48.36 | 199.3 | 1000 | 1500 |
| Turbidity | NTU | 172 | 26.98 | 5 | 5 |
| Total Dissolved Solids | mg/l | 48.34 | 199.28 | 500 | 500 |
| Total Hardness | mg/l$CaCO_3$ | 18 | 64.67 | 100 -200 | 150 |
| Chlorides | mg/l | 118.83 | 204.33 | 200 | 250 |
| Sodium Chlorides | mg/l | 196.08 | 337.15 | | |
| Sulphates | mg/l | 9.32 | 27.48 | 200 | 100 |
| Nitrate | mg/l | 2,93 | 21.12 | 50 | 50 |
| Nitrite | mg/l | 0.15 | 1.978 | 1 | 0.02 |
| Dissolved oxygen | mg/l | 7.07 | 6.93 | 5 | 6 |
| Ammonia | mg/l | 0.41 | 2.25 | | 0.05 |
| Sodium | mg/l | 3.18 | 23.6 | 500 | 120 |
| Phosphate | mg/l | 0.025 | 0.083 | 10 | 3.5 |
| Potassium | mg/l | 2.3 | 7.98 | 50 | |
| Manganese | mg/l | 0.027 | 0.011 | 0.5 | 0.5 |
| Iiron | mg/l | 5.68 | 1.745 | 0.3 – 1.0 | 0.5 |
| Lead | mg/l | 0.017 | 0.024 | 0.05 | 0.01 |
| Arsenic | mg/l | 0 | 0 | 0.01 | 0.05 |
| Hexavalent Chromium | mg/l | 0.02 | 0.296 | 0.1 | 0.001 |
| Copper | mg/l | 0.018 | 0.01 | 0.05 | 0.001 |
| Cadmium | mg/l | 0.037 | 0.040 | | 0.05 |
| Total Alkalinity | mg/l$CaCO_3$ | 20.2 | 53 | 100 | |
| Calcium Hardness | mg/l$CaCO_3$ | 16.5 | 59.33 | 200 | 180 |
| Magnesium Hardness | mg/l $CaCO_3$ | 2.4 | 5 | 1 | |
| Calcium Ion | mg/l | 6.33 | 23.73 | 50 | |
| Magnesium Ion | mg/l | 0.78 | 1.5 | 30 | 20 |
| Carbonate | mg/l | 0.0015 | 0.0077 | | |
| Bicarbonate | mg/l | 20.2 | 53 | 500mg/l | |
| BOD | mg/l | 1.8 | 3.28 | | 3 |
| COD | mg/l | 13.17 | 13.5 | | 30 |
| Total Coliform | Per 100ml | 148.3 | 125 | 3 | 10 |

### 4.2.1 Statistical Analysis of Geochemical and Bacteriological Parameters Using Histogram Diagram

The histogram as represented in the diagram shows the concentration distributions of geochemical parameters within various locations around River Ekulu and Asata. Measured values of water samples collected around both rivers recorded high salinity concentration as represented in figures below. This validates the Piper Classification below which places them at Calcium Chloride Type. Other parameters that show high concentrations include TDS, Total Hardness and Total Coliform.

