Water Quality Assessment of Ekulu and Asata Rivers in Enugu Area, Southeastern Nigeria, Using Physico-Chemical and Bacteriological Parameters

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Abstract

This study was aimed at assessing the impacts of human activities on the quality of Ekulu and Asata Rivers in Enugu Area, Southeastern Nigeria. Twelve (12) water samples six (6) from Ekulu River and (six 6) from Asata River) were collected at different points along the regime of the two rivers and their physico-chemical and bacteriological characteristics/parameters determined. Results of the study indicate that the two rivers do not satisfy the Drinking Water Quality Standard of World Health Organization (WHO) and Federal Ministry of Environment (FMENV) in terms of pH/acidity (values between 4.5 and 7.0 and outside the WHO Standard of 6-5-8-5); turbidity (values between 7.88 and 294NTU units and greater than WHO standard of 5.0NTU units); iron (values between 3.10 and 7.35 mg/1 and greater than WHO standard of below 0.30mg/l; and coliform (values between 20 and 180 counts per 100ml and greater than WHO Standard of 3 counts per 100ml). Though Ekulu River is more acidic (lower pH values), more turbid (higher NTU units) and contains higher concentration of iron than Asata River. On the other hand, only Asata River do not satisfy the WHO Standards in terms of nitrate concentration (values between 8.9 and 25.9mg/l and greater than WHO Standard of 10 mg/1): and chromium (heavy metal, values between 0.189 and 0.429 mg/1 and greater than WHO Standard of 0.00lmg/1) Human activities of mining at abandoned Onyeama Coal Mine, car watch and disposal of industrial/domestic wastes are believed to be responsible for poor water quality of the two rivers in Enugu area. On the basis of Piper Diagram Classification, Ekulu River may be classified as Calcium Chloride Type, while Asata River may be classified as Mixed Water Type. Water from the two rivers, to be used for domestic and industrial purposes, should be adequately treated; and there is need to institute regular water quality monitoring programme for the two rivers.

Keywords: Water Quality, Ekulu River, Asata River, Enugu Area, Assessment, Piper Diagram

DOI: 10.7176/JEES/11-4-07

Publication date: April 30th 2021

1.0 Introduction

Water is one of the most common substances known. More than 70% of the Earth's surface is covered with this simple oxygen molecule in the form of swamps, lakes, rivers and oceans. 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, recreation, agriculture, industry 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) regularly (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 Quality in 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).

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.

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.

In this study, the geochemical and bacteriological characteristics and quality assessment of Ekulu and Asata Rivers in Enugu area were evaluated.

2.0 Study Area Description
2.1 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 6^015'N and 6^037'N and longitude 7^020'E and 7^037'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 is 1500mm (Nigerian Meteorological Agency, 2007). 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 Nyaba river in the south (Ezenwaji *et al.*, 2014)
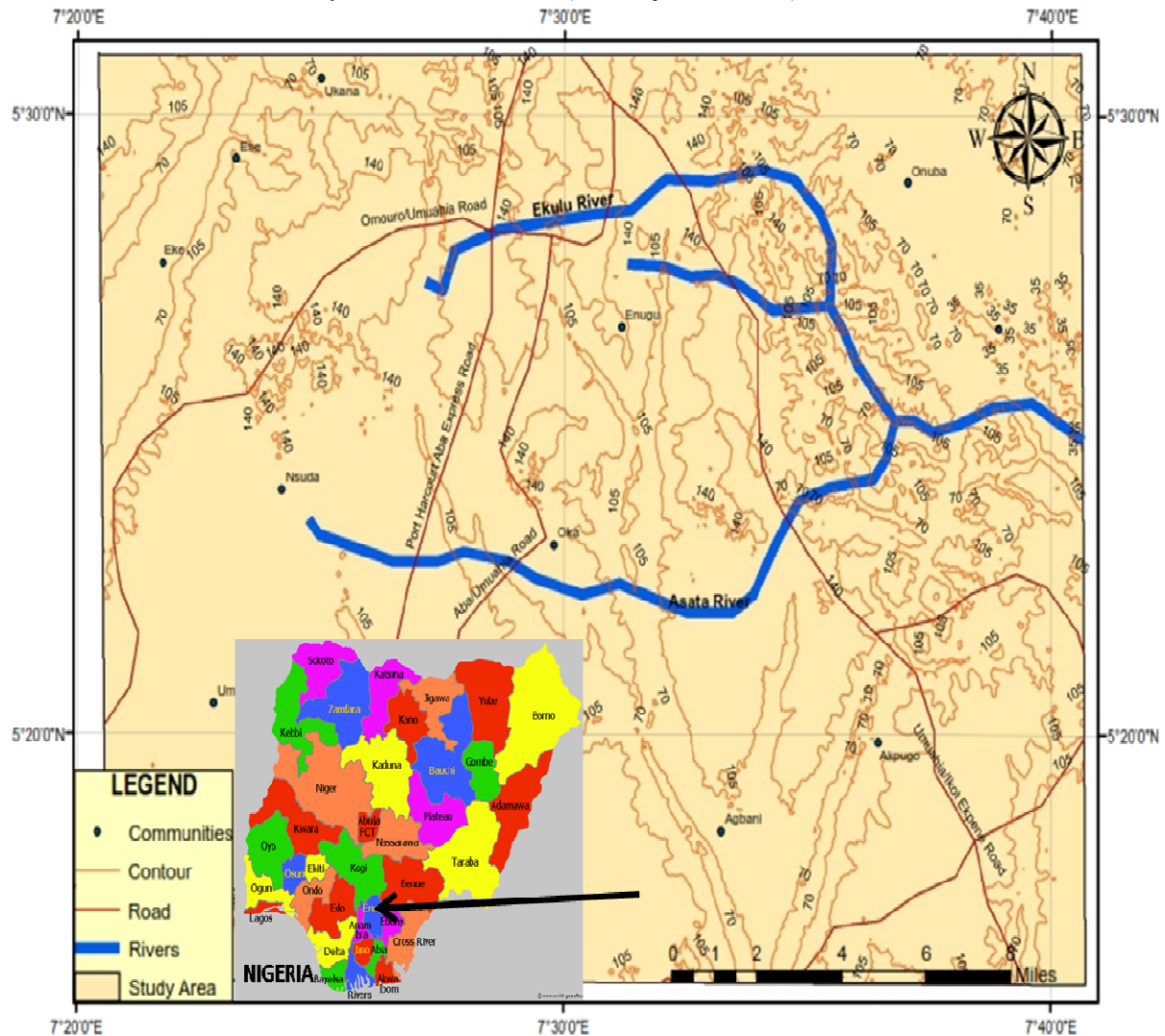

