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Evaluation of Physico-Chemical and Heavy Metals Concentration of Groundwater in Okrika, Rivers State, Nigeria

Dr. Geraldine Okwy Ojukwu, Prof. Godwin J. Udom, Prof. C.N. Ehirim

Institute of Natural Resources, Environment and Sustainable Development (INRES), University of Port Harcourt, Nigeria

Department of Geology, University of Port Harcourt, Choba, Port Harcourt, Nigeria

Department of Physics, University of Port Harcourt, Choba, Port Harcourt, Rivers State, Nigeria

ABSTRACT: Groundwater is susceptible to overexploitation and pollution, causing water stress. Seawater intrusion makes coastal aquifer groundwater more vulnerable. Therefore, this study examined groundwater samples from Okrika coastal community aquifers in Rivers State, Nigeria. Standard field and laboratory methods were used to analyze physico-chemical and microbiological parameters in 10 groundwater samples from functional boreholes in the study region. The water was tested for drinking, household, and other uses. Mean values for the following parameters are shown: pH: 5.6; Temperature: 29.3°C; Turbidity: 2.1 NTU; Dissolved Oxygen: 6.6 mg/L; Biological and Chemical Oxygen Demands: 0.4 and 0.6 mg/L; Hardness: 21.2 mg/L; Residual chlorine: <0.01 mg/L; Electrical conductivity: 52.7 μ S/cm; Salinity: 25.9 mg/L; Acidity: 0.4; Alkalinity: 6.6 mg/L; Total Suspended Solids: 0.5 mg/L; Total Dissolved Solids, 29mg/L; Nitrite, <0.001 mg/L; Chloride, 13.6 mg/L; Sulphate, 0.7 mg/L; Nitrate; 0.9 mg/L; Phosphate, 0.5 mg/L; Calcium, 0.3 mg/L; Sodium, 3.1mg/L; Iron, 0.1 mg/L; Magnesium, 0.9 mg/L; Zinc, 0.04 mg/L; Lead <0.001 mg/L; Total Coliform, 1574 MPN/100 mL; Faecal Coliform, 1510 MPN/100 mL. The parameters' values are within NSDWQ 2015 and WHO 2017 limits, except for Iron, which has a slightly high concentration, and Total and Faecal Coliform, which have high values in most of the study area. These data also suggest that the groundwater is soft, low in dissolved components, and slightly acidic. Few aquifers in the research area had salt-water incursion due to chloride levels. The water is appropriate for drinking and other domestic uses when compared to drinking water standards. Acidity of the water can be treated by base- exchange with dolomite, while iron by aeration and filtration methods. Total Coliform and Faecal Coliform treatment involve removing contamination sources, repairing systems, shock chlorinating and flushing impacted boreholes.

I. INTRODUCTION

Water is essential for maintaining hydration and, consequently, for sustaining life. For humans, it provides as a means for food preparation and cooking, maintaining cleanliness and hygiene, and fulfilling various other purposes. The main goal of the drinking-water supply is to safeguard human health by guaranteeing access to enough high-quality water (WHO, 2009).

The primary sources of potable water are surface water and groundwater, which can be obtained using boreholes. According to Diersing (2009), water quality refers to the characteristics of water in terms of its biological, chemical, and physical properties that determine its suitability for a specific purpose, based on safety considerations. Roy (2019) stated that regular monitoring of water sources is necessary to determine their suitability for certain purposes. This is important since poor water quality poses significant risks with potential economic and environmental consequences. Therefore, it is essential to thoroughly examine the quality of water before making any decision on its use, as stated by Kumar et al. (2014). Consuming water that fails to satisfy established criteria poses a risk of contracting diseases such as cholera, typhoid fever, hepatitis, gastrointestinal illnesses, as well as disorders affecting the nervous and reproductive systems (WHO, 2005; EPA, 2018).

Water has a crucial function in the global economy, acting as a solvent in many chemical preparations and being used in cooling towers, transportation, and manufacturing processes. Baroni et al. (2007) determined that almost 70% of the

global freshwater resources are used for agricultural activities. As a result of the growing human population and the demand for clean water for both household and economic use, the availability of water is becoming insufficient. The water quality is essential for human health and the quantity and quality of grain crops. It affects the soils, crops, and the environment (Kimbrough & David, 1996; Ho & Hui, 2001).

The evaluation of water quality involves the analysis of the physical, chemical, and biological attributes of water in reference to predetermined standards. This examination is performed to ascertain the potability of the water or to evaluate any potential environmental hazards it may present. Water is used for a variety of purposes, including domestic consumption, farming, industry, mining, energy generation, and forestry operations. However, many applications of water have negative effects on both its quality and quantity, leading to degradation. This has a substantial impact on the aquatic habitat and the accessibility of drinkable water for human consumption. The interdependence between water quality and quantity is often not assessed simultaneously. The assessment of water quality is conducted through the analysis of water samples collected periodically by these monitoring stations. The results of water quality monitoring are essential for evaluating the spatial and temporal trends in surface water and groundwater (Nitasha & Sanjiv, 2014). Evaluations of water quality monitoring data at local, regional, and global scales offer valuable information about key features of aquatic environments and clarify the impacts, both positive and negative, of human actions.