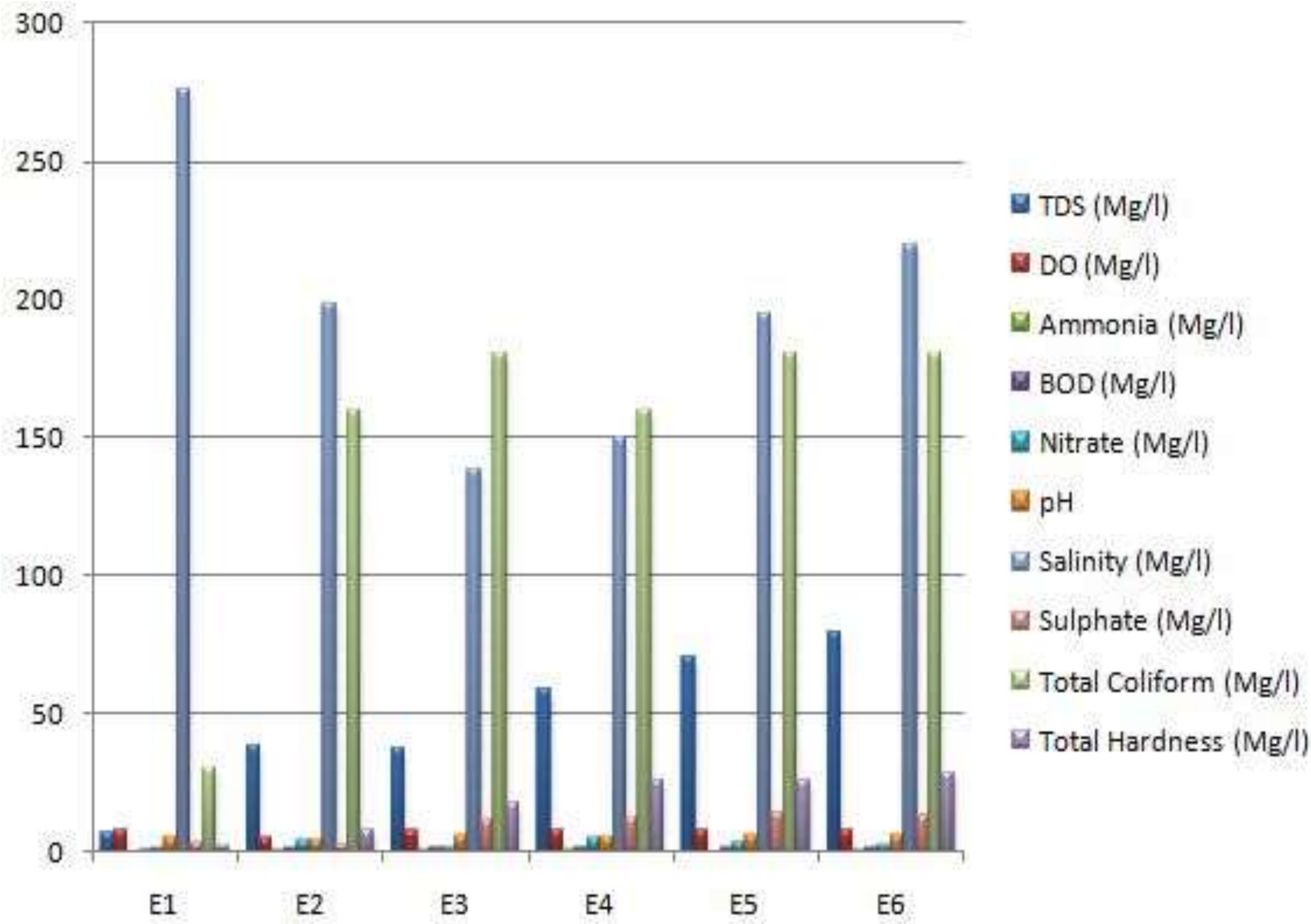


Figure 4.1: Histogram of Geochemical Constituents of River Ekulu

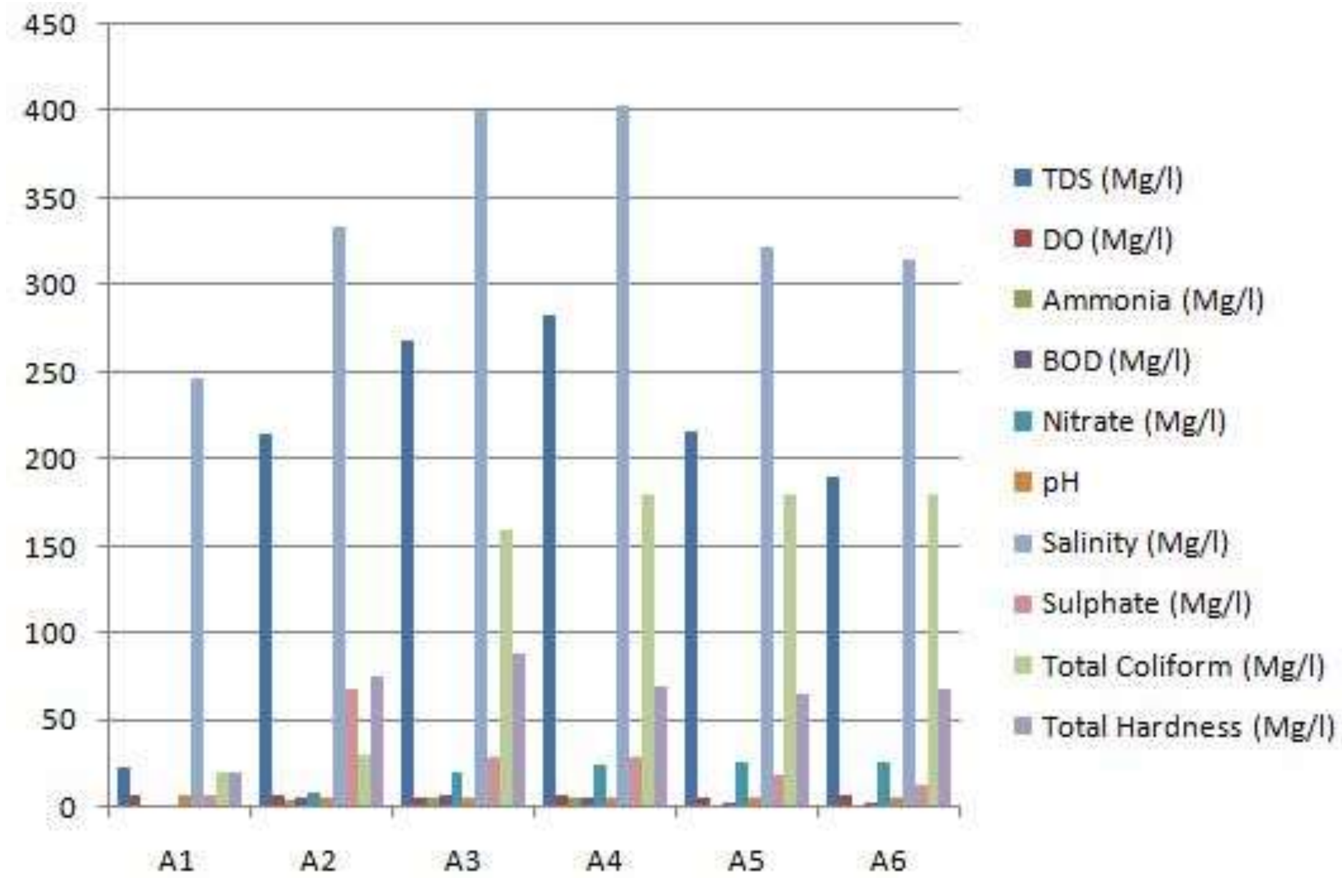


**Figure 4.2: Histogram of Geochemical Constituents of Rivers Asata**

### 4.2.2 Statistical Analysis of Heavy Metals Concentration within the Study Areas using Histogram

The histogram for the heavy metals concentration within both rivers shows the distribution of the heavy metals. The heavy metals analysed include Lead, Iron, Copper, Chromium, Manganese and Arsenic. Iron and Chromium are shown to be of significant concentrations. Highest concentrations of Iron (7.35mg/l) was recorded at Ekulu River while highest concentration of Hexavalent Chromium (0.429mg/l) was recorded at Asata River as shown in the histogram. Hexavalent Chromium value of 0.429mg/l is far above the FMENV limit of 0.001mg/l, and Iron concentration of 7.35mg/l exceedingly high when compared with WHO and FMENV standards of 1mg/l and 0.5mg/l respectively. Also, high level of Cadmium (0.078mg/l) was recorded at Akwata bridge Asata

River above WHO standard of 0.01mg/l. The rest of the Heavy Metals recorded low concentrations as some of them were below detection limits. Arsenic was not detected in any of the locations.