Fig. 1: Topographic Map of the Study Area (NGSA, 2004)

2.2 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 (Okeke and Ihediwa, 2001). The geology of Enugu State is part of the geology of Southeastern Nigeria underlain by the following geological formations (Table1), the Asu River Group, Ezeaku Formation, Awgu Formation, Nkporo /Enugu Shale, Mamu Formation, Ajali Formation, and Nsukka Formations (Okeke et al., 2004).

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) (Reyment 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.

The depositional process resumed in the Campanian with the deposition of Nkporo Shale (Anambra Basins) (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; Mebradu, 1990; Obi et al., 2001).

The Mamu Formation is the most important geological formation with respect to coal formation, occurrence and mining in Enugu Area. The Mamu Formation underlies Ajali Sandstone (aquiferous unit) (Okeke and Okogbue, 2010). The Area is richly endowed with sub-bituminous coal seams within the Mamu Formation. Enugu Area 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 Ajali Sandstone (Ajalli Formation), the Lower Coal Measures (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; Okeke and Okogbue, 2010)

| 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	Alternating sequence shale, sandstone and coal seams.
	Ajali Formation	Friable sandstone with Iron stains
	Mamu Formation	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
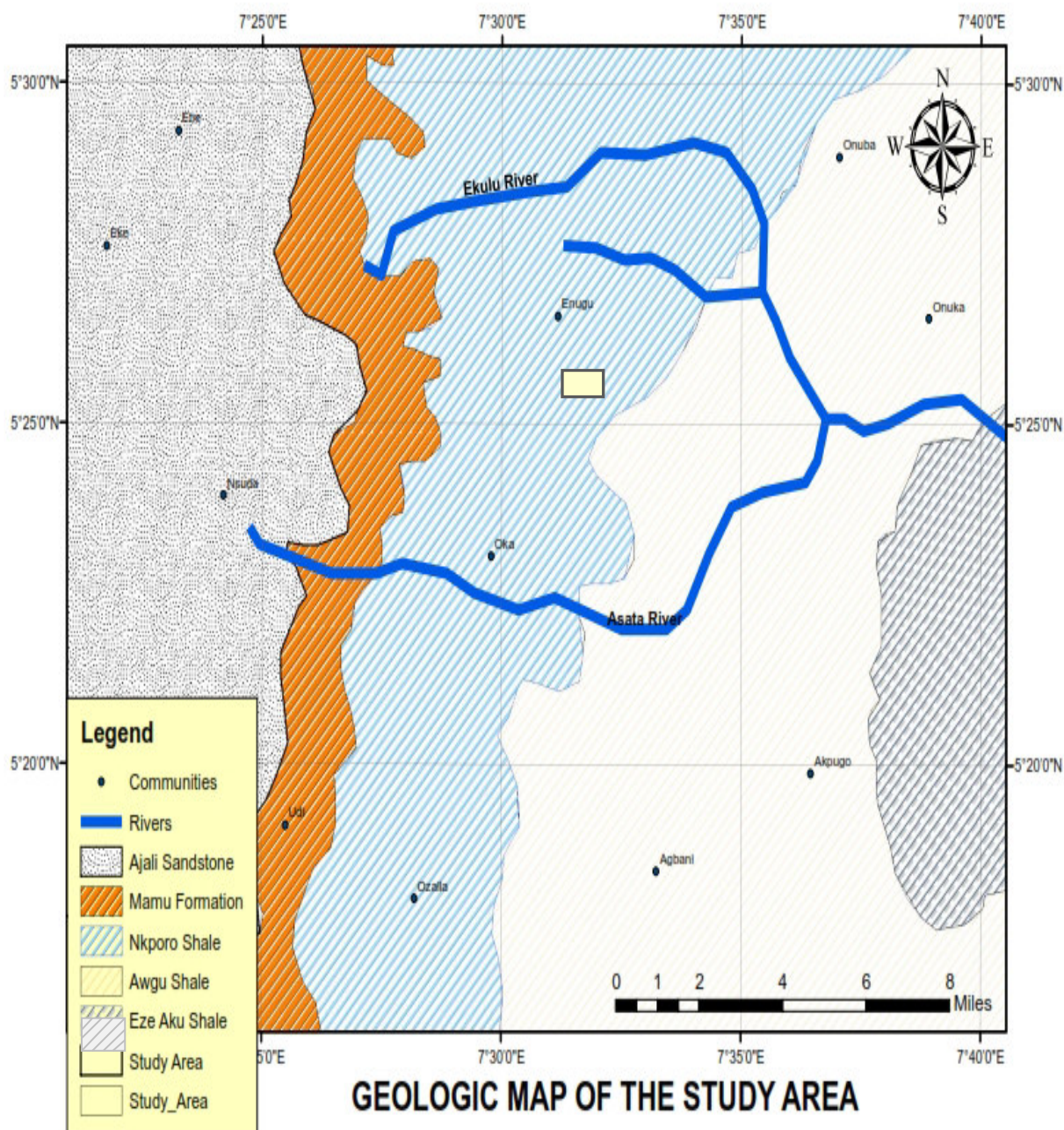
Fig 2: Geologic Map of the Study Area (NGSA, 2004)