II. LITERATURE REVIEW

Groundwater is a preferred source of drinkable water due to its abundant presence, accessibility, and consistently high quality in various locations. This has been the case for a significant portion of the past century. Additionally, it is highly reliable during periods of low rainfall and offers significant cost savings during construction (UNESCO, 2019). The relationship between groundwater and human well-being is a cause for concern, as it is directly influenced by the quality of recharged water, atmospheric precipitation, surface water, and subsurface geochemical processes. Ranjana (2010) clearly stated that the quality of groundwater is intricately linked to public health. Groundwater is highly regarded as one of the purest sources of water found in nature, and it is commonly used to supply the water needs of people living in rural and semi-rural areas (Tyagi et al., 2000). The appeal of groundwater for human activities, particularly in rural areas, is due to its reduced susceptibility to pollution and its lower treatment requirements prior to use (Oborie & Nwankwoala, 2012; Adetoyinbo et al., 2015).

Groundwater is the preferred source of drinking water in the Niger Delta because to its lower susceptibility to pollution, according to its rare filtration process (Agbalagba et al., 2011). The over exploitation of groundwater and deterioration of its quality has had a detrimental effect on the socio-economic framework of several regions worldwide, including the environmentally vulnerable Niger Delta regions of Nigeria (Udom et al., 2018).

The quality of potable water is mostly determined by its origin and the degree of contamination or pollution. Water contamination is responsible for almost 80% of tropical diseases, including cholera, typhoid, diarrhoea, and dysentery. Groundwater management presents a substantial challenge in numerous Nigerian towns because of industrial activities that result in oil spills and other perilous situations, predominantly caused by urbanisation, which is the primary factor contributing to groundwater contamination. The suitability of drinking water is assessed based on its quality for human consumption. The composition of water, which is modified by geological processes and human activities, determines its quality. The evaluation of water quality is decided by a range of water characteristics, encompassing physical, chemical, and microbiological aspects. If these levels exceed the acceptable limits, it is a potential danger to human health (Akter, et al. 2016).

III. GEOLOGY OF THE STUDY AREA

Okrika, a coastal community in Rivers State, Nigeria, is situated in the sedimentary basin of the Niger Delta. The region contains the sedimentary strata that are characteristic of the Niger Delta. Allen (1965), Reymont (1965), and Short and Stauble (1967) have offered a comprehensive description of the region's geology. The topography of the region slopes towards the north and reaches the Atlantic Ocean at its southernmost point. The gentle slope is a characteristic that distinguishes the Niger Delta region. In this area, the elevation rarely exceeds 80 metres. The Okrika region is characterised by a multitude of rivers and tributaries, among which the Bonny River stands out as the most prominent.

From a lithostratigraphic perspective, the rocks can be classified into three distinct formations based on their age: the oldest is the Akata Formation from the Paleocene era, followed by the Agbada Formation from the Eocene era, and finally the youngest is the Benin Formation from the Miocene to Recent era. Water is extracted from the Benin Formation, a sedimentary deposit located in the coastal plain, using boreholes and wells. The thickness of the lacustrine and river layers in this formation typically exceeds 1970 metres (Asseez, 1989). The Benin Formation consists of clayey intercalations, sands, silts, and gravel.

The hydrogeology in the study area has been described by several researchers, including Etu-Efeotor (1981), Amadi et al. (1989), Edet (1993), Akpokodje et al. (1996), Edet & Okereke (2001), Udom et al. (2002), Oteri and Atolagbe (2003), Song et al. (2007), Adepelum et al. (2008), and Nwankwoala and Udom (2011). The Benin Formation functions as the aquifer in the area. The composition of this area consists mainly of rapidly alternating layers of silty clay and sand. These deposits, which date back to the Quaternary period, become more prominent as one travels towards the sea. They have a thickness ranging from 40 to 150 metres, as documented by Etu-Efeotor and Akpokodje in 1990. The identification of multi-aquifer systems in the Delta region has primarily been accomplished by analysing strata records (Etu-Efeotor, 1981). Unlike the other confined aquifers, the first aquifer is mostly unconfined. The area's profound boreholes draw water from depths of no less than 200 metres. In their study, Nwankwoala and Walter (2012) found that the groundwater in Okrika is typically safe to drink and can be used for agricultural, industrial, and home purposes. The region exhibits a stable water level that varies between 0.5m and 7.9m. Precipitation is the main way that water is replenished in areas with annual rainfall between 2000 and 4500 mm (Adejuwon, 2012). To restore the aquifers, water infiltrates the highly permeable sediments of the Benin Formation. The research region is mainly distinguished by the presence of groundwater occurring below the water table. The research area consists of multi aquifer systems, with the top aquifers being mostly unconfined (Edet, 1993; Udom, 2004; Etu-Efeotor, 1981; Offodile, 2002).