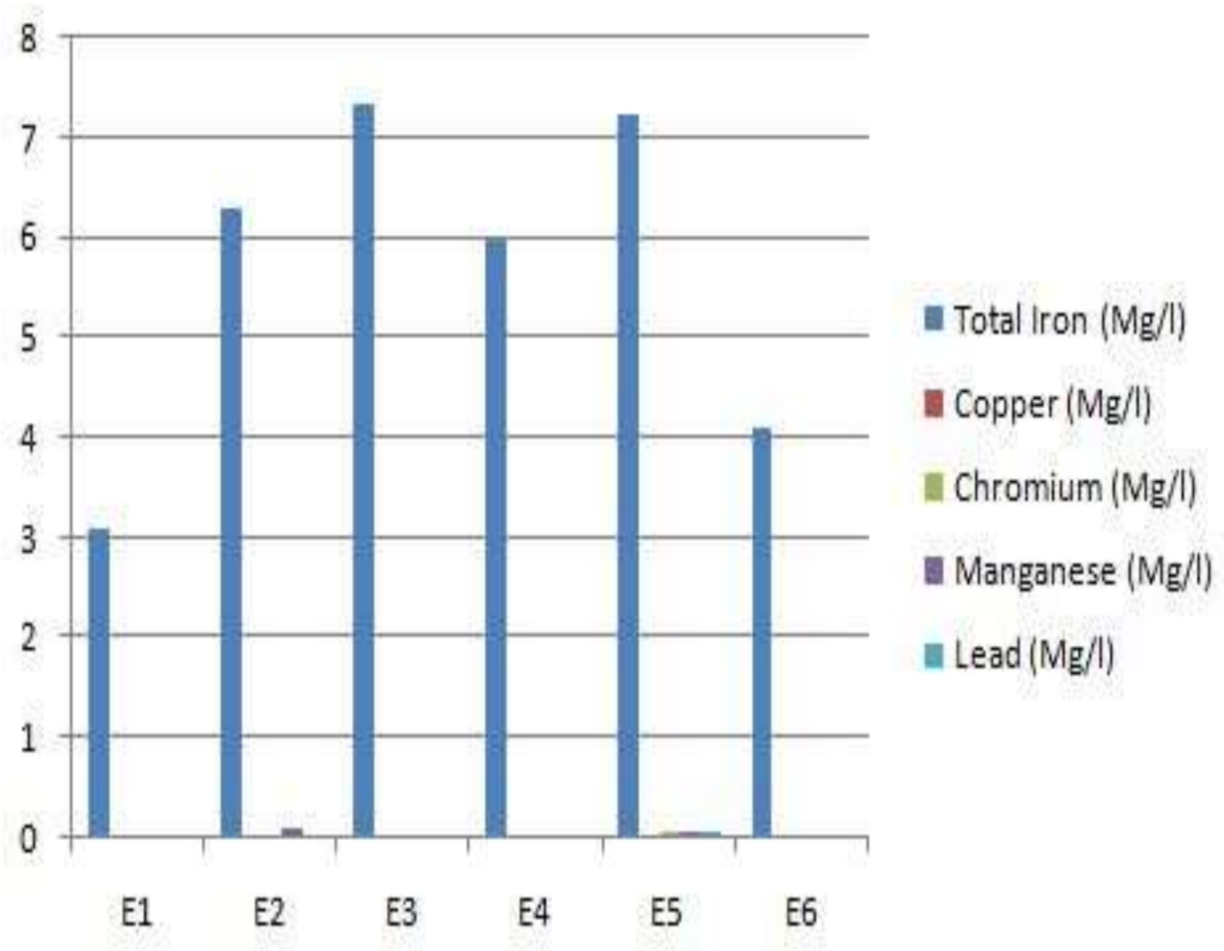


**Figure 4.3: Histogram for Heavy Metal Concentration within Rivers Ekulu**

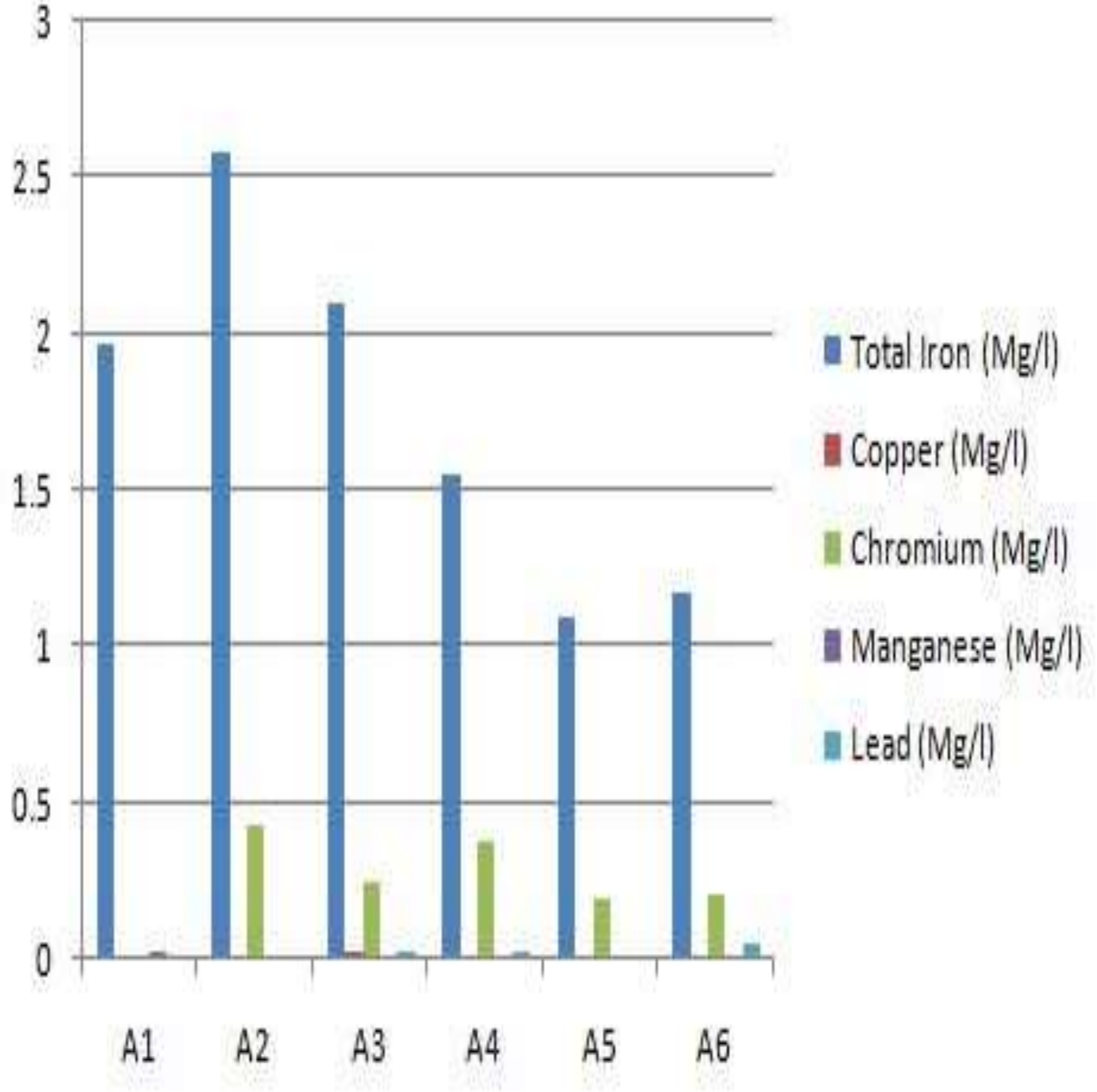


**Figure 4.4: Histogram for Heavy Metal Concentration within Rivers Asata**

### 4.2.3 Analysis of Piper Diagram for Ekulu and Asata Rivers

A piper diagram is a graphical representation of the chemisty of a water sample or samples. The Piper diagram is used to infer hydro-geochemical facies (Piper, 1948). Facies are recognizable parts of different characters belonging to any genetically related system. Hydrochemical facies are distinct zones that possess cation and anion concentration categories.

The piper plots include two triangles, one for plotting cations and the other for plotting anions. The cations and anion fields are combined to show a single point in a diamond-shaped field, from which inference is drawn on the basis of hydro-geochemical facies concept. These tri-linear diagrams are useful in bringing out chemical relationships among water samples in more definite terms rather than with other possible plotting methods. Water types are designed according to the domain in which they occur on the diagram segments (Sadashivaiah et al 2008).