3.0 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, (2012) 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 from each of the rivers. The samples were

analyzed 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/Ogbete 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 at Asata river Layout and sample A_6 from Asata river at New Artisan Market Independence Layout. The sample locations and their coordinates are shown in the table (Table 2) and the drainage map (Fig 3) 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° 26' 12'' N, 007° 27' 57'' E
E2	Ekulu River at Onyeama Mine, Ngwo, Udi L.G.A	06° 28' 20'' N, 007° 26' 47'' E
E3	Ekulu River at Agu-Abor Bridge, G.R.A, Enugu East L.G.A	06° 28' 02'' N, 007° 28' 21'' E
E4	Ekulu River at Trans-Ekulu, Trans-Ekulu Enugu East L.G.A	06° 28' 08'' N, 007° 29' 46'' E
E5	Ekulu River at Air Force Bridge, Abakpa Nike, Enugu East L.G.A	06° 28' 27'' N, 007° 30' 47'' E
E6	Ekulu River at Emene Bridge near Orie Emene Market, Enugu East L.G.A	06° 28' 34'' N,007° 34' 46.4'' E
A1	Asata River at a Source in Ngwo Udi L.G.A	06° 26' 12'' N, 007° 27' 57'' E
A2	Asata River at Akwata Bridge near Akwata Market Ogbete, Enugu North L.G.A	06° 26' 11'' N, 007° 29' 42'' E
A3	Asata River at Zik Ave Bridge, Ogui Enugu North L.G.A	06° 26' 11'' N, 007° 29' 42'' E
A4	Asata River at O' Connor St. Bridge, Asata Enugu North L.G.A	06° 26' 34'' N, 007° 30' 04'' E
A5	Asata River at Bissalla Road, Opp. Golden Royale, Asata River Layout Enugu North L.G.A	06° 27' 18'' N, 007° 30' 47'' E
A6	Asata River at New Artisan Market Independent Layout.	06° 27' 17'' N, 007° 32' 23.3'' E
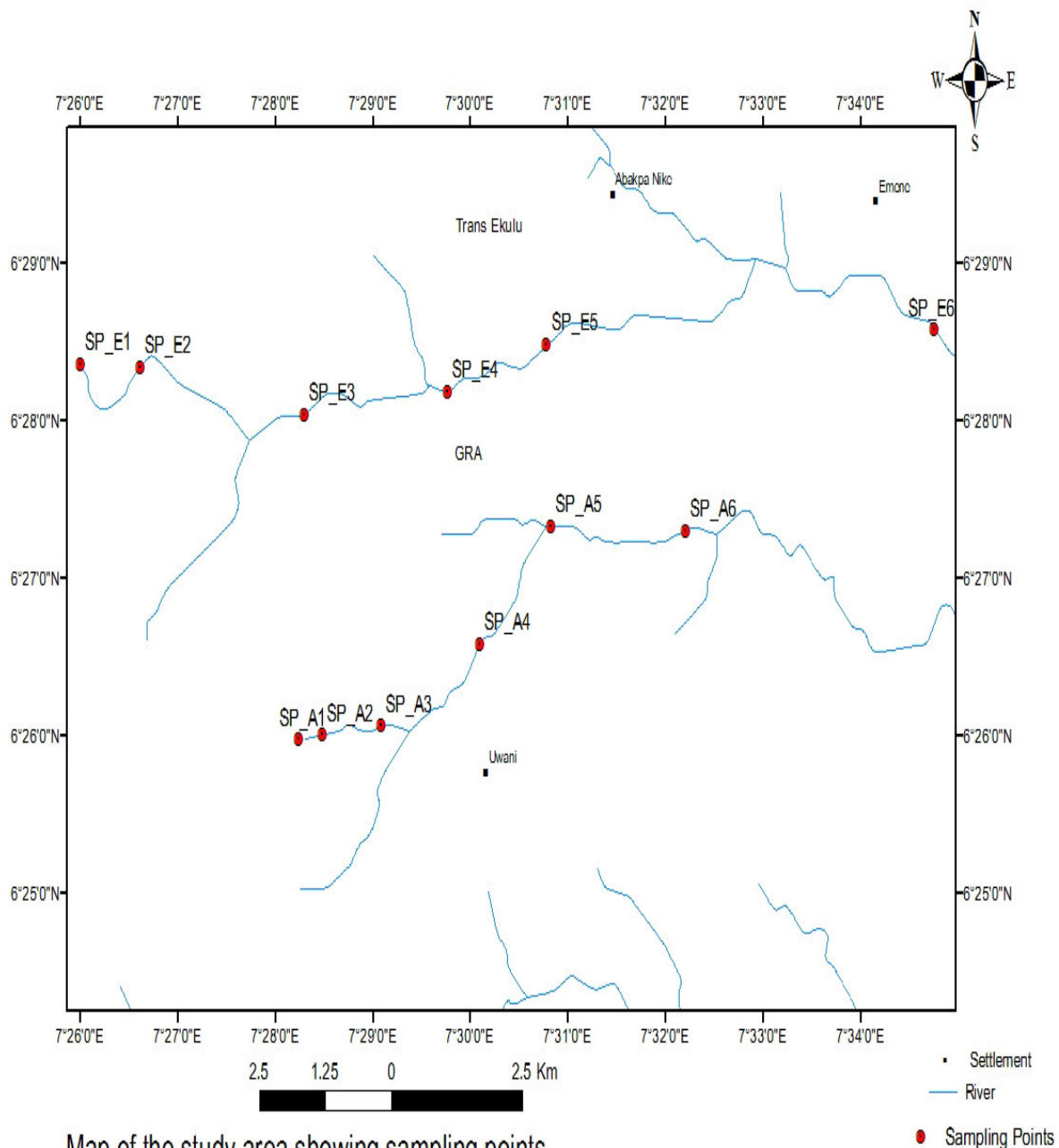
Map of the study area showing sampling points

Fig 3 Drainage Map of the Study Area Showing Sample Points (NGSA, 2004)

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. The bacteriological parameters were also measured. All the analyses were carried out according to guidelines of APHA, (2012) and Bartram and Balance (1996).