IV. MATERIALS AND METHODS

Sampling Procedures/Laboratory Techniques

The water samples were analyzed for physico-chemical parameters using standard techniques. The parameters were determined using analytical procedures that followed the standards specified in the American Standard for Testing Materials - ASTM (1969) and the American Public Health Association - APHA (1992) Standards.

The heavy metals examined comprise Iron, Zinc, and Lead, as well as metals such as Calcium, Sodium, and Magnesium. The physico-chemical parameters that were analysed include temperature, pH, total suspended solids (TSS), total dissolved solids (TDS), electrical conductivity (EC), turbidity, hardness, salinity, acidity, alkalinity, sulphates, nitrates, nitrite, chloride, phosphates, residual chlorine, dissolved oxygen (DO), biological oxygen demand (BOD), and chemical oxygen demand (COD). The microbiological parameters included the Total Coliform Count and the Faecal Coliform Count.

Sampling

The technique of collecting samples is crucial in the field of water studies. Groundwater samples were obtained from the vicinity of the wellhead of each of the sampled boreholes prior to undergoing any treatment or passing through tanks. A quantity of one (1) liter of water was gathered from every borehole. Before any sample collection took place, the wells were pumped for approximately three to five minutes. This was done to assure the gathering of samples that accurately represent the whole. Three (3) 250ml polypropylene containers, marked and tightly corked, were used to collect the samples. A plastic container was selected in order to minimize contaminants that could potentially modify the composition of the water. The initial container was designated for microbiological testing. To determine the cations, the second container was acidified by adding two (2) drops of pure Nitric acid (HNO₃).

The sample techniques and utilization of suitable sampling equipment, as prescribed in the Nigeria Standard for Water Quality (NSDWQ), World Health Organization (WHO), Federal Ministry of Environment (FMENV) recommendations, and other global guidelines, were strictly adhered to. The bottles and caps underwent a triple rinsing process using tap water prior to the collection of samples. The sampling bottles were meticulously filled to their maximum capacity and securely sealed to prevent any oxygen contamination, as such contamination could potentially induce reactions and compromise the accuracy of the data. All the samples were accurately tagged with the corresponding sampling parameter, sampling point, and date. The sampling bottles were securely sealed to prevent any

spillage. A GARMIN Etrex 10, a portable Global Positioning System (GPS) unit, was utilized to capture coordinates and elevation readings. The following metrics were measured and recorded in-situ due of their volatile nature: Temperature, pH, Electrical Conductivity, and TDS. The field activities were primarily conducted during the wet season, specifically from May 2023 to June 2023. The samples were then transported to the laboratory in ice – packed coolers for analysis using standard methods as seen in Table 1.

Analyses were promptly performed upon the arrival of the water samples at the laboratory. The quality assurance measures involved doing three analyses for each parameter in every sample and calculating the average of the results.

Parameters	Analytical Methods
Magnesium, Calcium, Iron, Zinc, Lead, Sodium	Direct Atomic Absorption
Salinity, Acidity, Alkalinity, Residual Chlorine, Biological Oxygen Demand, Chemical Oxygen Demand, Dissolved Oxygen, Hardness, Chloride	Titration
TDS, TSS	Gravimetric
Total Coliform, Faecal Coliform	Most Probable Number (MPN)
Turbidity, Sulphate	Turbidimetric
Temperature, Electrical Conductivity, pH	Hanna Portable Pocket Combo-Meters
Nitrate, Nitrite	Automated Cadmium Reduction

Table 1: Summary of Analytical Techniques used in the Laboratory

Coordinates of the Study Area

The study area – Okrika, is situated on an island south of Port Harcourt, making it a suburb of the much larger city (Britannica, 2009). The average elevation of Okrika is 452m. It lies on the north of the Bonny River and 35 miles (56 km) upstream from the Bight of Bonny. The town can be reached by vessels of a draft of 29 feet (9m) or less. The study area is accessible. There are tarred roads and a network of accessible link roads. Okrika can also be accessed by boats. The coordinates of the sampling points of the study area are shown in Table 2. Map showing the sampling points of the Study Area in Okrika LGA of Rivers State is shown in Figure 1.

