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Assessment Of Quality And Hydrochemical Characteristics Of Groundwater From Ogu Community In Rivers State Nigeria

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ABSTRACT
The quality and hydrochemical characteristics of groundwater obtained from Ogu community in Rivers state, were evaluated. The levels of Physicochemical and Microbial Properties were determined using standard methods recommended by the American Public Health Association (APHA) and heavy metals with Atomic Absorption Spectrophotometer. Hydrochemical properties were determined by plotting Piper and Durov diagrams; Water Quality Indices were determined using an adopted mathematical model. The results showed maximum mean levels of pH (6.40±0.14), Total Heterotrophic Bacteria (3.90 ± 0.07 cfu/mL), Total Coliform Bacteria (0.45±0.49 MPN/100mL) and Faecal Coliform Bacteria (0.00±0.00 MPN/100mL), Manganese (1.19±0.01), Iron (0.51±0.00 mg/L), Lead (0.87±0.00 mg/L), Cadmium (0.28±0.12 mg/L), Chromium (1.67±0.00 mg/L) and Nickel (0.19±0.00 mg/L). pH levels of water in the area were below the set limits of Nigerian Standard for Drinking Water Quality (NSDWQ). Lead, Chromium, Cadmium and Manganese levels were above their standard limits in some stations. Plots of the Piper and Durov diagrams showed that the hydrochemistry of the water in the area is characterized majorly by Ion Exchange, Reverse Ion Exchange and Simple Dissolution processes. The Water Quality Indices showed that the groundwater in the area ranged from Good to Unsuitable for drinking. The findings of this study showed that the groundwater in the area requires proper treatment because it is unfit for human consumption.

Key words: *Groundwater, Water Quality Index, Hydrochemistry, Ogu, Rivers, Nigeria*

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I. INTRODUCTION

Ogu community is located in Ogu/Bolo Local Government Area, Rivers State, Nigeria. Ogu community is highly industrialized with some Chemical Companies like Indorama Fertilizer Company, and other chemical companies situated at the Ikpokiri/Onne Wharf, which could have some levels of impacts on the environment.

Despite making up nearly 71% of the earth's surface, water is one of the most in-demand resources, particularly in developing nations (Karikari and Ansa-Asare, 2006). They added that water is a necessity for human activity and is one of the most sought-after urban and rural utilities. Water is plentiful throughout the entire planet Earth, but it is not always accessible for human or ecosystem usage at the appropriate time or location, according to Oketola et al. (2010). Water is unquestionably the most valuable natural resource that is essential to life. Also, they asserted that water is spread naturally as surface and ground water from a variety of sources, including oceans, seas, rivers, streams, lakes, ponds, wells, boreholes and springs (Higler, 2012).

Water is a resource that can be used for a variety of purposes, such as recreation, transportation, hydroelectricity, and home, industrial, and commercial usage (Kumar, 2007). He further emphasized that water nourishes all life forms and has an impact on our health, way of life, and financial well-being. Just 2.8% of the water on Earth is suitable for human consumption, despite the fact that more than 75% of its surface is made up of water (Iskandar, 2010). Since the global freshwater consumption increased six times between 1900 and 1995, more than twice as quickly as the rate of population growth, one-third of the world's population currently lives in regions with moderate to high water stress. As a result, many regions of the world are experiencing water scarcity issues as a result of limited water resources and an aging population (UNEP, 2002).

There are numerous reports in the literature about people using water from surface and groundwater sources without any kind of treatment (Edokpayi et al., 2018). Due to its perceived cleanliness and safety, groundwater is frequently the first alternative choice for many consumers. Yet, numerous studies have demonstrated that even though groundwater may seem clean, it often harbors a variety of pathogenic species. The safety of groundwater (both shallow and deep groundwater sources) is influenced by a number of variables, including (I) the local geology (II) local human activity (including land use) (III) and local environmental and meteorological circumstances. Global reports of elevated amounts of cyanide, mercury, fluoride, and arsenic in groundwater have been made (Durowoju et al., 2016). Groundwater monitoring must be done constantly as a crucial part of water resource management (Wallender et al., 2014). When compared to areas that are susceptible to anthropogenic influences, surface water sources in pristine ecosystems are always of higher quality. Surface waters serve as the finest sinks for a variety of point and non-point sources of pollution, including storm runoff and wastewater from industrial and agricultural processes (Odiyo et al., 2012).

Positive health outcomes have been related to the use of clean and safe drinking water, and vice versa. For millions of people worldwide, obtaining a steady supply of potable water remains a huge concern. Due to a lack of water supply infrastructure or an insufficient amount of drinkable water, this issue is made worse in rural areas of the majority of developing countries (Edokpayi *et al.*, 2018). People are forced to look for alternate water sources, which are frequently groundwater sources through shallow or deep wells and boreholes or the abstraction of water from rivers and lakes, in the lack of sustainable access to drinkable water (Obi et al., 2002). A number of epidemics of water-borne illnesses have been documented in earlier research as a result of drinking tainted surface and groundwater (Bessong et al., 2009). As a result, drinking untreated or insufficiently treated water continues to pose a serious threat to public health. Most research on the quality of surface and groundwater fall short of giving policymakers and concerned people the most straightforward presentation of the findings regarding the condition of their water resources (Singaraja, 2017). If the findings are reported using the Water quality index, this issue is resolved (WQI). Because of this, complicated water quality criteria studied on water resources can be incorporated in a straightforward mathematical equation to produce conclusions that policymakers who may not be water specialists can easily grasp (Singaraja, 2017). Hence, WQI reduces a sizable amount of water quality data to a single number. By combining complex data and generating a score that describes the state of the water quality, it helps people understand problems with water quality (RamyaPriya & Elango 2018).

The inhabitants of Ogu community have over the years depended on borehole (groundwater) as their major source of drinking water, cooking, bathing, fishing as well as other domestic and agricultural activities. There has been outbreak of water borne diseases like typhoid fever, cholera and skin infections, traceable to the quality of water in the community. Therefore, it is necessary that research be carried out to evaluate the quality of water in Ogu community to provide baseline data for future studies.

II. MATERIALS AND METHODS

Study Area

The study was carried out in Ogu Community in Ogu-Bolo Local Government Area of Rivers State. It is located on Lat 4° 40' 10" North and Long 7° 12' 10" East (Fig. 1). It is readily accessible by a network of roads and foot paths and accessible to ships, boats, and canoes through the Bonny River and its tributaries. Ogu is a settlement with several archipelago type of villages and fishing ports straddled along its numerous and dense network of creeks. It is accessible through network of roads via Eleme, Okrika, and some other bounding communities.

The study area is confined within the humid-hot equatorial climate; the average annual temperature is between 180°C to 220°C with annual range of about 200°C. It is known for having two main seasons, the dry season and the wet season. The dry season begins from November and ends in March, while the wet stretches from mid-March to October. Fresh water is generally supplied by heavy precipitation estimated to have met annual rainfall above 2600 mm (Nwankwoala *et al.,* 2013).

The underlying sediments within this study area forms part of the stratigraphic sequence in the Niger Delta. They consist of unconsolidated fresh water bearing continental sands and gravels with occasional interbedded shale of the Benin Formation, deposited during the late Tertiary to early Quaternary period with an average thickness of about 2100m. The Benin Formation constitutes the main aquifer system of the study area and forms the main source of portable ground water supply. Structurally, the sediments in the area are deposited in the NW-SE trend and groundwater flow occurs in line with this trend (Ehirim and Ebeniro, 2006). However, local variations occur in places due to the anisotropic behaviour of the sediments. Rainfall in the area varies over a wide range in temporal context because of the occurrence of wet and dry season. The bulk of groundwater in the Niger Delta is contained in very thick and extensive sediments of Benin Formation.