The relative ionic composition of the surface water samples in the study area in milli-equivalent per litre (meq/l) were calculated and employed in plotting the piper trilinear diagram in which the ions in milli-equivalent per litre are expressed in percentages of total cations and anions as shown in the figures below

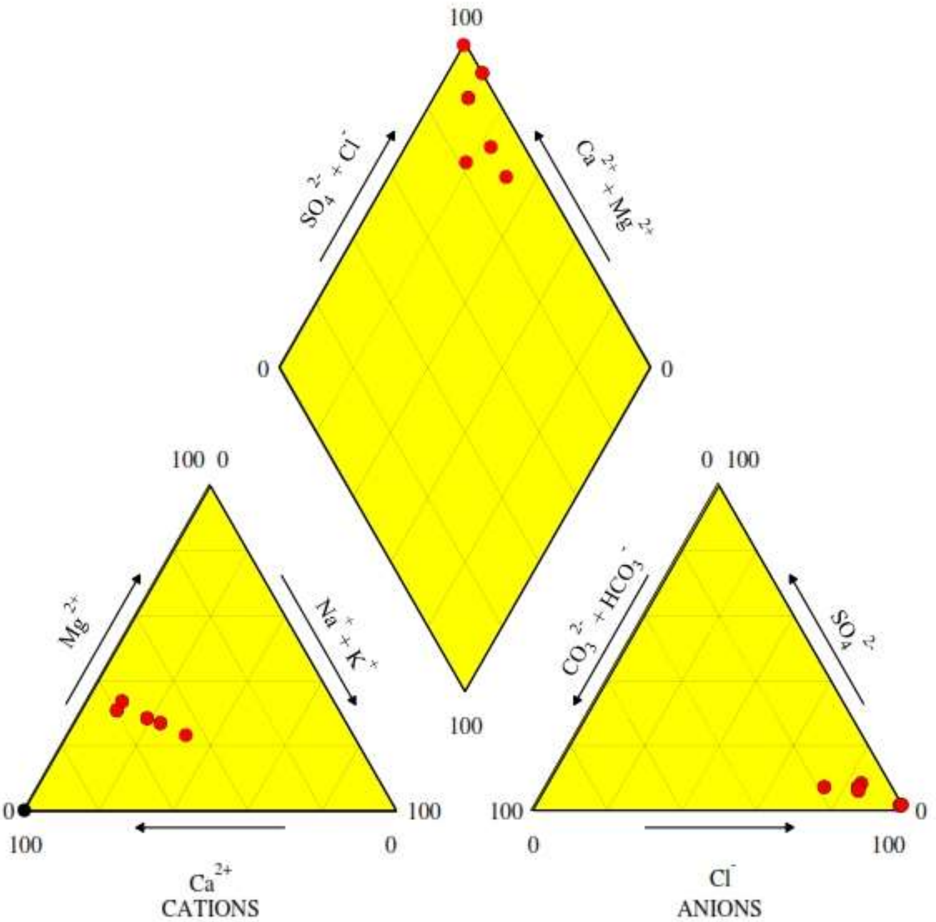


**Figure 4.5: Piper Diagram for River Ekulu**

The ternary plot at the left hand side indicates that the water samples are rich in calcium ions while the right ternary plot indicates richness of water samples in Chloride ions. River Ekulu has concentration points for cations falling within Calcium type (50%), while the anions fall within the Chloride (85%) type. The corresponding sub divisions of surface water can be classified as Calcium Chloride Type, meaning that the samples are high in $Ca^{2+}$ + $Mg^{2+}$ and $Cl^-$ + $SO_4^{2-}$.

River Asata has concentration points for cations falling within Calcium type (85%), while the anions fall within the Chloride (90%) type. The corresponding sub divisions of the surface water can be classified as Mixed Type.