S/No	Sample Location	Sample Point	Coordinates
1	Okrika LGA	Ambemebiri Sandfilled	4°44'48.8"N 7°05'14.6"E
2	Okrika LGA	Christian Mission Compound Tomobiri, Kirike	4°44'42.9"N 7°05'16.4"E
3	Okrika LGA	Egwemebiri – Beside football Field, Kirike	4°44'43.2"N 7°05'10.6"E
4	Okrika LGA	Amayanabo Polo	4°44'49.3"N 7°05'09.6"E
5	Okrika LGA	Seaside Estate – Kangochuku (Oba/Adudumoru)	4°44'50.6"N 7°05'06.7"E
6	Okrika LGA	Kalio Polo	4°44'59.9"N 7°05'04.6"E
7	Okrika LGA	Church of Jesus Christ of Latter-Day Saints - Kalio Sandfilled	4°44'42.7"N 7°05'19.8"E
8	Okrika LGA	ATC Ring Road	4°44'26.5"N 7°04'39.1"E
9	Okrika LGA	Ogoloma Ring Road I	4°44'16.0"N 7°04'39.1"E
10	Okrika LGA	Ogoloma Ring Road II	4°44'08.6"N 7°04'42.7"E

Table 2: The Coordinates of The Sampling Points of the Study Area

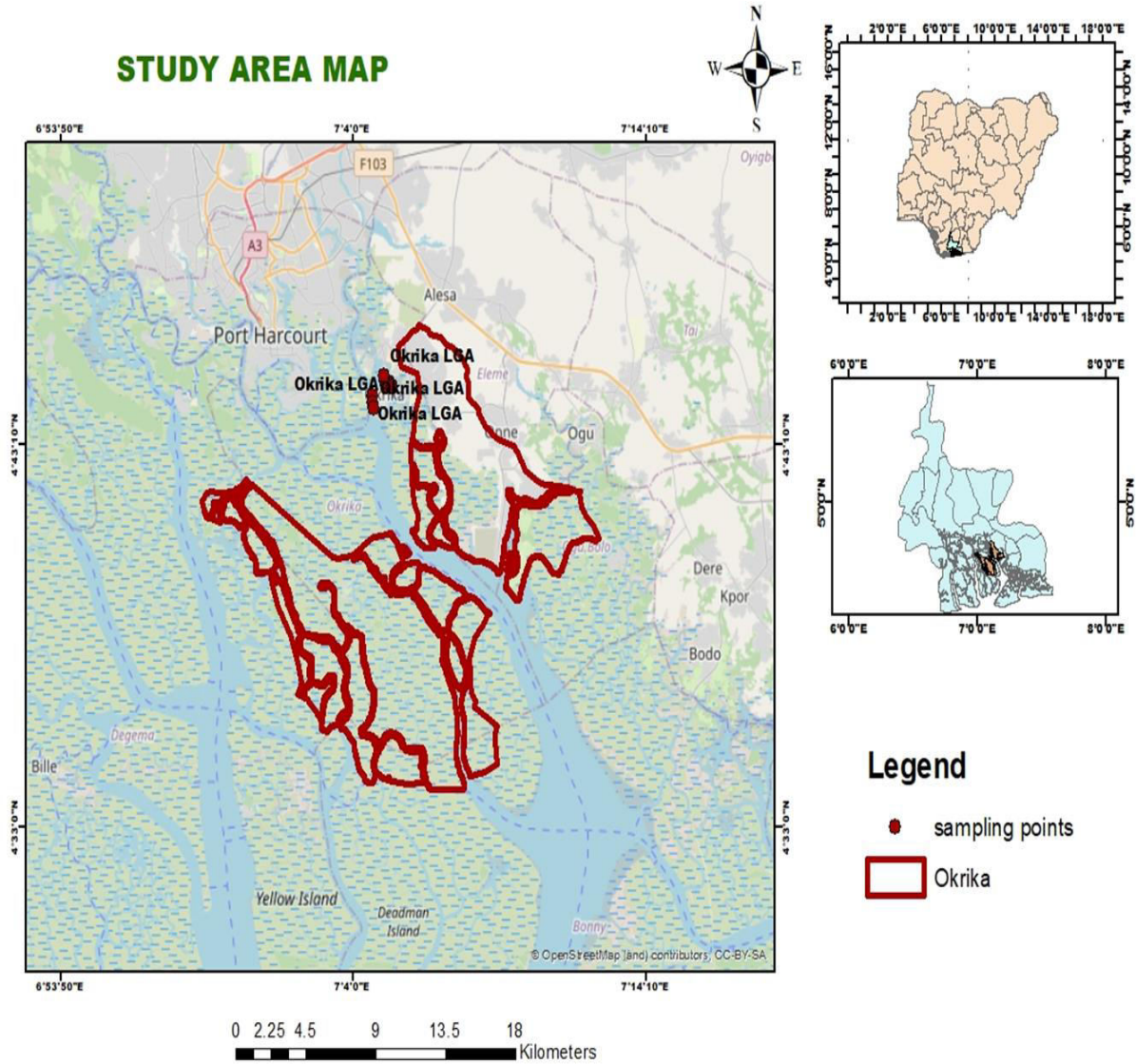


Figure 1: Map Showing the Sampling Points of the Study Area

V. RESULTS AND DISCUSSION

The results of all the analyzed physico-chemical, heavy metals and microbiological parameters from the study area are presented hereunder in Table 3.