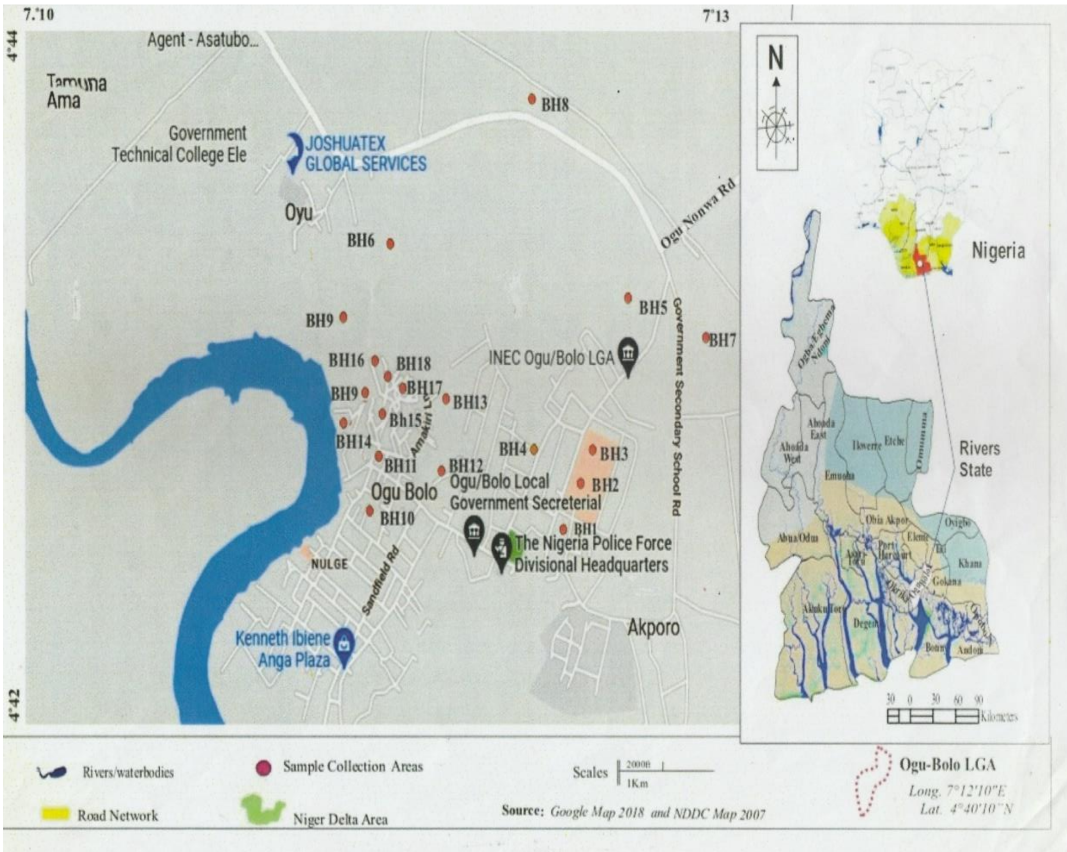

Figure 1: Map of Ogu town showing sampling locations

pH (Electrometric Method)
The pH meter was first calibrated with prepared buffer solutions 7.0, 4.0 and 10.0 and afterwards, the pH of respective samples was measured at room temperature.

Total Alkalinity
Exactly 50 ml of the sample was transferred into a 200 ml Erlenmeyer flask. Then 3 drops of methyl orange was added and titrated against 0.025N H_2SO_4 which changed from orange to pink as end-point.
Calculation:

$$\text{Total Alkalinity as } CaCO_3 \text{ (ppm)} = \frac{\text{R x N x 50 x 1000}}{\text{V}} \qquad (1)$$

Where R = Reading of 0.02N H_2SO_4 in ml for Total alkalinity
N = Normality of Sulphuric acid
V = Volume in ml of the Sample taken for analysis

Electrical Conductivity
The conductivity meter was first calibrated using 0.01N KCl solution and the electrodes submerged in the samples. The results were read directly from the conductivity meter displayed in µS/cm.

Total Hardness
Exactly 25 ml of the sample was transferred into a 200 ml Erlenmeyer flask. 1 ml of NH_4 buffer was added as an indicator. Then a pinch of Erychrome black T was added. This prepared solution was titrated against EDTA solution. The pink colour of solution was turned into blue showing the completion of titration.
Calculation:

$$\text{Total Hardness as } CaCO_3 \text{ (ppm)} = \frac{\text{R x M x 100 x 1000}}{\text{V}} \qquad (2)$$

Where:
R = Corresponding volumes in ml of EDTA added till end point
M = Molarity of EDTA solution
V = Volume in ml of sample taken

Chloride (Cl^-)

This was determined by placing 50 ml of the water sample in a 250 ml beaker. The pH was adjusted to the range of 7-10 by gradually adding H_2SO_4. Then 0.25 ml of K_2CrO_4 was added as indicator and the solution was titrated with 0.1 N silver nitrate which changed from yellow to brick red end-point.
Calculation:

$$\text{Chloride in ppm} = \frac{\text{BR x N x 35.5 x 1000}}{\text{Volume of sample (ml)}} \qquad (3)$$

Where:
BR = Volume in ml of Silver nitrate consumed
N = Normality of Silver nitrate

Phosphate (PO_4^{3-})
(Stannous Chloride method)

To 25 mL of the water in a conical flask, 0.5 mL of ammonium molybdate and 0.2 mL of stannous chloride was added; the mixture was then made to stand for about twelve minutes, and immediately the absorbance read at the wavelength of 690 nm, using a spectrumlab S23A spectrophotometer.
Calculation:

$$\text{Phosphate as } PO_4^{3-} = \frac{\text{Absorbance reading x 1000}}{\text{Slope value x Volume of sample (ml)}} \qquad (4)$$

Nitrate (NO_3^-)

Nitrate reagent powder was added to 25 mL of the sample previously poured into the sample cell and the concentration of nitrate was measured at a wavelength of 400 nm after 5 minutes.
Calculation:

$$\text{Nitrate as } NO_3^{2-} = \frac{\text{Absorbance reading x 1000}}{\text{Slope value x Volume of sample (ml)}} \qquad (5)$$

Turbidity

The sample cell of the spectrophotometer was filled with the water sample and wiped with tissue paper and placed in the sample holder. The absorbance was measured after few seconds.

Total Dissolved Solids (TDS)

A cleaned and dried evaporating dish was used, kept in a desiccator for 30 mins to cool and weighed (W1 grams). The filtrate was evaporated to dryness on a water / steam bath.
The evaporating dish was then dried in an oven for 1 hour and cooled in a desiccator for 30 minutes and weighed (W2 grams).
Calculation:

$$\text{Total Dissolved Solids} = \frac{(\text{W2} - \text{W1}) \text{ x } 10^6}{\text{Volume of sample in ml}} \qquad (6)$$

Where,
W2 = Weight of residue + evaporating dish in gram
W1 = Weight of empty evaporating dish in gram

Determination of Heavy Metals

Sample collected from study area was analyzed using Atomic Absorption Spectrophotometer (AAS). To determine the concentrations of heavy metals, the sample was aspirated into a flame where it became atomized. A beam of light was directed through the flame into a monochromator and later into a detector that measured the intensity of the light energy absorbed. The quantity of light produced by a specific lamp, absorbed in the flame is directly proportional to the concentration of the element in the sample.
Calculation:

$$\text{Conc. of sample (ppm)} = \frac{\text{Sample absorbance}}{\text{Standard absorbance}} \text{ x conc. of std. x dilution factor} \qquad (7)$$

Determination of Microbiological Content

Preparation of MacConkey purple media of single and double strength in test tubes with Durham's tube was done and thereafter it was autoclaved. Three sets of test tubes containing five tubes in each set; one set with 10 ml of double strength (DS) other two containing 10 ml of single strength (SS) were taken. Sterile pipettes were used to transfer 10 ml of water to each of the DS broth tubes. 1 ml of water sample was transferred to each of 5 tubes of one set of SS broth as well as 0.1 ml water to five tubes of the remaining last set of SS broth tubes. The tubes were then incubated at 37 ºC for 24 hours. After incubation, the gas production in Durham's tube was observed as well as the colour change

Water Quality Index

The WQI is computed in four steps, calculated using the following Equations 8 – 12 adopted from Sener (2017). A weight (w_i) was assigned to each parameter recording to its importance in drinking water purposes.

Step 1: Compute the Relative Weight (W_i) for each parameter using equation (8)

$$W_i = \frac{W_i}{\sum_{i=1}^{n} W_i} \qquad (9)$$

Step 2: Assign a quality rating scale (q_i) for each parameter by dividing its determined concentration (c_i) in each sample by its respective guideline value (s_i); multiplied by 10

$$q_i = \left(\frac{C_i}{S_i}\right) \text{ x } 100 \qquad (10)$$

Step 3: Determine the sub index (SI_i) for each parameter using equation (11)

$$SI_i = W_i \text{ x } q_i \qquad (11)$$

Step 4: Sum all sub-indices to get the WQI

$$WQI = \sum_{i=1}^{n} SI_i \qquad (12)$$

"Where SI_i represents the sub-index of the ith indicator, W_i is the relative weight, q_i represents the quality rating for each chemical indicator, w_i is the weight of each element". The WQI classifies the water quality as "Excellent (WQI<50), Good (WQI = 50 – 100), Poor (WQI = 100 - 200), Very Poor (WQI = 200 -300) and Unsuitable for Drinking (WQI > 300)" (Ramakrishnaiah *et al*., 2009; Batabyal & Chakraborty, 2015).

III. RESULTS AND DISCUSSION

Physicochemical Properties

The mean levels of physicochemical properties of the groundwater samples from the study are presented in Figs. 2a-d - 5 and Tables 1 and 2.

Variations in the levels of the physicochemical properties analyzed in the groundwater samples across the stations in the study area are shown in Figs. 2a-d – 5.