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° 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 110^0C. 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, (APHA) (2012). The BOD test involves taking an initial dissolved oxygen (DO) reading and a second reading after five days of incubation at 20^oC. **Chemical Oxygen Demand COD** was determined titrimetrically using open reflux method according to American Public Health Association, (2012). 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, (2012) 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, (APHA) (2012). 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 112.1^0F) 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*

4.0 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 (2008)	FMENV (2011)
		E1	E2	E3	E4	E5	E6		
Appearance		Clear	Cloudy	Cloudy	Cloudy	Muddy	Muddy		
Temperature	°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/lCaCO$_3$	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/lCaCO$_3$	2	BDL	13	38	22	26	100	
Calcium Hardness	mg/lCaCO$_3$	2	7	16	23	26	25	200	180
Magnesium Hardness	mg/lCaCO$_3$	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 Asata River

PARAMETERS	UNITS	SAMPLE RESULT FOR RIVER ASATA						WHO STD (2008)	FMENV (2011)
		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/lCaCO$_3$	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/lCaCO$_3$	2	24	72	82	80	58	100	
Calcium Hardness	mg/lCaCO$_3$	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
4.2.1 Overview
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°C and 31°C with highest temperature value recorded at Ekulu River Agu-Abor Bridge (31°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. 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

Journal of Environment and Earth Science
www.iiste.org
ISSN 2224-3216 (Paper) ISSN 2225-0948 (Online)
Vol.11, No.4, 2021
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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 Ekulu and Asata Rivers.

PARAMETERS	UNIT	EKULU AVERAGE VALUE	ASATA AVERAGE VALUE	WHO STANDARD (2008)	FMENV STANDARD (2011)
Temperature	ºCelsius	29.5	28.16	ºCelsius	ºCelsius
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/lCaCO$_3$	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
Iron	mg/l	5.680	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	0.020	0.296	0.1	0.001

PARAMETERS	UNIT	EKULU AVERAGE VALUE	ASATA AVERAGE VALUE	WHO STANDARD (2008)	FMENV STANDARD (2011)
Copper	mg/l	0.018	0.01	0.05	0.001
Cadmium	mg/l	0.037	0.040		0.05
Total Alkalinity	mg/lCaCO$_3$	20.2	53	100	
Calcium Hardness	mg/lCaCO$_3$	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

4.2.2 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.
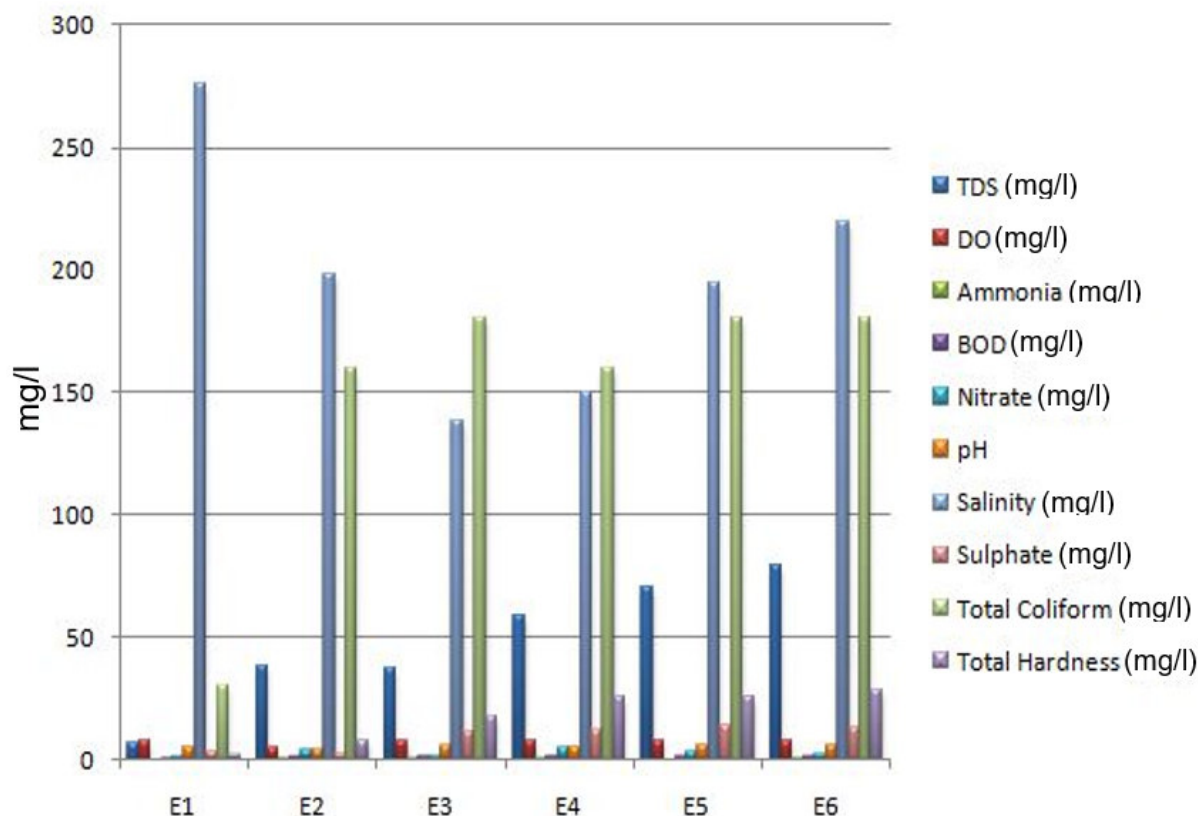
Figure 4: Histogram of Geochemical Constituents of Ekulu River
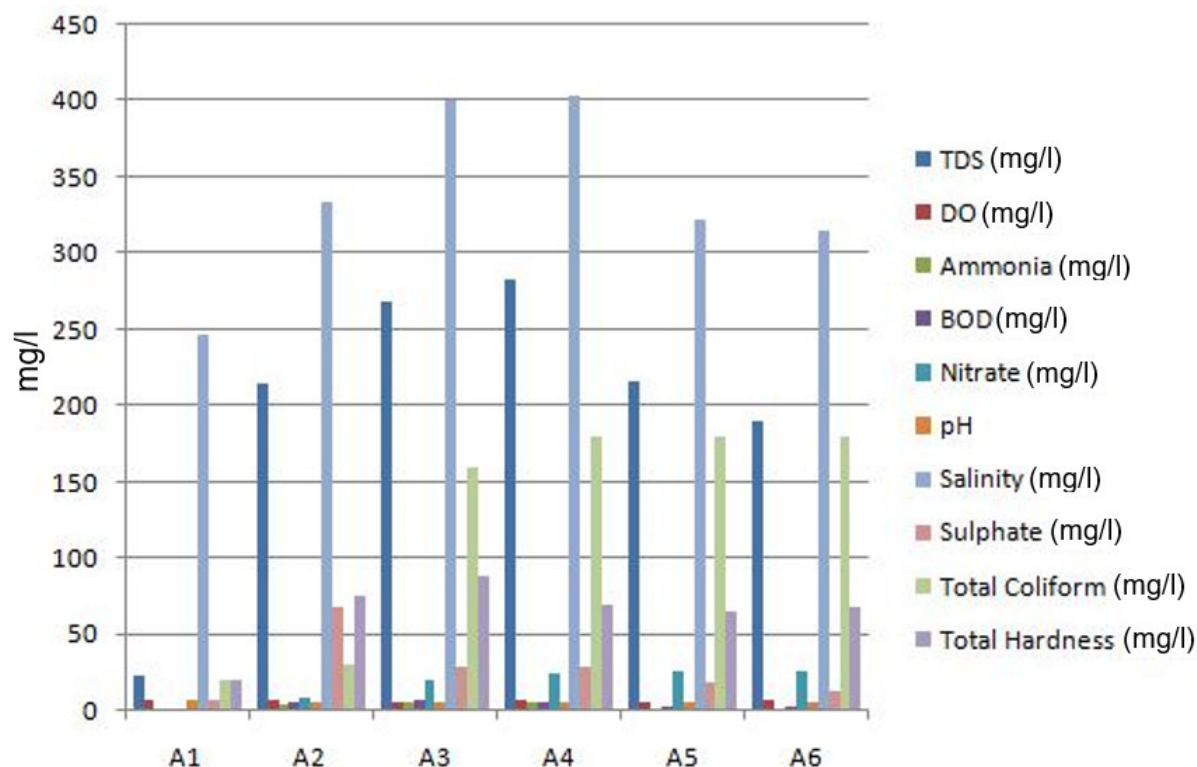
Figure 5: Histogram of Geochemical Constituents of Asata River