Study area groundwater temperatures range from 29.2°C to 29.5°C. NSDWQ (2015) and WHO (2017) do not suggest groundwater temperature. Groundwater pH in the study area ranges from 5.3 to 6, averaging 5.6. The Nigeria Standard for Drinking Water Quality (NSDWQ) and WHO recommend a pH range of 6.5 to 8.5 for drinking water. The water samples' pH is acidic and below the permissible range. Based on these criteria, these sites' water is unfit for drinking. The research area's water samples have dissolved oxygen (DO) levels ranging from 6 to 7.4 mg/L, with an average of 6.6 mg/L. Biochemical Oxygen Demand (BOD) water values in the research region range from 0.2 to 0.5 mg/L, averaging 0.4 mg/L. The NSDWQ and WHO have no groundwater Biochemical Oxygen Demand (BOD) criterion. Sensorex (2021) states that a low Biochemical Oxygen Demand (BOD) indicates a lack of organic components in the water, preserving water purity. The low Biochemical Oxygen Demand (BOD) means the water is safe for drinking and other household uses. The Chemical Oxygen Demand (COD) water values in the research region range from 0.3 to 0.8 mg/L, averaging 0.6 mg/L. The NSDWQ and WHO have not set groundwater COD thresholds. However, standard

environmental contaminant discharge rules limit COD to 250 mg /L. COD should not exceed 294 mg/L, according to NAFDAC (1999). According to Chapman's categorization (1996) and NAFDAC (1999), a low COD implies that the water sample is appropriate for drinking, irrigation, and industrial use.

The electrical conductivity ranges from 14 to 139 $\mu\text{S}/\text{cm}$. All samples meet the permissible range of 1000 $\mu\text{S}/\text{cm}$ and 900 $\mu\text{S}/\text{cm}$, as established by the NSDWQ (2015) and WHO (2017) recommendations. Water's electrical conductivity depends on ion concentration and movement. Electrical conductivity indicates dissolved ionizable compounds, according to research. All areas have low electrical conductivity, indicating low dissolved ions and enrichment of groundwater ionic activity. The research region's water samples have Total Dissolved Solids (TDS) values between 8 and 76 mg/L, with an average of 29 mg/L. The WHO and NSDWQ limit potable water TDS to 500 mg/L. Based on these criteria, the water is potable for drinking, household, and irrigation use. Groundwater must be categorized by Total Dissolved Solids (TDS), which is closely related to Electrical Conductivity, to evaluate its suitability for any usage. Groundwater is classified for drinking and irrigation using Freeze and Cherry (1979) and Davis and De Wiest (1966) classifications. According to Davis and De Wiest (1966), this TDS level is safe for drinking, household, industrial, and irrigation. The research region's water samples have salinities from 7 to 70 mg/L, with an average of 25.9 mg/L. The readings meet the NSDWQ and WHO guidelines of 250–400 mg/L. This investigation's salinity measurements meet the threshold, indicating minor aquifer overexploitation. Based on salinity, these water sources are safe for drinking and irrigation. Research region water samples had Total Suspended Solids (TSS) values from 0 to 2 mg/L, with an average of 0.5 mg/L. The TSS values meet the NSDWQ and WHO 500 mg/L standard. TSS cannot pass through a two-micrometre sieve, unlike TDS. TSS stay suspended in solution indefinitely (Dezuane, 1997). All water samples had TSS levels between 0 and 2 mg/L, indicating the absence of suspended and colloidal contaminants such as damaged vegetation, sewage, and sediments. With respect to TSS, the water samples are suitable for drinking and other uses. Hardness in the 10 water samples ranges from 5 to 36 mg/L. The average hardness is 14mg/L. The values meet NSDWQ and WHO standards of 150 and 100 mg/L. None of the groundwater samples are hard, according to Sawyer and McCarthy (1967) and Todd (1980). The residual chlorine levels in this study were below 0.01 mg/L. This is because water samples were not treated. The groundwater samples in the research region contained iron values ranging from <0.001 mg/L to 0.8 mg/L, with an average of 0.1 mg/L. In 20% of water samples, the NSDWQ's 0.3 mg/L standard was exceeded. The main source of iron contamination is geological; therefore, this value still falls below the WHO's 1 mg/L standard for groundwater iron. According to Alabo et al. (1984), Benin Formation laterites are iron-rich and presumably discoloured by limonite and goethite. Leaching releases iron into groundwater from the elements specified (Ngha & Allen, 2006). Iron is discovered in drinking water due to steel and cast-iron pipe degradation during distribution, according to WHO (2006). Udom et al. (2015) found iron in most Niger Delta groundwater. Weathering of geologic igneous and metamorphic rocks causes most iron pollution. Benin Formation laterites are iron-rich and possibly discoloured by limonite, goethite, and hematite (Etu-Efeotor, 1981; Alabo et al., 1984). The use of coagulants and the erosion of steel and cast pipes in water distribution systems can also produce iron, according to WHO (2004). The groundwater samples in the studied location had zinc values ranging from <0.001 mg/L to 0.088 mg/L, with an average of 0.04 mg/L. These readings are below the NSDWQ and WHO drinking water limits of 3 mg/L and 1 mg/L, respectively. This means that groundwater is uncontaminated by contaminants from steel mills, coal-fired power stations, or trash incineration. No water source tested positive for lead. The groundwater levels are below the NSDWQ and WHO 0.01 mg/L threshold. The 10 groundwater samples had CaCO₃-based acidity levels from 0.3 to 0.5 mg/L, averaging 0.4 mg/L. The NSDWQ and WHO have no groundwater acidity standard. All tested groundwater sources had alkalinity levels from 2 to 16 mg/L. The 10 groundwater sources averaged 6.6 mg/L alkalinity. The readings meet WHO standards of 100 mg/L. The NSDWQ has no groundwater alkalinity standard. Thus, these sites have alkalinity-safe drinking water. Lower chloride levels (4 mg/L) were seen in Seaside Estate and Kalio Sandfilled, while the highest was 42 mg/L at Amayanabo Polo. The average chloride content is 15.6mg/L, which is within the NSDWQ and WHO standard of 250 mg/L for drinking water. However, 10% of samples (Amayanabo Polo) have levels > 40 mg/L, indicating saltwater intrusion (Tremblay et al., 1973; Udom et al., 2002; Amadi, 2004; Nwankwoala, 2013). In 10% of the research area's aquifers, saltwater encroachment is evident. The research region's water samples had phosphate contents of 0.2 to 1.2 mg/L, averaging 0.5 mg/L. The NSDWQ (2015) and WHO (2017) have not set a groundwater phosphate concentration benchmark. However, the research region's phosphate concentrations are within the WHO's 5 mg/L and 12 mg/L drinking water guidelines (WHO, 2006; WHO, 2004). Groundwater samples in the research location show sodium values ranging from <0.001 mg/L to 9.9 mg/L, with an average of 3.1 mg/L. None of the water samples exceeded WHO and NSDWQ sodium limits of 75 mg/L and 200 mg/L, respectively. Given the sodium parameter, the research area's groundwater is potable. Todd (1980) said that groundwater often contains a sodium concentration of less than 100mg/l, which was confirmed in all the sampling points. Each water sample has sodium concentrations within