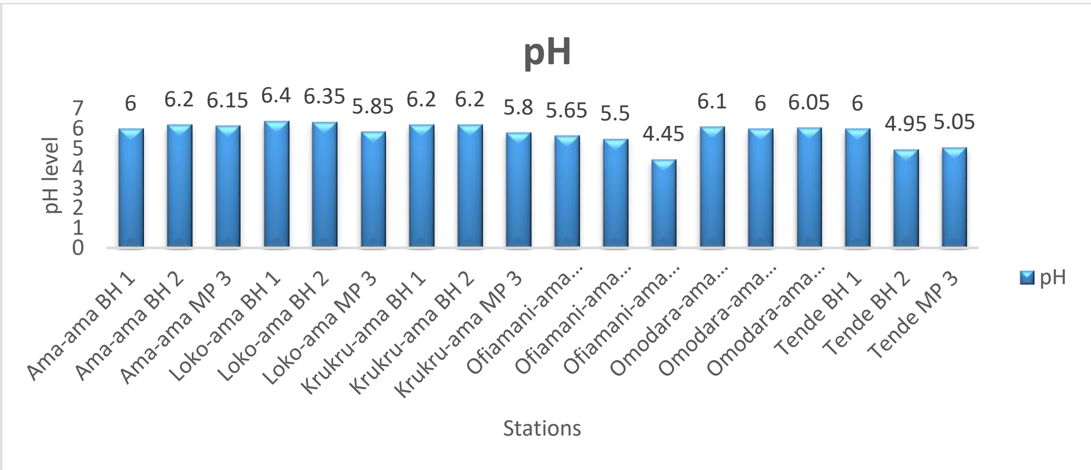

Fig. 2a: Mean pH Level across all Stations

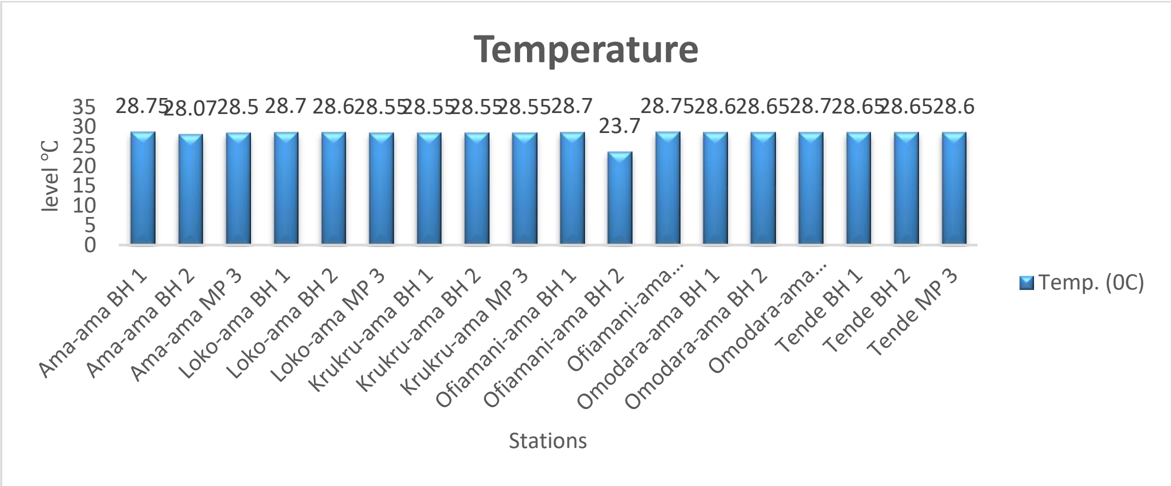

Fig. 2b: Mean Temperature Level across all Stations

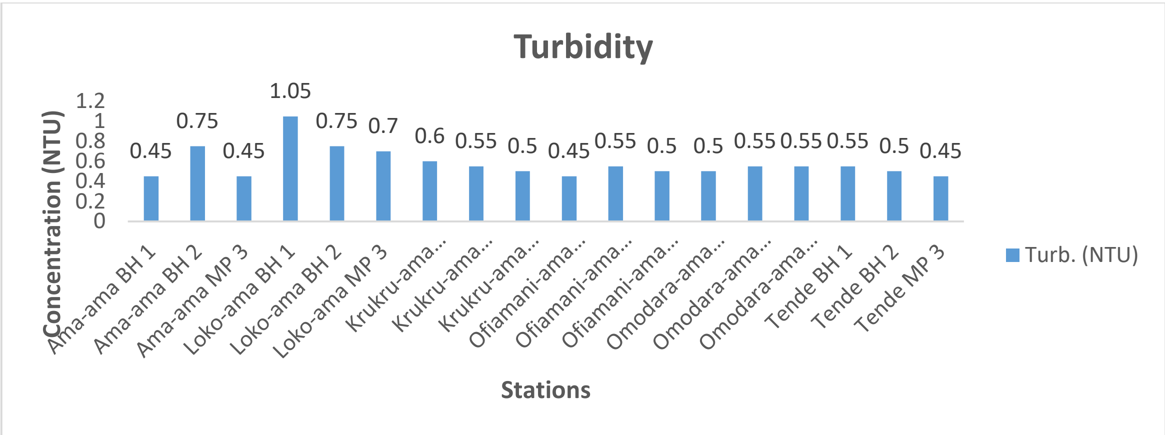

Fig. 2c: Mean Turbidity Level across all Stations

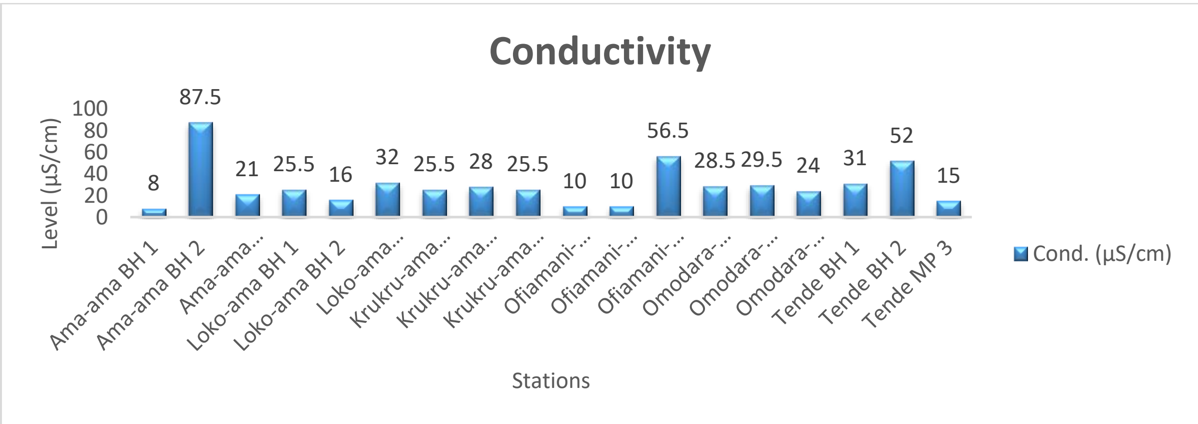

Fig. 2d: Mean Conductivity Level across all Stations

Fig. 2 (a-d): Variations in Levels of some Physicochemical Parameters

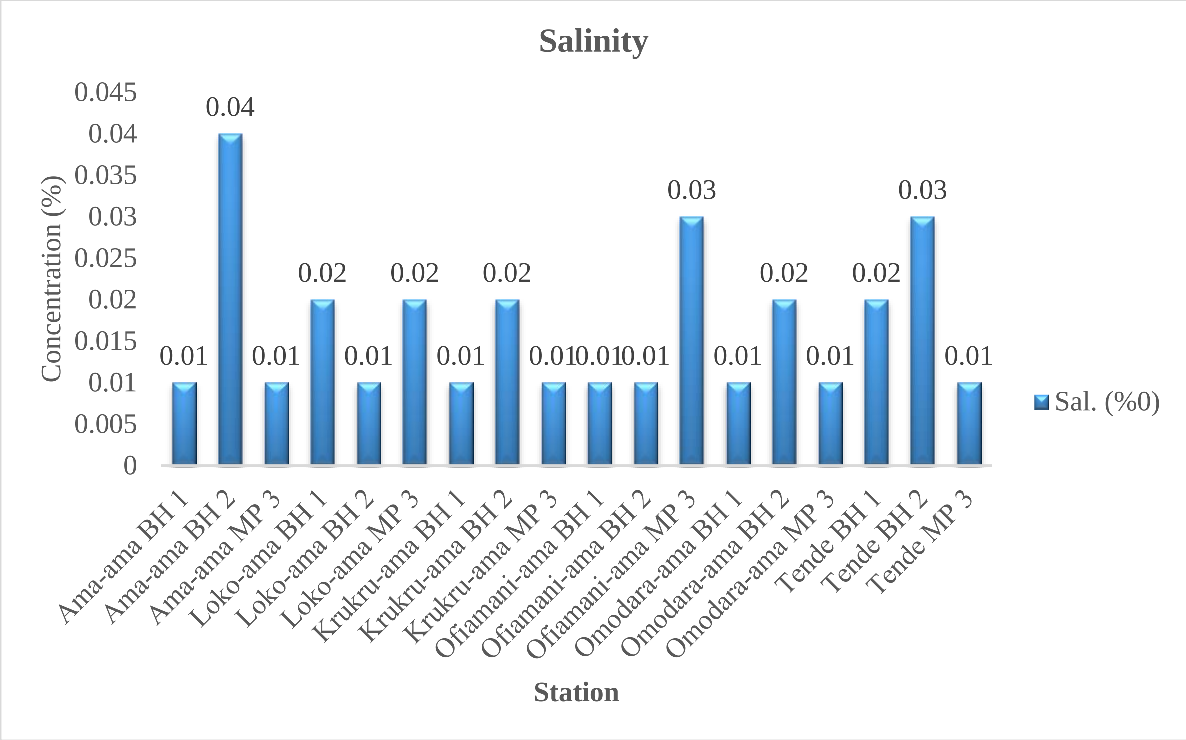

Fig. 3: Variations in Levels of Salinity at the Study Area

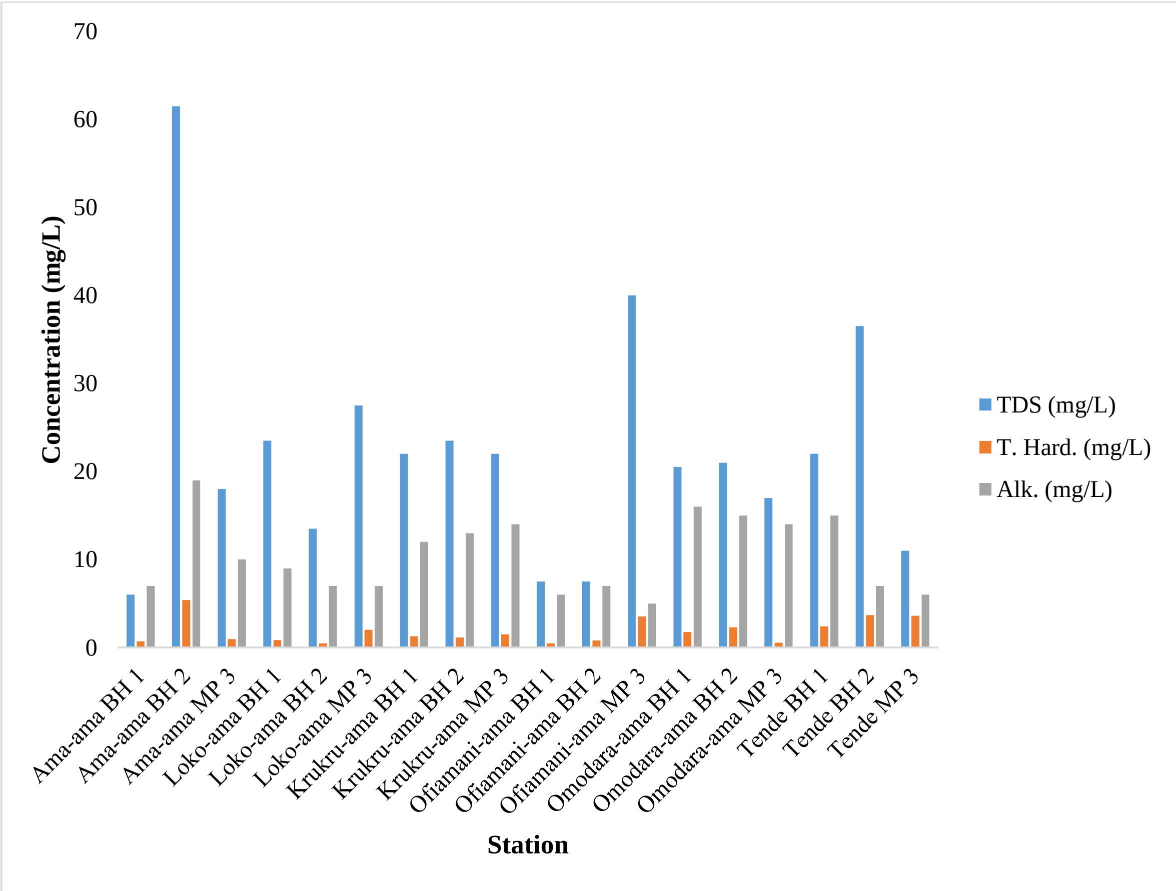

Fig. 4: Variations in Levels of some Physicochemical Properties

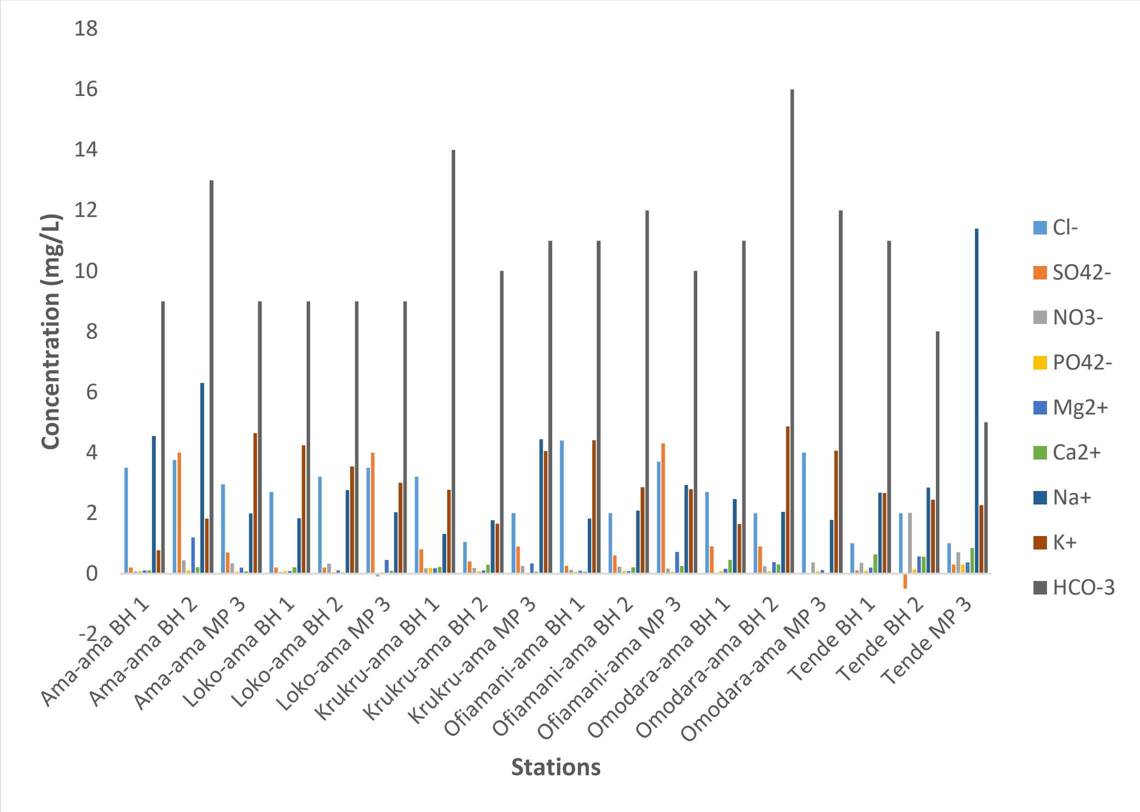

Fig. 5: Variations in Levels of some Physicochemical Properties

Levels of physicochemical properties analyzed in the groundwater samples were compared with acceptable limits set by WHO (1996), USEPA (2004) and NSDWQ (2015).

The mean pH levels of the groundwater samples were all below the WHO and USEPA acceptable limits of 6.5 – 8.5. The lower pH implies that the water in some stations was slightly acidic and can cause redness and irritation of eyes in human beings during the usage and corrode pipes (Obunwo & Opurum, 2013). However, the values obtained in the present study for pH were similar to the studies reported by Woke and Umesi, (2018) and Agbalagba *et al.*, (2011) in the Niger Delta area.

The temperature levels obtained from the groundwater samples were within the NSDWQ acceptable limits. Temperature influences the reduction in solubility of gases in water, amplification of taste and colour and also controls the rate of chemical reactions (Olajire and Imeppeoria, 2001). High temperature increases chemical reactions in the aquifer such as weathering of rocks which leads to the release of the chemical contaminants in water and reduces the level of dissolved gas in water (Murhekar, 2011). Generally, cool water is more potable than warm water; high water temperature enhances the growth of microorganisms and may increase problems related to taste, odour, colour and corrosion (WHO, 2011). The results of this study are similar to that reported by Agbalagba *et al.*, (2011).