4.2.2.1Statistical 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.
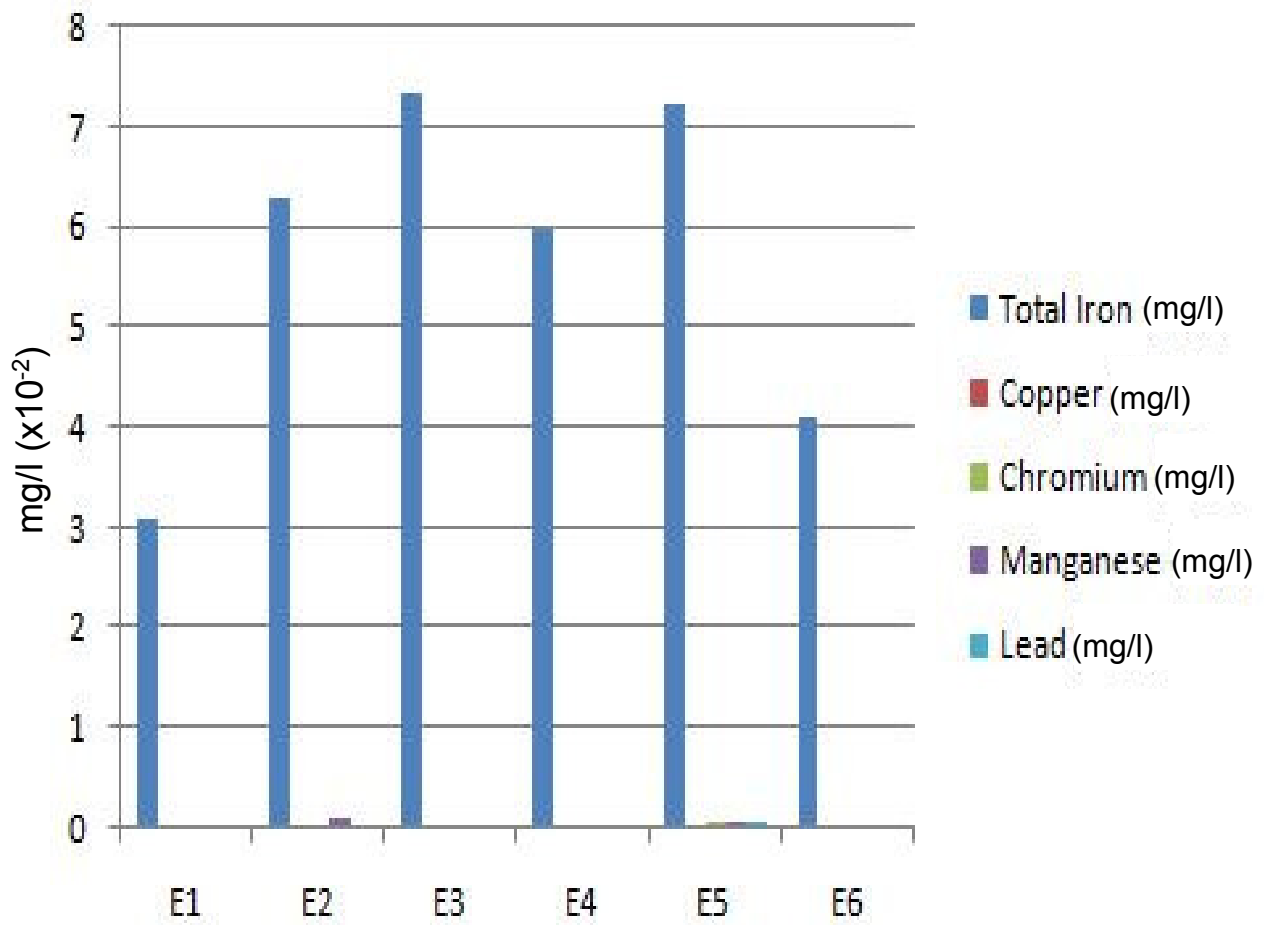
Figure 6: Histogram for Heavy Metal Concentration within Ekulu River
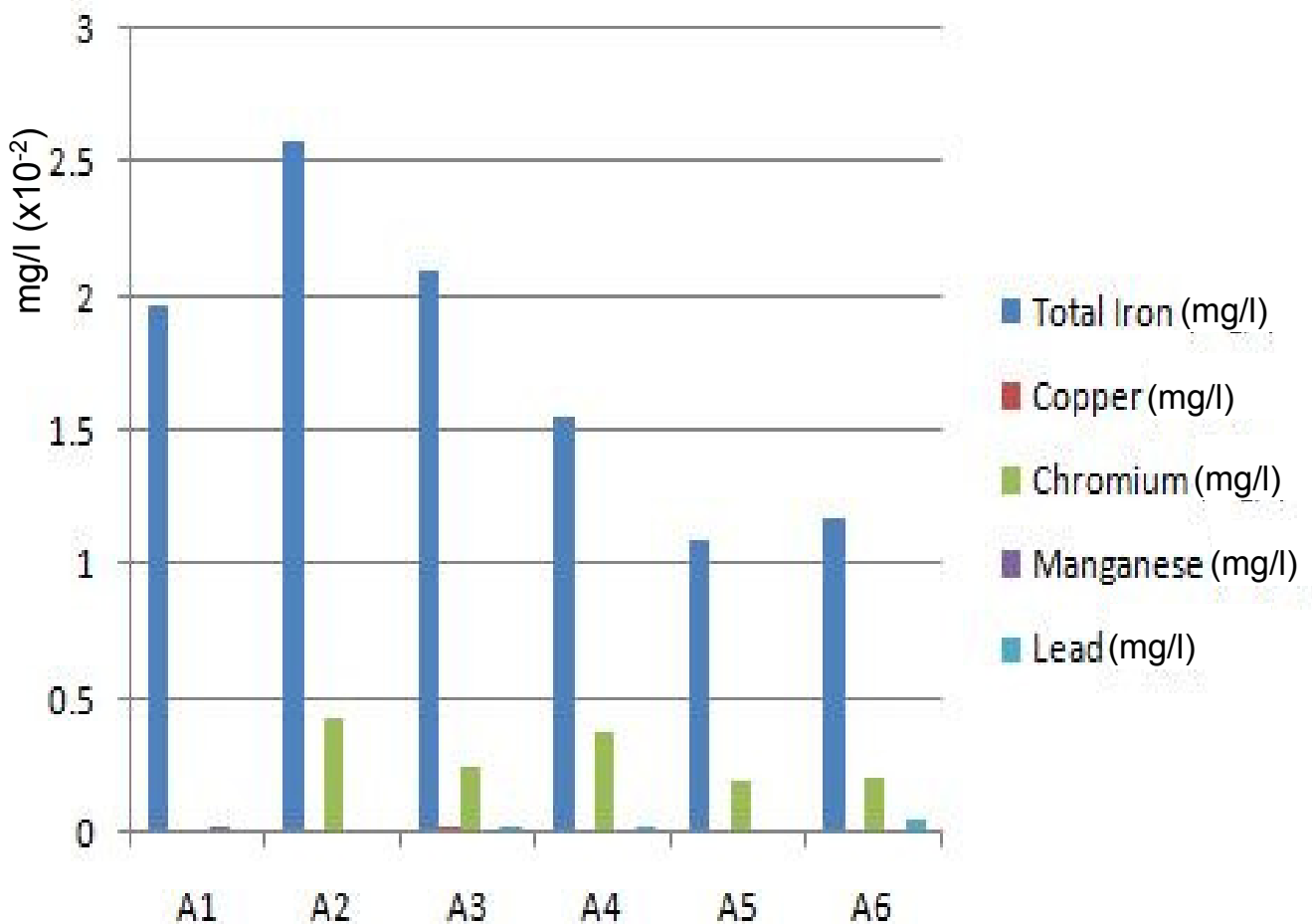
Figure 7: Histogram for Heavy Metal Concentration within Asata River