drinkable water standards. When freshwater combines with saline water due to sea transgression, Rahman et al. (2015) observed that sodium concentration increases. All water samples in this investigation had nitrite values below 0.001 mg/L, suggesting no nitrite. These values are below the NSDWQ and WHO's 0.2 mg/L drinking water limit. The research region's water samples had nitrate amounts of 0.2 to 2.3 mg/L, averaging 0.9 mg/L. These levels are below the WHO and NSDWQ maximum allowed limits for drinkable water, 10 mg/L and 50 mg/L, respectively. The low nitrate levels in the area show that the groundwater is clean and acceptable for use in homes, agriculture, industry, and other applications. Nitrate in groundwater is caused by plant decomposition, human sewage, soakaways, industrial and domestic effluents, livestock manure, erosion of natural deposits, farm fertilizer application, combustion engine emissions. The research area's water samples have Sulphate readings from 0 to 2 mg/L, averaging 0.7 mg/L. As to the NSDWQ and WHO, all groundwater sulphate measurements are considerably below the maximum permitted values of 100 mg/L and 250 mg/L. Calcium values in water samples in the research location ranged from <0.001 mg/L to 0.3 mg/L, with an average of 0.03 mg/L. The NSDWQ (2015) and WHO (2017) have no groundwater calcium content standard. The mean calcium levels of 0.03mg/L are below the WHO (2006) calcium limit of 75 mg/L. The groundwater samples in the research region had magnesium contents ranging from 0 to 2.7 mg/L, averaging 0.9 mg/L. These levels are below the WHO and NSDWQ maximum permitted limits of 20 mg/L for drinkable water. Total coliform concentrations ranged from 0 MPN/100 mL to 2400 MPN/100 mL in all water sources. The average is 1574 MPN/100 mL. 80% of water tests exceed the Nigeria Standard for Drinking Water Quality (NSDWQ) Total coliform limit of 10 MPN / 100 mL. The WHO has not set a groundwater Total Coliform criterion. Total coliform contamination of groundwater sources can be caused by human and animal waste, inadequate borehole construction or drilling, storage tank contamination, manure preparation sites, and seepage from poorly constructed sewage disposal facilities. Pathogens from this site can enter borehole water without impermeable casings. These microbes can spread waterborne diseases such as dysentery, typhoid fever, cholera, and others in household water (Udoh, et al., 2021). Faecal coliform concentrations in water samples ranged from 0 to 2400 MPN/100 mL across all sources. The average MPN/100 mL value is 1510.0. 80% of water tests exceed the NSDWQ Faecal coliform limit of 0 MPN / 100 mL. The WHO has not set a groundwater Faecal Coliform criterion. Faecal coliforms are a better indicator of animal or human waste pollution than total coliforms. Although other diseases may be present, faecal contamination is the most dependable sign. Faecal coliform indicates bacterial pollution from humans and other warm-blooded creatures (Seiyaboh et al., 2020). High water faecal coliform levels can harm public health and the economy. The high faecal coliform bacteria content in water samples implies pollution. The NSDWQ requires drinking water to have a faecal coliform content of 0 MPN/100 mL. Thus, water must be treated to be safe for consumption.