Turbidity levels in the groundwater samples were below the WHO acceptable limit of 5.0 NTU. Turbidity is an important parameter in drinking water analysis and it's also related to the population of disease-causing microorganisms present in water which could come from soil runoff (WHO, 2011). Turbidity of water has influence on other parameters such as color and even chemical parameters which affect water quality (Olumuyiwa *et al.*, 2012). The values obtained were similar to previously reported values in the Niger delta region, Nigeria (Woke and Umesi 2018).

Electrical conductivity levels of all the groundwater samples analyses in the study area were below the NSDWQ acceptable limit of 1000 µS/cm. Ideriah, (2015), reported similar conductivity values in a study carried out at Andoni Rivers State, Nigeria. Electrical conductivity is the ability of an object to conduct electric current. It gives the total concentration of the electrolytes; it depends upon the presence of various ionic species. Electrical conductivity increases with increase in chloride, Hardness, calcium, magnesium and total dissolved solids (Ideriah, 2015).

The acceptable limit for TDS in drinking water is 600 mg/L and 500 mg/L as set by WHO and NSDWQ. Analysis revealed that all the stations had TDS levels below the acceptable limit. TDS values were within the range of values obtained from the studies of Balogun *et al.*, (2014), on drinking water in Abeokuta.

Ama BH2 recorded the highest salinity level of 0.04 ‰; and there are no set limits for salinity by WHO, USEPA or NSDWQ. The levels of electrical conductivity, salinity as well as TDS mostly go together (Amangabara & Ejenma., 2012). High levels of salinity in water and soil may cause corrosion of machinery and infrastructure such as fences, roads and bridges, poor health or death of native vegetation, leading to a decline in biodiversity through dominance of salt-resistant species, potentially altering ecosystem structures and reduction in crop yields by impairing the growth and health of salt intolerant crops (Yasmeen, 2019).

The acceptable limit for total hardness (T.H) in drinking water is 150 mg/L as set by NSDWQ. All groundwater samples had total hardness levels below the acceptable limit. Agbalagba *et al.,* (2011) reported higher levels of hardness in groundwater in a study carried out at Rumuola, Rumuigba and Rumuokwuta Communities, Rivers State.

Hard water does not pose a health hazard, but may constitute a nuisance concerning its use for other domestic activities such as washing and household cleaning. Hardness is an important parameter in reducing the harmful effect of poisonous elements in water (Bhatt *et al*., 1999); also continued intake of soft water has been linked to cardiovascular diseases (Miroslav and Vladimir, 1999).

Alkalinity levels were below the acceptable limit of 120 mg/L set by WHO for drinking water in all the groundwater samples. Alkalinity levels recorded in this study are in agreement with those obtained by Ideriah (2015). Alkalinity is a measure of weak acid and their salts present in water or as the acid neutralizing capacity of water body. Alkalinity in natural water is due to the presence of salts of weak acids (Nirmala *et al*., 2012). Natural waters contain appreciable amounts of carbonate and hydroxyl alkalinities. The slightly higher mean values can be attributed to alkaline substances which are able to reach water body during this period from the sea (Ombaka *et al*., 2013).

All groundwater samples analyzed in the study area had chloride levels below the NSDWQ and USEPA acceptable limit of 250 mg/L. The levels obtained are also within the range of values reported by Nwala *et al.*, (2007); but are below the values reported by Bolaji and Tse (2009) in the Niger Delta region. Chloride is mainly obtained from the dissolution of salts of hydrochloric acid such as table salt (NaCl) and $NaCO_2$, and added through industrial waste, sewage, sea water etc. Chloride is important in the metabolic activities in human body and also takes part in other physiological process. High chloride concentration is harmful to growing plants and also damage metallic pipes and structure. The sources of chloride in natural water could be attributed to the dissolution of chloride containing minerals and rocks when water comes in contact with them due to pollution from discharge of agriculture, industrial and domestic waste waters which get their way into the water sources (Bohlke, 2002).

Sulphate levels in the groundwater samples were all below the NSDWQ and WHO acceptable limits of 100 mg/L and 250 mg/L respectively. Station Ofiamani MP3 recorded the highest sulphate level of 4.30 mg/L. The levels of sulphate recorded in this study are below that reported by Agbalagba *et al.*, (2011) in Yenagoa Bayelsa State. The low concentrations of sulphate recorded in the groundwater samples could be due to the absence of anthropogenic activities that influence its concentration in water bodies. Sulphates naturally occur in groundwater via sulphides dissolution by percolating water, passing through the interstratified materials, such as pyrite, producing sulphate ions (Olobaniyi and Owoyemi, 2006).

Nitrate levels recorded in the groundwater samples were below the standard limits of 50 mg/L set by NSDWQ and WHO. The highest level of 2.01 mg/L was recorded at station Tende BH2. These values are below reported values by Nwala *et al.,* (2007) and Bolaji and Tse (2009) within the Niger Delta region. Prolonged exposure to nitrite and nitrate at levels above the maximum acceptable concentration could cause such problems as diuresis, increased starch deposits and hemorrhaging of the spleen (Reimann *et al*., 2003). The low levels of nitrates generally across all stations which were all within standards limits showed that heavy agricultural activities were not carried out near the sampling sites and this is confirmed by suthar *et al*. (2009). In his studies, where he associated high levels of nitrates in ground water places with intensive agriculture and heavy use of nitrogen fertilizer. The low level of nitrate agrees with Chavan and Zambare (2014).

Phosphate levels in the groundwater samples from the study area varied between 0.03 ± 0.00 to 0.29±0.33. All values were below the standard limit of 200mg/L set by NSDWQ. Agbalagba *et al.*, (2011), reported similar phosphate level in a study carried out in same region.

Generally, the low concentration of phosphate in all stations implies that there are minimal interferences of waters from anthropogenic activities in the area. This was in line with a study done by Olumuyiwa *et al.* (2012). Natural geogenic sources might have a greater influence on concentrations in groundwater than anthropogenic sources. Concentrations of dissolved phosphorous (DP) in ground water are low because phosphorous tends to sorbs to soil and aquifer sediments and is not readily transported into the groundwater (Holman *et al*., 2008).

Calcium levels in the groundwater samples fell below the acceptable limit of 50 mg/L by WHO for drinking water. The acceptable limits for magnesium are 50 mg/l and 20 mg/L as set by WHO and NSDWQ respectively. All samples fell below the standard limit set by WHO and NSDWQ. These values of calcium and magnesium from this study are lower than the values reported by Nwala *et al.*, (2007) and Bolaji and Tse (2009) in the Niger Delta region. Leoni *et al.*, (1985), in studies carried out in Abruzzo, Italy, reported an inverse relationship between the hardness (Calcium and Magnesium ions content) of drinking water and cardiovascular diseases. It has also been reported that calcium and magnesium in drinking water may help protect against gastric, colon, rectal cancer, and pancreatic cancer, and magnesium may help protect against esophageal and ovarian cancer (Pallav, 2013).

Sodium levels in the groundwater samples from the study area varied from 1.31±0.46 mg/L – 11.4 ± 8.24 mg/L. There is no WHO and NSDWQ set limit for sodium in drinking water. The recorded potassium levels in the groundwater samples were all below the acceptable limit of 200 mg/L set by NSDWQ. Station Omodara BH2 recorded the highest level of 4.86 mg/L. These values obtained are similar to those reported by Bolaji and Tse (2009) and has no health implication to the public consumer of the water in terms of Na^+ and k^+.

The maximum and minimum bicarbonate levels of 16.0±5.66 mg/L and 5.00±1.41 mg/L were recorded at Omodara BH2 and Tende BH3 respectively. Edet *et al* (2011) reported a HCO_3^- level of 71.50 mg/L within the Niger Delta area. There is no set limit for bicarbonate by WHO and NSDWQ. According to Davis and Dewiest (1966), bicarbonate rarely exceeds 40 - 400 mg/L in groundwater. Bicarbonate helps to buffer lactic acid generated during exercise and also reduces the acidity of dietary components (Mason, 2001).

Microbial Content

The results of microbial analysis of the groundwater samples are shown in Table 1.

Mean Feacel Colifrm Bacteria (FCB) count was between 0.00±0.00 and 0.00±0.00 MPN/100mL; Total Coliform Bacteria (TCB) count ranged from 0.00±0.00 to 0.45±0.49 cfu/mL while Total Heterotrophic Bacteria (THB) count ranged between $0.04\times10^2\pm0.57\times10^2$ and 3.90×10±0.07×10 cfu/mL.

Groundwater at stations Ama BH2 (0.20 cfu/mL), Loko BH2 (0.45 cfu/mL) and Ofiamani MP3 (0.05 cfu/mL) had Total Coliform Bacteria present and above the safety limit of 0.00 cfu/mL by NSDWQ. Total Heterotrophic Bacteria present and above the NSDWQ safety limit in all the stations with station Loke (MP3) having the highest count of 3.90 x 10. However, all the groundwater samples showed no presence of Faecal Coliform Bacteria thus there is risk no risk of faetherercal contamination.