4.2.2.2 Analysis of Piper Diagram for Ekulu and Asata Rivers

A piper diagram is a graphical representation of the chemistry 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
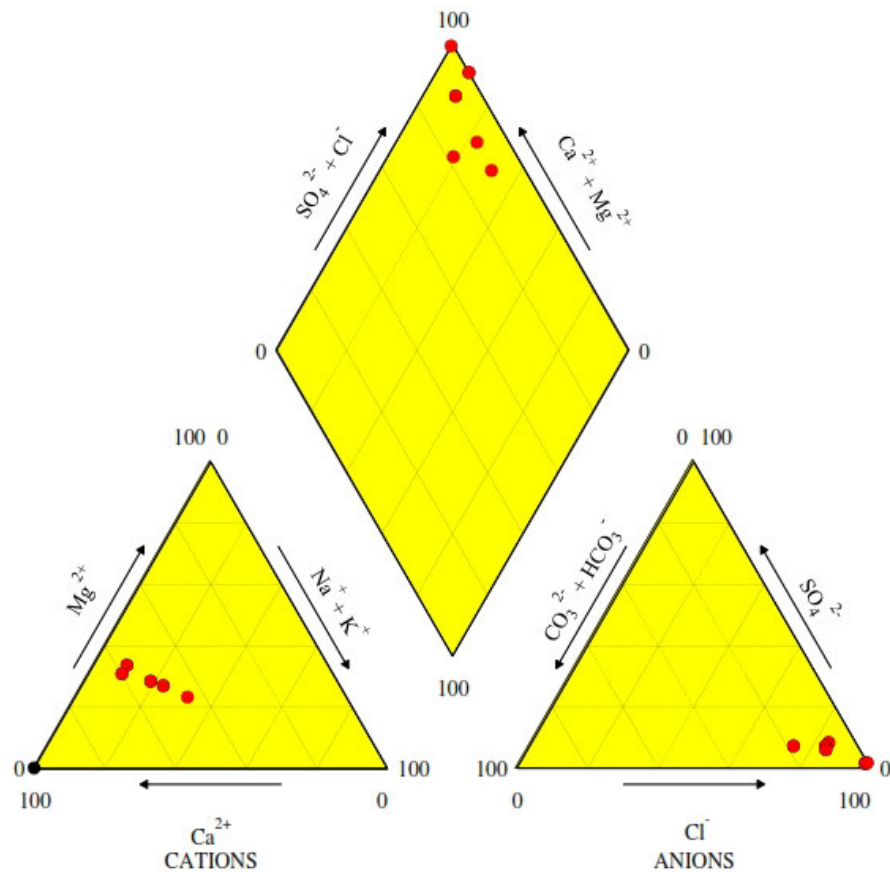
Figure 8: Piper Diagram for Ekulu River

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 corresp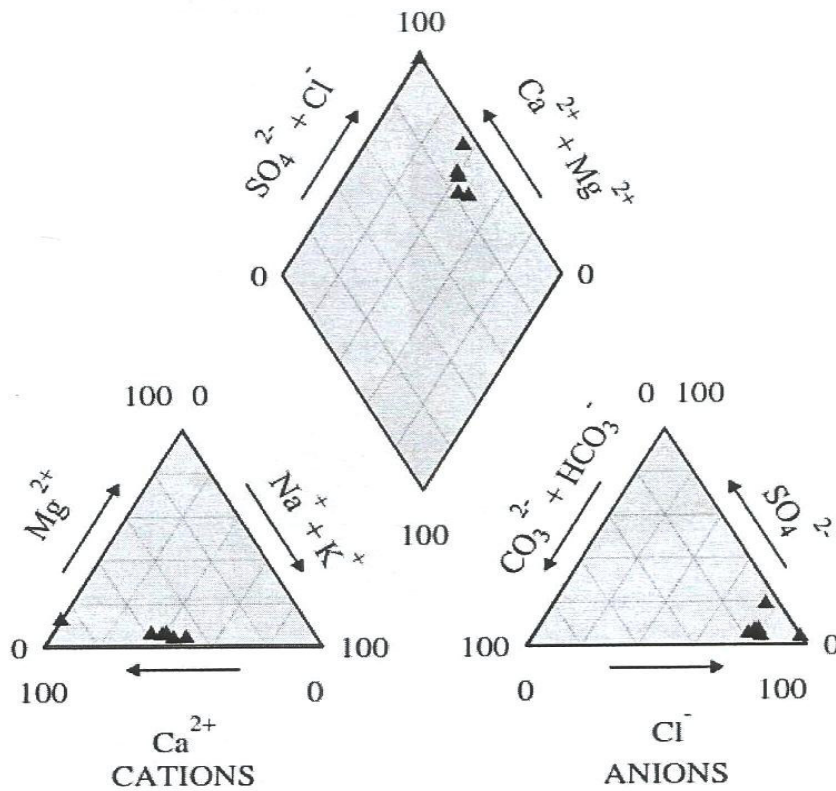onding sub divisions of surface water can be classified as Calcium Chloride Type, meaning that the samples are high in $Ca^{2+} + Mg^{2+}$ and $Cl^- + SO_4^{2-}$.

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 9:Piper diagram for Asata River