LGA	SN	Sampling Point	pH	Turbidity (NTU)	Chloride, Cl- (mg/L)	Temperature (oC)	Dissolved Oxygen, DO (mg/L)	Biochemical Oxygen Demand, BOD (mg/L)	Chemical Oxygen Demand, COD (mg/L)	Hardness (mg/L)	Residual Chlorine (mg/L)	Electrical Conductivity (µS/cm)	Salinity (mg/L)	Acidity CaCO3 (mg/L)	Alkalinity(mg/L)
OKRIKALA LGA	1	Ambenebiri Sandfilled	5.6	2	8	29.2	6.8	0.463	0.695	10	<0.01	29	14	0.5	5
	2	Tomobiri Kirike	5.8	2	34	29.5	6.5	0.257	0.386	25	<0.01	112	56	0.4	12
	3	Egwenebiri Kirike	5.6	3	13	29.4	7.2	0.243	0.364	17	<0.01	44	22	0.4	8
	4	Amayanabo Polo	5.4	1	42	29.3	6.5	0.502	0.753	36	<0.01	139	70	0.5	16
	5	Seaside Estate	5.3	2	4	29.2	6.2	0.544	0.816	5	<0.01	14	7	0.5	2
	6	Kalio Polo	5.6	3	6	29.4	6.0	0.183	0.275	6	<0.01	22	10	0.4	3
	7	Kalio Sandfilled	6.0	3	4	29.2	7.4	0.451	0.676	5	<0.01	14	7	0.3	3
	8	ATC Ring Road	5.7	2	7	29.3	6.5	0.343	0.514	8	<0.01	23	11	0.4	4
	9	Ogoloma Ring Road I	5.3	3	5	29.3	6.3	0.373	0.560	6	<0.01	17	8	0.5	3
	10	Ogoloma Ring Road II	5.5	0	33	29.3	6.4	0.417	0.625	22	<0.01	113	54	0.5	10
	11	MEAN	5.6	2.1	15.6	29.3	6.6	0.4	0.6	14.0	<0.01	52.7	25.9	0.4	6.6
	12	MAX	6.0	3.0	42.0	29.5	7.4	0.5	0.8	36.0	<0.01	139.0	70.0	0.5	16.0
	13	MIN	5.3	0.0	4.0	29.2	6.0	0.2	0.3	5.0	<0.01	14.0	7.0	0.3	2.0
	14	RANGE	5.3-6	0-3	4-42	29.2-29.5	6-7.4	0.2-0.5	0.3-0.8	5-36	<0.01	14-139	7-70	0.3-0.5	2-16

Table 3: Physico-chemical and Heavy Metals Composition of Groundwater Samples in the Okrika LGA Sampling Points