Table 1: Mean Levels of Microbial Content in the Groundwater

PARAMETERS	FCB (MPN/100mL)	TCB (MPN/100mL)	THB (cfu/mL)
Ama-ama BH 1	0.00 ± 0	0.00 ± 0	$0.16 \times 10^2 \pm 0.057 \times 10^2$
Ama-ama BH 2	0.00 ± 0	0.20 x 10 ± 0.28 x 10	$0.65 \times 10^2 \pm 0.92 \times 10^2$
Ama-ama MP 3	0.00 ± 0	0.00 ± 0	0.60 x 10 ± 0.90 x 10
Loko-ama BH 1	0.00 ± 0	0.00 ± 0	$0.33 \times 10^2 \pm 0.37 \times 10^2$
Loko-ama BH 2	0.00 ± 0	0.45 x 10 ± 0.49 x 10	$0.40 \times 10^2 \pm 0.46 \times 10^2$
Loko-ama MP 3	0.00 ± 0	0.00 ± 0	3.90 x 10 ± 0.07 x 10
Krukru-ama BH 1	0.00 ± 0	0.00 ± 0	$0.09 \times 10^2 \pm 0.11 \times 10^2$
Krukru-ama BH 2	0.00 ± 0	0.00 ± 0	0.30 x 10 ± 0.10 x 10
Krukru-ama MP 3	0.00 ± 0	0.00 ± 0	$0.28 \times 10^2 \pm 0.16 \times 10^2$
Ofiamani-ama BH 1	0.00 ± 0	0.00 ± 0	$0.34 \times 10^2 \pm 0.48 \times 10^2$
Ofiamani-ama BH 2	0.00 ± 0	0.00 ± 0	0.20 x 10 ± 0.30 x 10
Ofiamani-ama MP 3	0.00 ± 0	0.05 x 10 ± 0.71 x 10	$0.28 \times 10^2 \pm 0.12 \times 10^2$
Omodara-ama BH 1	0.00 ± 0	0.00 ± 0	0.30 x 10 ± 0.40 x 10
Omodara-ama BH 2	0.00 ± 0	0.00 ± 0	0.70 x 10 ± 0.40 x 10
Omodara-ama MP 3	0.00 ± 0	0.00 ± 0	$0.04 \times 10^2 \pm 0.57 \times 10^2$
Tende BH 1	0.00 ± 0	0.00 ± 0	$0.35 \times 10^2 \pm 0.36 \times 10^2$
Tende BH 2	0.00 ± 0	0.00 ± 0	$0.55 \times 10^2 \pm 0.64 \times 10^2$
Tende MP 3	0.00 ± 0	0.00 ± 0	$0.20 \times 10^2 \pm 0.39 \times 10^2$

Heavy Metal Analysis

Variation in the heavy metal levels analyzed in the groundwater samples across the stations in the study area is shown in Fig. 4.

Nickel levels in the groundwater samples fell below the acceptable limits of 0.07 mg/L and 0.02 mg/L set by WHO and NSDWQ respectively, except for stations Tende BH2 (0.19 mg/L), which had level above the WHO and NSDWQ limits. Nickel may be present in groundwater as a consequence of dissolution from nickel ore-bearing rocks, influenced by high acidity of the water (WHO, 2006).

The acceptable limit for chromium in drinking water, as set by WHO and NSDWQ, is 0.05 mg/L. All the groundwater samples analyzed had chromium levels above the set limit. Evidently, it was seen that the results were higher and this is also attributed to the soil composition and probably dilution during the wet season couple with anthropogenic wastes disposal on the environment (Appiah-Opong *et al.*, 2020).

Iron levels in the groundwater samples fell below the WHO and NSDWQ acceptable limit of 0.30 mg/L except for those of stations Ama BH1 (0.41 mg/L) and Omodara BH1 (0.51 mg/L). Biologically iron is the most important nutrient for most living creatures as it is the cofactor for many vital proteins and enzymes (Jaishankar *et al*, 2014). Water containing an excessive concentration of iron has been reported to constitute a human health hazard leading to hemochromatosis, whose signs include fatigue and eventually, heart disease, liver complications, and diabetes (Ekere *et al*, 2014). Children are highly susceptible to iron toxicity as they are exposed to a maximum of iron containing products (Albretsen, 2006). Anthropogenic sources of iron in groundwater resources may also include the use of paints, indiscriminate disposal of smelter slag and waste containing high iron concentrations may leach into the ground at a higher rate during dry season and as a result increase the concentrations (Ombaka *et al.*, 2013).

The acceptable limit for lead as set by WHO and NSDWQ is 0.01 mg/L. Groundwater samples at stations Ama MP3 (0.30 mg/L), Loko (0.39 mg/L), Loko MP3 (0.50 mg/L), Kurukuru BH2 (0.26 mg/L), Ofiamani BH1 (0.34 mg/L), Ofiamani MP3 (0.72 mg/L), Omodara BH1 (0.64 mg/L), Omodara MP3 (0.27 mg/L), Tende BH2 (0.20 mg/L) and Tende MP3 (0.87 mg/L) had levels above the set acceptable limit. Lead is considered very important heavy metal because it is toxic, very common and hazardous even in low concentration. Although lead could be remove from humans via urine, however increased exposure to lead over a long period may result to excessive accumulation, especially in children. High concentration of lead can cause serious brain damage and kidney failure (Gebrekidan & Samuel 2011).

Manganese levels in the groundwater samples were below the acceptable limits of 0.05 mg/L and 0.20 mg/L set by WHO and NSDWQ respectively, except for those of stations Loko MP3(0.45 mg/L), Kurukuru MP3 (0.34 mg/L), Ofiamani MP3 (0.72 mg/L), Omodara BH2 (0.38 mg/L), Tende BH2 (0.57 mg/L) and Tende MP3 (0.37 mg/L) which recorded levels higher than the NSDWQ set limit. Studies have linked excessive manganese to the human kidney, liver, and pancreas diseases and also causes of neurological disorders (Longe and Balogun, 2010).

The acceptable limit for Cadmium in drinking water, as set by WHO and NSDWQ is 0.003 mg/L. Groundwater samples from all the stations had cadmium levels above the acceptable limits.

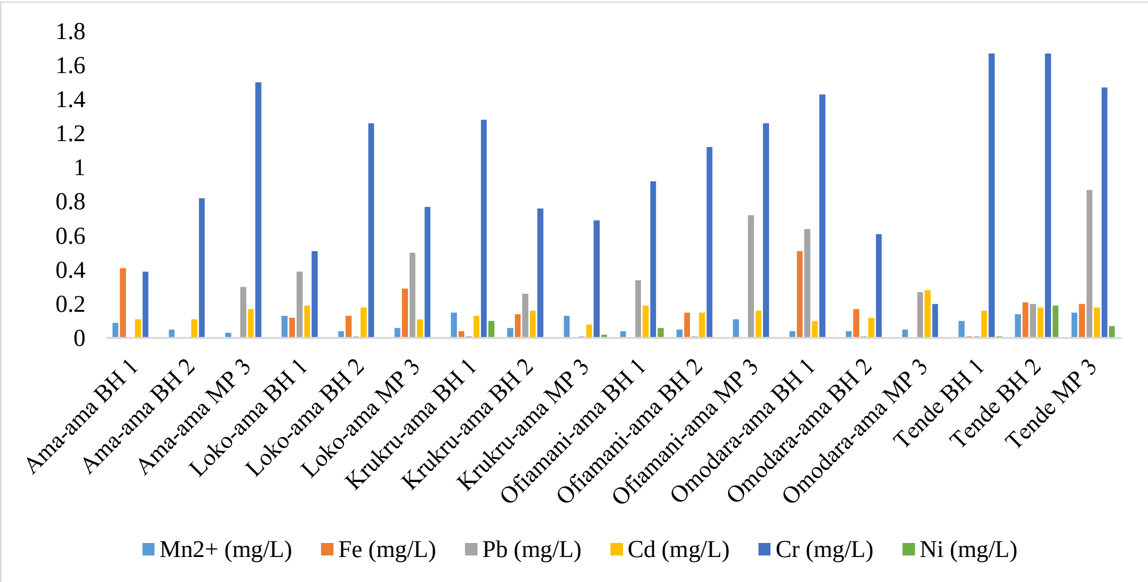

Fig. 6: Variations in Levels of Heavy Metals

Water Quality Index

The Water Quality Index values obtained for groundwater samples in the study area are shown in Fig. 7. The index values ranged between 36 and 643.

The Water Quality Index values showed that station Ama BH1 (82) had water quality rated as GOOD for drinking; Ama BH2 (128), Loko BH2 (188), Kurukuru MP3(119), Ofiamani BH2 (169) and Omodara BH2 (104) had their water quality rated as poor for drinking; Tende BH1 (214) and Kurukuru BH1 (241) had their water quality rated as very poor for drinking; Tende MP3 (1188), Tende BH2 (552), Omodara MP3 (328), Omodara BH1 (905), Ofiamani MP3 (954), Ofiamani BH1 (529), Kurukuru BH2 (394), Loko MP3 (661), Loko BH1(503) and Ama MP3 (530) had their water quality rated as unsuitable for drinking.