4.2.2.4 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, $Fe > Ca^{2+} > Mg^{3+} > Na + K$.
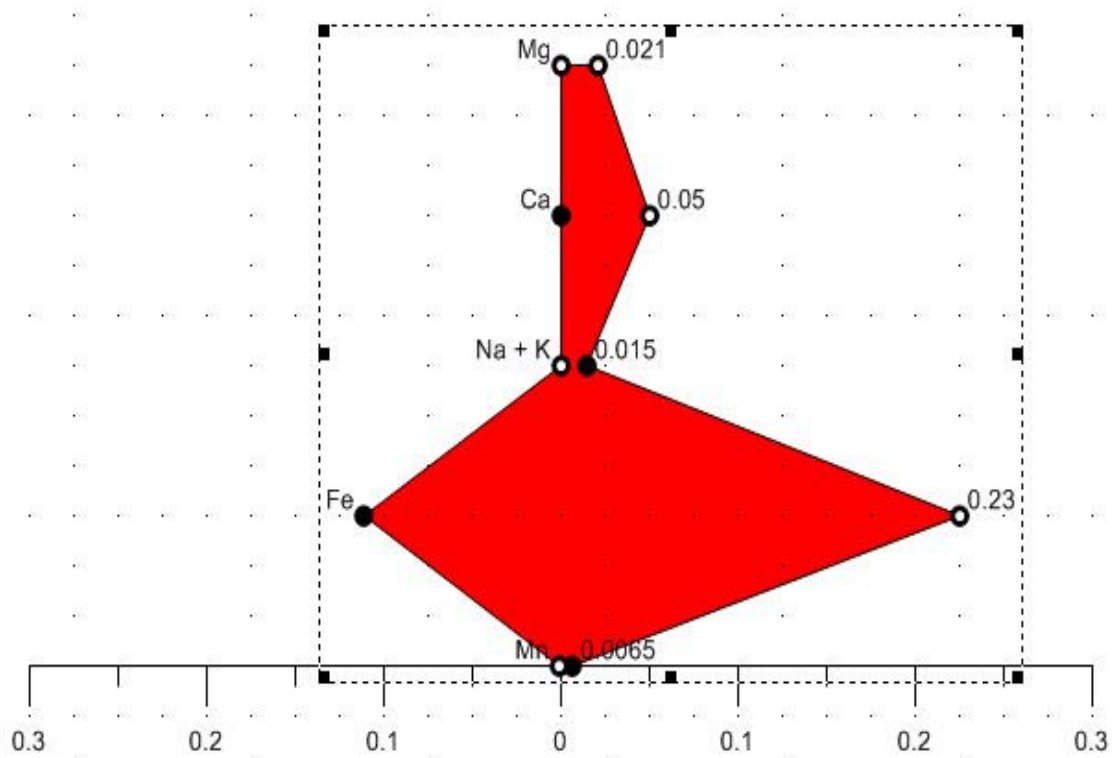
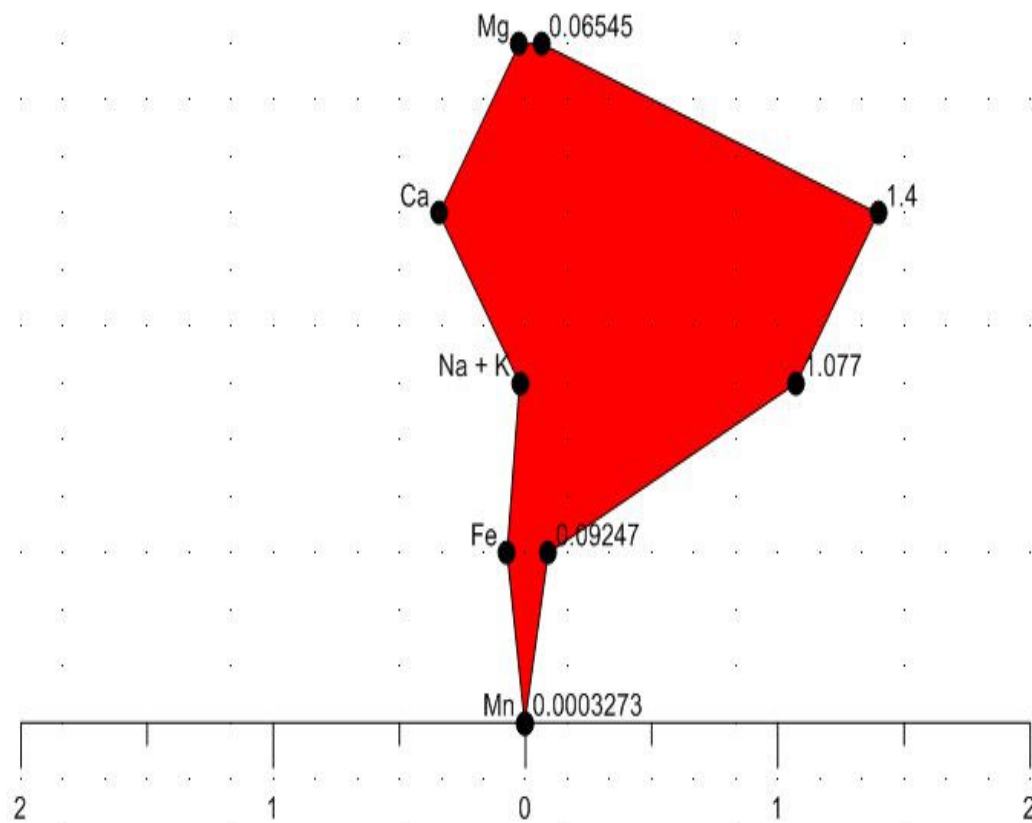Fig 10: Stiff diagram for Ekulu River

Fig 11:   Stiff diagram for Asata River

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.

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4.2.2.5 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;

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

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 (USDA, 1965; Wagoli, 1968)

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.

5.0 Conclusion

Measurements and analysis of geochemical and bacteriological characteristics of water samples from Ekulu and Asata rivers in Enugu Areas, collected from different points along their regimes indicate that the two rivers are not generally suitable for domestic/industrial uses because they do not satisfy the World Health Organization (WHO) and Federal Ministry of Environment (FMENV) Drinking Water Quality Standards, in terms of acidity, (Unacceptable pH Values); turbidity, (Unacceptable High Turbidity Values); and high coliform/nitrate, iron and chromium contents.

Ekulu river water is more acidic and contains more iron than Asata river. This is due to sand extraction from Ekulu river (source of iron) and mine waters from Onyema coal mine (source of acid/high pH values). On the

other hand, Asata river water contains more nitrate and chromium than Ekulu river water. Human activities of urban agriculture (including use of fertilizers), disposal of industrial/domestic wastes (Solid waste dump sites), motor mechanic workshops and sand extraction from the rivers and coal mining at Onyema coal mine are responsible for the poor water quality of the two rivers in Enugu Area. Though water quality from the two rivers satisfy the US Department of Agriculture (USDA) Sodium Adsorption Ratio (SAR) requirement for irrigation water. They are therefore good for agricultural uses.

On the basis of Piper Diagram classification, Ekulu river may be classified as Calcium Chloride Type while Asata river may be classified as Mixed Water Type. It is recommended that water from the two rivers, to be used for domestic and industrial purposes, should be adequately treated. It is also recommended that regular water monitoring programme should be instituted for the two rivers.

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.

Acknowledgement

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