LGA	SN	Sampling Point	Nitrite, NO2 (mg/L)	Nitrate, NO3 (mg/L)	Sulphate, SO42 (mg/L)	Phosphate, PO43 (mg/L)	Total Suspended Solids, TSS (mg/L)	Total Dissolved Solids, TDS (mg/L)	Calcium, Ca (mg/L)	Sodium, Na (mg/L)	Iron, Fe (mg/L)	Magnesium, Mg (mg/L)	Zinc, Zn (mg/L)	Lead, Pb (mg/L)	Total Coliform (MPN/100mL)	Fecal Coliform (MPN/100mL)
OKRIKALA LGA	1	Ambenebiri Sandfilled	<0.001	0.6	0	0.40	0	16	<0.001	0.432	0	0.133	0.043	<0.001	2,400	2,400
	2	Tomobiri Kirike	<0.001	1.8	2	1.02	0	62	<0.001	9.080	0	2.693	0.043	<0.001	2,400	2,400
	3	Egwenebiri Kirike	<0.001	0.8	1	0.45	0	24	<0.001	1.672	0	1.124	0.068	<0.001	2,400	2,400
	4	Amayanabo Polo	<0.001	2.3	2	1.15	0	76	<0.001	9.500	0.792	1.281	0.076	<0.001	0	0
	5	Seaside Estate	<0.001	0.2	0	0.16	0	8	0.344	0.080	0	0.934	0.010	<0.001	0	0
	6	Kalio Polo	<0.001	0.4	0	0.30	0	12	<0.001	0.054	0.074	1.412	0.037	<0.001	2,400	2,400
	7	Kalio Sandfilled	<0.001	0.2	0	0.25	2	8	<0.001	0.058	0.315	0.347	0.088	<0.001	2,400	2,400
	8	ATC Ring Road	<0.001	0.4	0	0.32	2	13	<0.001	0	0	0.343	0.009	<0.001	2,400	2,400
	9	Ogoloma Ring Road I	<0.001	0.2	0	0.21	1	9	<0.001	0.162	0	0.006	0.017	<0.001	240	240
	10	Ogoloma Ring Road II	<0.001	1.9	2	1.03	0	62	<0.001	9.892	0	0.942	<0.001	<0.001	1,100	460
	11	MEAN	<0.001	0.9	0.7	0.5	0.5	29.0	0.3	3.1	0.1	0.9	0.04	<0.001	1574.0	1510.0
	12	MAX	<0.001	2.3	2.0	1.2	2.0	76.0	0.3	9.9	0.8	2.7	0.088	<0.001	2400.0	2400.0
	13	MIN	<0.001	0.2	0.0	0.2	0.0	8.0	<0.001	<0.001	<0.001	0.0	0.0	<0.001	0.0	0.0
	14	RANGE	<0.001	0.2-2.3	0-2	0.2-1.2	0-2	8-76	<0.001-0.3	<0.001-9.9	<0.001-0.8	0-2.7	<0.001-0.088	<0.001	0-2400	0-2400

Table 4: Physico-chemical and Heavy Metals Composition of Groundwater Samples in the Okrika LGA Sampling Points (Continued)

VI. CONCLUSIONS AND RECOMMENDATIONS

The results of the physico-chemical investigation of the study area have revealed the following:

1. The analysis of the results of most of the physico-chemical and heavy metals parameters of the groundwater are below the stipulated standards (NSDWQ and WHO), consequently, the water is found to be fresh and suitable for drinking, domestic uses in view of these parameters.
2. The results of the study show that pH values reveal slightly acidic groundwater in the study area. Consequently, the water should be treated to raise the value to the acceptable NSDWQ and WHO standard of 6.5 - 8.5. Base exchange method with dolomite is suitable for treating low pH. Another treatment method that can be used to treat low pH is Soda ash (sodium carbonate) and sodium hydroxide. This treatment technique, raise the pH of water to near neutral when injected into a water system. Unlike neutralizing filters, which is another treatment method, they do not cause hardness problems in treated water. Acidic groundwater is aggressive, hence boreholes in the area should be constructed with polyvinyl chloride (PVC) pipes and other non-corrosive materials. This is imperative because if pH is treated for at locations where they exceed the acceptable limits, the water will be potable and suitable for drinking and other domestic purposes.
3. Iron values are marginally high in some locations. The permissible limit of 0.3 mg/L as set by the NSDWQ were exceeded in some of the water samples. There are several methods for removal of iron from drinking water such as ion exchange and water softening. The process of oxidation by aeration, supercritical fluid extraction, limestone treatment, chlorination, ozonation followed by filtration are typically effective in eliminating iron from water.
4. The results of the study show that Total Coliform and Faecal Coliform values reveal considerably high values in 80% of the study area. Hence, at locations where Total Coliform and Faecal Coliform values are more than 10 MPN / 100 mL and 0 MPN / 100 mL respectively, as stipulated by NSDWQ as the permissible limit, it is essential to treat water acquired from these sources that exceeded the limit before consuming it. The best approach is inspection of the water system to find and eliminate any possible sources of contamination, once the source is identified, it can be resolved by making system repairs, and have the borehole system be disinfected by shock chlorination and flushing.
5. The study also reveals saltwater intrusion in 10% of the locations as chloride concentrations in some boreholes are up to 40 mg/L. This agrees with Udom et al. (2002); Amadi (2004); Nwankwoala (2013) as an indication of saltwater intrusion using the specification of Tremblay et al. (1973). This is probably due to the closeness of these locations to the sea. Therefore, seawater-freshwater interface should be delineated in the area.
6. The assessment of some contamination indicators, such as the concentrations levels of nitrate, phosphate, sulphate, lead, zinc, and nitrite indicate that the water chemistry has not been heavily contaminated by the land use in the area and is still mainly controlled by geogenic processes rather than anthropogenic activities.

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