Hydrochemical Characteristics

The triangular plots of the Piper diagram reveal the ion types of the groundwater samples.

The Cations showed dominance of the Na^{+}+K^{+} type, having 100% of the groundwater samples - Ama BH1, Ama BH2, Ama MP3, Loko BH1, Loko BH 2, Loko MP3, Kurukuru BH1, Kurukuru BH 2, Kurukuru MP3, Ofiamani BH1, Ofiamani BH2, Ofiamani MP3, Omodara BHI, Omodara BH2, Omodara MP3, Tende BH1, Tende BH2 and Tende MP3.

The Anions showed a dominance of the HCO_3^- type, having 90% of the groundwater samples - Ama BH1, Ama BH2, Ama MP3, Loko BH1, Loko BH 2, Kurukuru BH1, Kurukuru BH 2, Kurukuru MP3, Ofiamani BH1, Ofiamani BH2, Omodara BHI, Omodara BH2, Omodara MP3, Tende BH1, Tende BH2 and Tende MP3.; 10% were of the mixed ion type.

The diamond plot reveals the classification of the water types. 75% of the groundwater samples (Ama BH1, Ama MP3, Loko BH1, Loko BH 2, Kurukuru BH1, Kurukuru BH 2, Kurukuru MP3, Ofiamani BH1, Ofiamani BH2, Omodara BH2, Omodara MP3, Tende BH1, Tende BH2 and Tende MP3.) were classified as the Sodium Bicarbonate type; 25% (Ama BH2, Loko MP3, Ofiamani MP3) were classified as the mixed ion type.

The classification by Lloyd and Heathcoat (1985) was used to interpret the Durov Diagram.

The diagram revealed that 45 % of the samples (Ofiamani MP3, Loko MP3, Ama BH2, Loko BH1, Loko BH2, Ama MP3 and Ofiamani BH1) were plotted in square 6, indicating an exhibition of simple dissolution or mixing process; 55 % (Tende BH1, Omodara BH2, Kurukuru BH2, Ofiamani BH2, Kurukuru MP3, Tende MP3, Kurukuru BH1, Tende BH2 and Omodara BH1) fell in square 9, indicating they exhibit reverse ion exchange process.

According to Lloyd and Heathcoat (1985), the three major water-rock interactions are Ion Exchange, Reverse Ion Exchange and Simple Dissolution or Mixing. Depending on the components of the rock type, groundwater quality is affected by either of these processes. For example, ion exchange with clay materials in rock formations can be responsible for the concentration of ions in groundwater**.** Direct ion exchange and reverse ion exchange processes can be expressed as shown in equations 13 and 14 respectively.

$$2Na^{+} + CaX_2 = 2NaX + Ca^{2+} \quad (13)$$

$$Ca^{2+} + 2NaX = CaX_2 + 2Na^{+} \quad (14)$$

Where X indicates the soil exchanger

An excess of Ca^{2+} or Mg^{2+} in groundwater may be due to the exchange of Na^{+} in the water by Ca^{2+} or Mg^{2+} in clay material, while an excess of Na^{+} may be due to the exchange of Ca^{2+} or Mg^{2+} in the water by Na^{+} in clay material. In simple dissolution, $CaCO_3$ in rocks, for example, can be readily dissolved by water giving rise to Ca^{2+} ions**.**

Groundwater quality is also dependent on nature of bedrock, topography, geology, soils, climate, atmospheric precipitation and quality of the recharged water in addition to anthropogenic pollution sources in terms of agricultural and industrial activities. Gaining a clear understanding of the main factors governing groundwater chemistry is important for managing groundwater resources. The hydrochemical properties of groundwater in the study area were investigated by hydrochemistry. The plots of the Piper, Durov and Gibbs diagrams revealed the hydrochemical characteristics of the groundwater samples.

plotting the Piper and Durov diagrams.

Piper Trilinear Diagram, developed by Piper (1944), evaluates the evolution of the river water and relationship between rock types and water composition. Plotting of samples on the Piper Trilinear Diagram reveals the composition of the water in the different sampling stations, indicating the water type. The milliequivalents of the various anions and cations are used and are plotted in two different triangular graphs as shown in Fig. 8. The points of these anions and cations on the x, y and z axes of the triangular graphs are extrapolated to determine the dominant ion types. The extrapolated points on the triangular graphs are further projected onto the diamond graph to determine the water type.

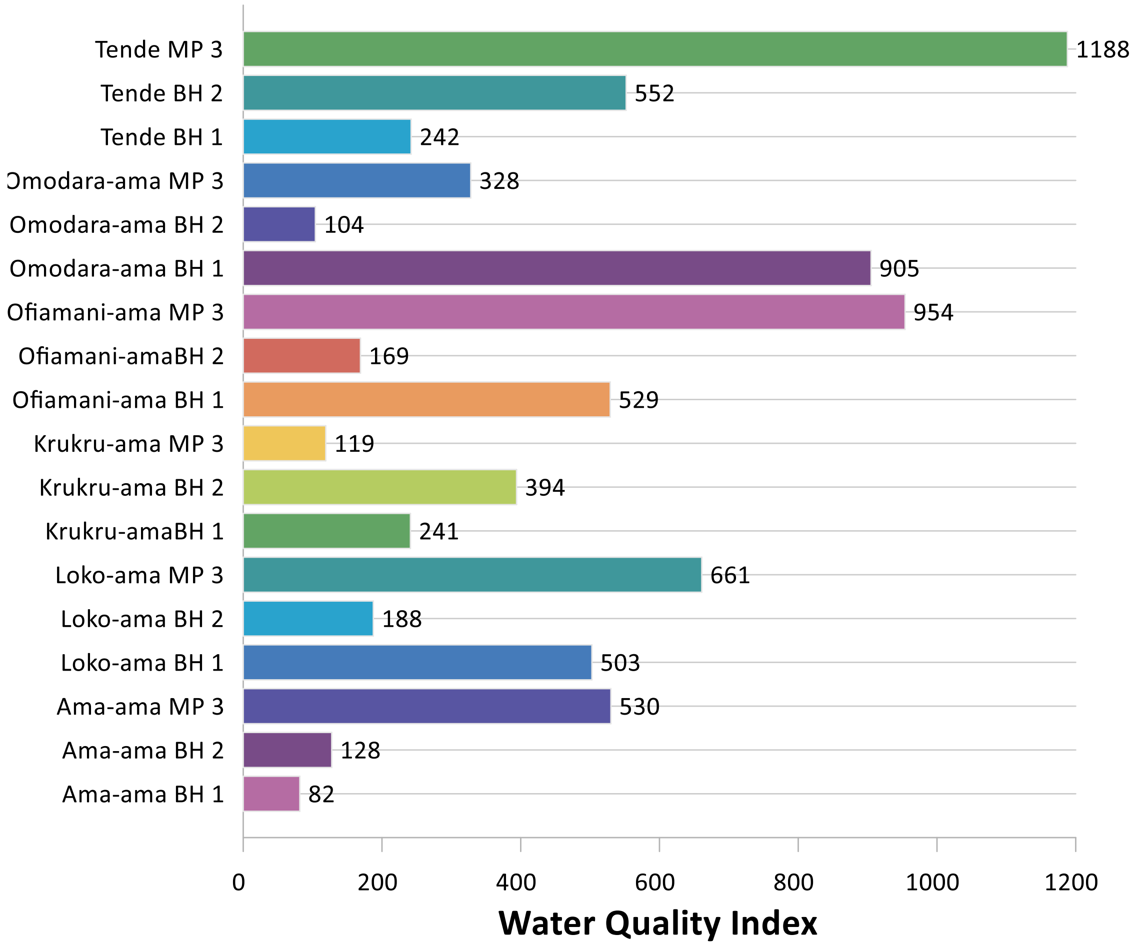

Fig. 7: Water Quality Index

WQI Rating:
0 – 50 = **Excellent,** 50 – 100 = **Good,** 100 – 200 = **Poor,** 200 – 300 = **Very Poor**
>300 = **Unsuitable for Drinking**