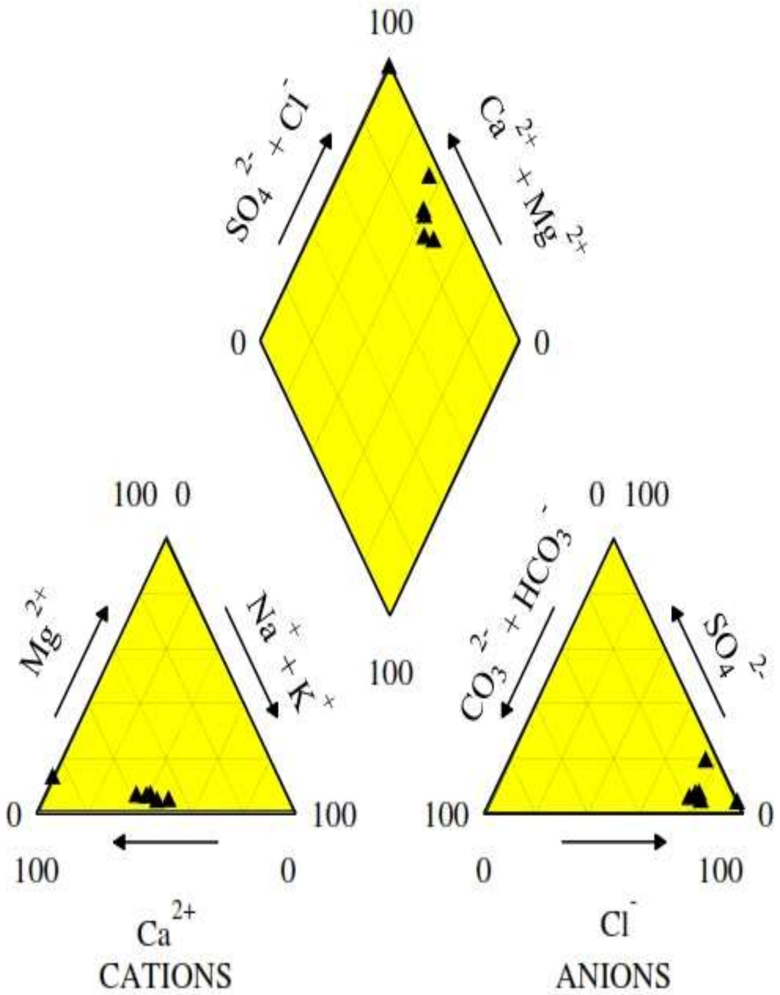


**Figure 4.6: Piper diagram for River Asata**

### 4.2.4 Analysis of Stiff Diagram for Ekulu and Asata Rivers

Stiff diagrams are graphical representation of water chemical analysis, first developed by H.A. Stiff in 1951. It is used to making a rapid visual comparison between water from different sources. Cations are plotted in milliequivalents per litre on the left side of the zero axis, one to each horizontal axis, and anions are plotted on the right side. The stiff diagram shows dominance of iron and

Calcium cations in the water samples of Ekulu river. Therefore the chemical species are present thus, Fe>$Ca^{2+}$>$Mg^{3+}$>Na+K.