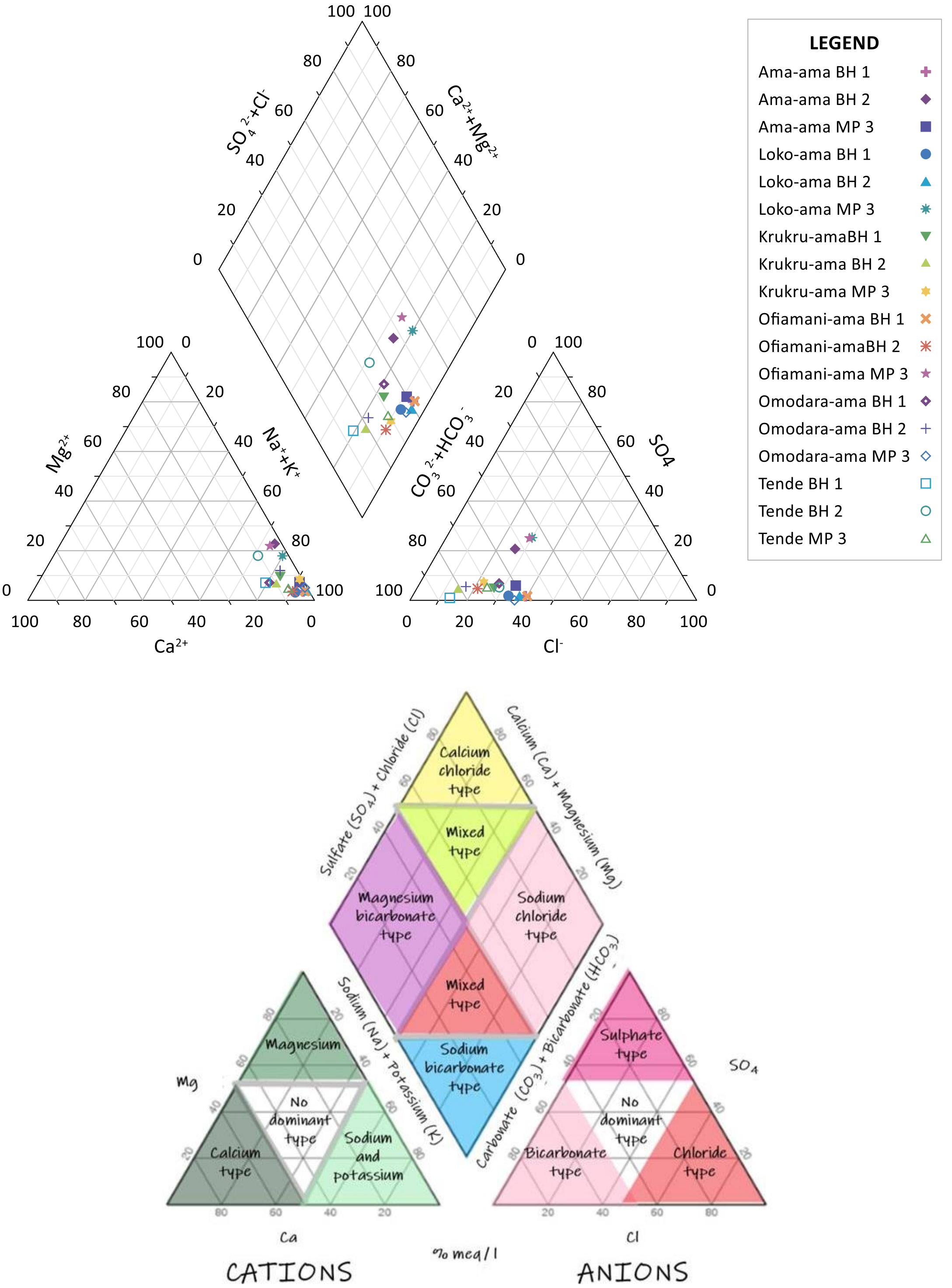

Fig. 8: Piper Trilinear Diagram

Durov diagram

A Durov diagram (Fig. 9) is a useful graphical tool that is widely used to identify the chemical relationship and evolution of groundwater samples (Chen *et al*, 2019), and helps in the interpretation of the evolutionary trends and the hydrogeochemical processes occurring in the groundwater system. Like the piper diagram, milliequivalents of cations and anions are plotted on the triangular graphs and the extrapolated points are projected onto the square plot to determine the hydrochemical process.

Water in the study areas was plotted on the Durov's diagram and classified according to Lloyd and Heathcoat (1985) as shown in Table 9.

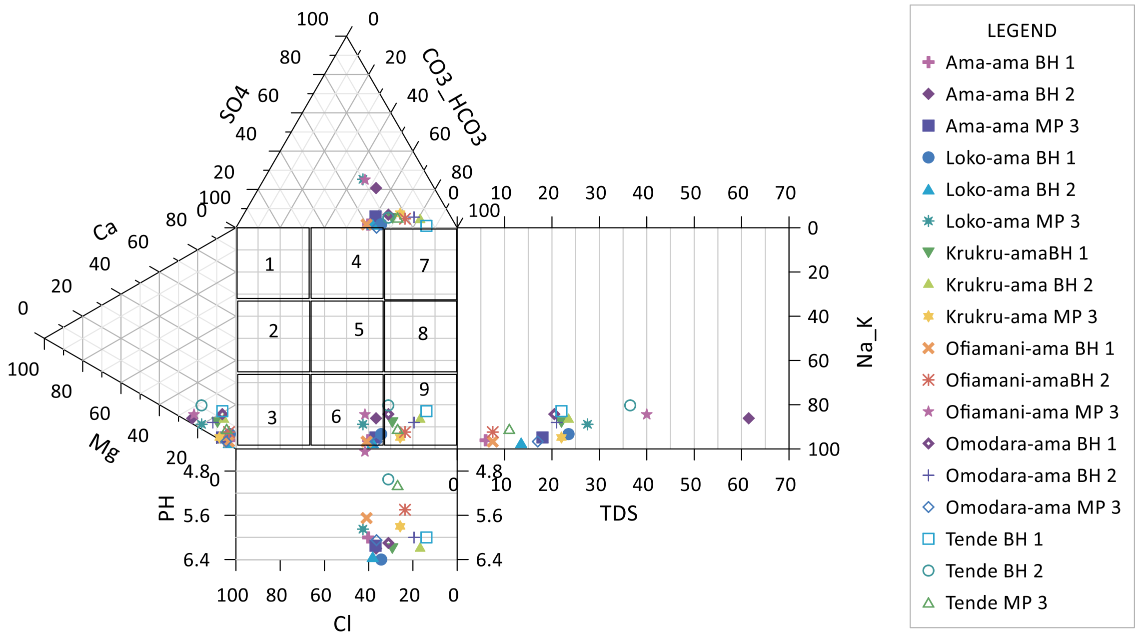

Fig. 4.7: Durov Diagram

Table 2: Classification of Water Based on Durov Diagram (Lloyd and Heathcoat, 1985)

Square No.	Description of Water Type
1	HCO_3^- and Ca^{2+} are dominant; this frequently indicates recharging waters in limestone, sandstone, and many other aquifers
2	This water type is dominated by Ca^{2+} and HCO_3^- ions. Association with dolomite is presumed if Mg^{2+} is significant. However, those samples in which Na^+ is significant, an important ion exchange is presumed
3	HCO_3^- and Na^+ are dominant; this normally indicates ion exchanged water, although the generation of CO_2 at depth can produce HCO_3^- where Na^+ is dominant under certain circumstances
4	SO_4^{2-} dominates, (or anion discriminant) and Ca^{2+} dominant; Ca^{2+} and SO_4^{2-} dominance frequently indicates recharge water in lava and gypsiferous deposits, otherwise mixed water or water exhibiting simple dissolution may be indicated.
5	No dominant anion or cation, indicates water exhibiting simple dissolution or mixing.
6	SO_4^{2-} dominant (or anion discriminate) and Na^+ dominant; this is a water type that is not frequently encountered and indicates probable mixing or uncommon dissolution influences.
7	Cl^- and Na^+ dominant; this is frequently encountered unless cement pollution is present, otherwise the water may result from reverse ion exchange of Na-Cl waters.
8	Cl^- dominant anion and Na^+ dominant cation; this indicates that the ground waters may be related to reverse ion exchange of Na-Cl waters.
9	Cl^- and Na^+ dominant frequently indicate end-point down gradient waters through dissolution

IV. CONCLUSION

The results of the study showed pH levels to be below the set limits and therefore, the water is acidic. Most of the stations had Mn, Fe, Pb, Cd, Cr and Ni levels above the permissible level. Some of the stations had Total Coliform Bacteria (TCB) count within standard limits. The water quality index classified the water in the area, ranging from Good to Unsuitable for drinking purposes. Piper diagram revealed that Sodium-potassium ions, chloride ions and bicarbonate ions were found to be the dominant cations and anions, respectively. Durov diagram showed simple dissolution/mixing, ion exchange and reverse-ion exchange and were the main hydrochemical processes governing the groundwater in the study area. Health risk assessment showed that the high levels of heavy metals, especially cadmium and lead, pose probable high toxic and carcinogenic risks, especially in children of the population in the study areas. Irrigation indices showed that the water in the area is suitable for irrigation purposes.

The research serves as an awareness to the inhabitants of Ogu community to be conscious of the quality of their drinking-water. Also, it has provided data to the literature of groundwater from the Area.

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