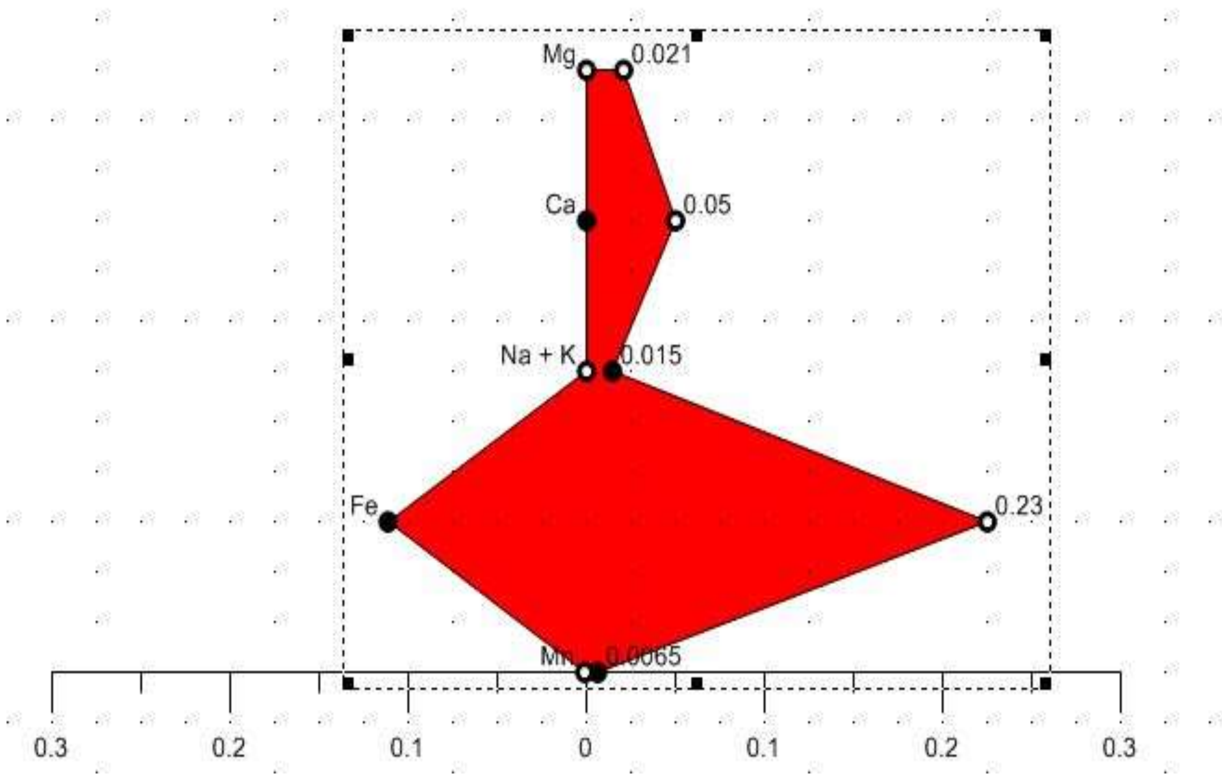


**Fig 4.7: Stiff diagram for River Ekulu**

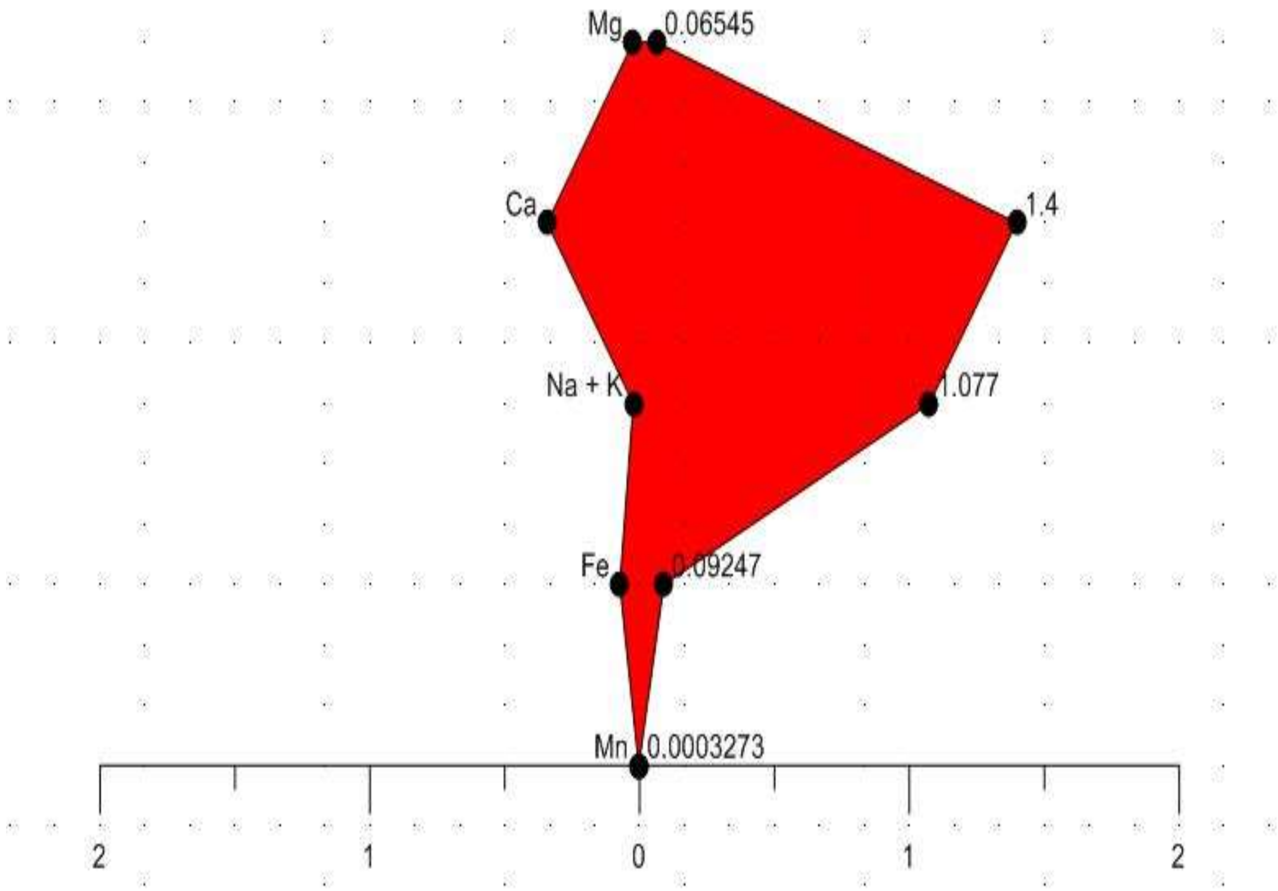


**Fig 4.8: Stiff diagram for River Asata**

The stiff diagram for River Asata shows dominance of Calcium cations and Na+K ions in the water samples. Therefore the chemical species are present thus, $Ca^{2+}$>Na+K> $Fe^{2+}$> $Mg^{3+}$. This result conforms to that of piper plot for the river with dominance of calcium ion.

### 4.3 Assessment of Sodium Adsorption Ratio (SAR)

Sodium-adsorption ratio (SAR) describes the tendency for sodium cations to be adsorbed at cation-exchange sites in soil at the expense of other cations, calculated as the ratio of sodium to calcium and magnesium in the soil. SAR is used to assess the relative concentrations of sodium, calcium, and magnesium in irrigation water and provide a useful indicator of its potential damaging effects on soil structure and permeability.

Plants are detrimentally affected both physically and chemically by excess salts in some soils and by high levels of exchangeable sodium in others. A saline soil contains excess soluble salts that reduce the growth of most plants. These soluble salts contain cations such as sodium ($Na^{+}$), potassium ($K^{+}$), calcium ($Ca^{2+}$) and magnesium ($Mg^{2+}$) along with anions chloride ($Cl^{-}$), sulfate ($SO_4^{2-}$), nitrate ($NO_3^{-}$), bicarbonate ($HCO_3^{-}$) and carbonate ($CO_3^{2-}$). Salinity may be as a result of land use, saltwater intrusion, and saline industrial waters. Accumulation of salts can result in sodic soil conditions. When SAR is greater than 15, the soil is called a sodic soil. Soil sodicity is caused by high sodium levels in soils at concentrations greater than 15 percent of the cation exchange capacity. Sodic soils tend to have poor structure with unfavourable physical properties such as poor water infiltration and air exchange, which can reduce plant growth (Munshower, 1994). Excess sodium in sodic soils causes soil particles to repel each other, preventing the formation of soil aggregates. This results in a very tight soil structure with poor water infiltration, poor aeration and surface crusting, which makes tillage difficult and restricts seedling emergence and root growth (Munshower, 1994, Seelig, 2000; Horneck *et al*. 2007).

High salt levels hinder water absorption, inducing physiological drought in the plant. The soil may contain adequate water, but plant roots are unable to absorb the water due to unfavourable osmotic pressure. This is referred to as the osmotic or water-deficit effect of salinity. The second effect of salinity is shown when excessive amounts of salt enter the plant in the transpiration stream and injure leaf cells, which further reduces growth. This is called the salt-specific or ion-excess effect of salinity (Greenway and Munns, 1980).

Sodium Adsorption Ratio (SAR) equation and classification was developed by the United States Department of Agriculture (USDA, 1965) and stated thus;

$$\mathbf{SAR} = \frac{\mathbf{Na^{+}}}{\sqrt{\frac{(\mathbf{Ca^{2+}} + \mathbf{Mg^{2+}})}{\mathbf{2}}}}$$

The concentrations of $Na^{+}$, $Ca^{2+}$ and $Mg^{2+}$ are calculated in milliequivalent per litre (Meq/l). The table below shows the classification water based on SAR by USDA 1965

**Table 6: Classification of Water Based on SAR**

| SAR Range | Water Class |
|---|---|
| 0-10 | Excellent |
| 10-18 | Good |
| 18-26 | Fair |
| >26 | Poor |

Sodium is commonly used to determine the stability of water for agricultural purpose because its reaction with soil reduces permeability. According to Lamond and Whitney (1992) water containing SAR values from 0–10 can be applicable on all agricultural soils, while water having SAR range of 18 – 26 may produce harmful effect. SAR range of 26 – 100 is unsuitable for irrigation purposes

The sodium adsorption ratio concentrations for Asata and Ekulu Rivers were obtained as 1.1887meq/l and 0.2956meq/l respectively. From the Table above (Table 6), the SAR values obtained falls within the range of 0-10 known as excellent. This therefore implies that both surface waters in the study area are applicable to all soil types in terms of agriculture and equally excellent for irrigation purposes.

# CHAPTER FIVE

# CONCLUSION AND RECOMMENDATION

## 5.1 Conclusion

The need to continuously study the quality of water from rivers that pass through urban areas is very necessary because of the importance of such rivers to the health and general development of the urban areas.

The study reveals the degree of pollution of the two rivers by each of the geochemical and bacteriological parameters analysed as compared to the standards set by World Health Organisation and Federal Ministry of Environments. The concentrations of some of the analysed parameters fall within the set standards including the heavy metals. Records of River Asata shows higher electrical conductivities, Total Dissolved Solids, Dissolved Oxygen, Calcium, Magnesium, salinity and total hardness than those of River Ekulu. Concentrations of Iron and Manganese were higher at River Ekulu which is evident in the high acidity level recorded in the River. River Ekulu is classified as the Calcium Chloride Type and River Asata as Mixed Water type by Piper Classification.

Deductions from the study indicates that River Ekulu is generally unsuitable for domestic use due to high acidic content (pH 4.5), high turbidity value (180NTU) and high level of faecal pollution in excess of the set standards. Ekulu River has more acidic content than Asata River, this can be attributed to the presence of Iron Sulphide (Pyrite) usually associated with coal deposits.

The most polluted spot around River Ekulu is at E3; Agu-Abor bridge with most of the parameters ranking high including turbidity, temperature, acidity and coliform index. The most polluted spot around River Asata is at A2; Akwta Bridge with high record of acidity, heavy metals, lowest concentration of dissolved oxygen etc. The best spot within the study area is A1; River Asata at source with neutral pH, colourless and low coliform index. Asata River at source is clear water that requires little treatment which is being utilized by a Pharmaceutical Water Bottling Company located close to the river for their production (See Appendix 2).

The pollution of Ekulu and Asata Rivers in this study is partly attributed to negative human impact on the environment. Urban agriculture, waste dumps, construction, commercial and industrial activities as important as they are produce and inject contaminants into the rivers. The study showed that the surface water in the two rivers have elements of high human activities that results in pollution of the surface water bodies. Therefore, appropriate water treatment measures are required to upgrade the quality of both rivers to domestic, recreational and industrial standards. However, the SAR analysis shows that both surface waters in the study area are applicable to all soil types in terms of agriculture and equally excellent for irrigation purposes.

## 5.2 Recommendations

i. Appropriate water treatment measures are required to upgrade the water quality to domestic, recreational and industrial standards.

ii. Automobile workshops and huge waste dump along the rivers should be relocated and cleaned up.

iii. Residents and factories should be regulated by the government and community leaders to ensure that no part of the river or its watershed is used to dump wastes. There should be effective enforcement of these regulations and offenders punished with equivalent fines or jail sentences.

iv. The Onyeama mines should be adequately monitored and sustainably exploited for environmental sustainability.

v. Public Awareness/Education should be intensified**;** the more people know about the causes and effects of pollution, the more they try to avoid the consequences.

vi. People that make use of the water from the river for drinking, cooking and domestic uses should endeavour to locally treat it by boiling and filtering before use.

vii. Water from both rivers is generally recommended for agriculture and irrigation purposes based on the SAR assessment of the two rivers.

viii. Farming activities near the rivers must be such that will not be done with artificial fertilizer.

ix. Industries located close to the river to ensure that wastes are treated before releasing them into the river water.

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# APPENDIX

## Appendix 1: Ekulu River @ Agu-Abor Bridge

## Appendix 2: Water Treatment Plant Located close to Asata River at Source

## Appendix 3: Ekulu River at Emene Bridge