



Assessment of the Quality of water samples from Private Boreholes in Eket Local Government Area, Akwa Ibom State, Nigeria

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Abstract

The major source of drinking water in our local communities is private boreholes, in which the quality of water becomes a public health concern. In an attempt to ascertain the health risk that the people are exposed to, this study was conducted to assess the quality of water from private boreholes in Eket Local Government Area. Water samples from the boreholes were subjected to analyses for physico-chemical characteristics. For this purpose, water samples were collected from ten private boreholes for analyses and compared with the World Health Organization (WHO) permissible guidelines for potable water. Some of the parameters analyzed for by the standard test methods for the examination of water and

wastewater were: pH, conductivity, dissolved oxygen, redox potentials, nutrients, trace metals, iron, total hardness, calcium, magnesium, total alkalinity, bicarbonate alkalinity, carbonate, hydroxide and alkalinity. pH values of the water samples gave values that were below the permissible range of 6.5 to 8.5 for potable water, whereas, values for dissolved oxygen, redox potential, total dissolved solids, total hardness, calcium content, magnesium content, sulphate, phosphate, nitrate and sulphide were below the permissible limits for potable water. Alkalinity determination indicated that the water samples from boreholes have predominantly bicarbonate alkalinity, with negligible carbonate and hydroxide alkalinity. Though, the total alkalinity was below the permissible limit, the water samples are likely to form scales in boilers and heaters. The total hardness of the considered samples indicated the hardness classification range of 17.5 mg/l to 59.5 mg/l, which is slightly hard and may require minor treatment for drinking and

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other domestic purposes. Notwithstanding the fact that the exploited aquifer in Eket has shallow depths of between 16.0 m to 30.4 m, values for lead, cadmium, copper, zinc, iron and manganese were below the permissible limits, except in station 1, in which the water has enhanced iron content above the permissible limit of 0.3 mg/l. The water samples had mean salinity of 0.01 %, indicating that there is no salt water intrusion even though Eket is a coastal area. The mean pollution index calculated for all the sample parameters gave values that were below the critical value of one, indicating no contamination of the aquifer by anthropogenic activities.

Keywords Water Quality Index; Pollution Index; Boreholes; Potable Water; Aquifer

1. Introduction

A greater proportion of the populace resident in Eket Local Government Area and the environs rely on private boreholes for drinking water, domestic and recreational purposes. Each year, unaccounted boreholes are drilled, which many may fail in at least one drinking water standard, considering the fact that many of the private well owners may be ignorant of any existing private well regulations. Recall that one of the objectives of the United Nation Millennium Development Goals is to double the number of the population having access to potable drinking water in order to minimize water-borne diseases (Okarafor *et al.*, 2012; Owamah *et al.*, 2013). Water is the most common commodity in all aspects of human life. According to Akankpo and Igbowe (2011) and other researchers (Atakpo, 2009, Magnus *et al.*, 2012; Adekola *et al.*, 2015, water is one of the most essential of human beings, for drinking, domestic purposes and recreation. The presence of water or lack of it determines what becomes of the nature of the natural environment in which life and economic activities depend on. This study was conducted to better understand the prevalence and causes of private

well contamination and to evaluate the role of regulatory versus voluntary management of private boreholes in the study area.

In a study conducted by Magnus *et al.*, (2012), on the determination of aquifer characteristics in Eket, Akwa Ibom State, Nigeria using the vertical electrical sounding method, it was deduced that Eket has prolific aquifers with shallow depths of between 16.0 m and 30 m from the earth surface. From that deduction, it was strongly recommended that efforts should be made to check the quality of water in such a region, since the economically exploited aquifer in Eket region is located at shallow depths from the earth surface. Groundwater without doubt is considered a natural resource that is of immense importance to life, and its characteristics are greatly determined by the properties and immediate geologic formations (Atakpo, 2009). Groundwater constitutes more than 90 per cent of the world's fresh water resources with only 10 percent in lakes, rivers, reservoirs, oceans and wetlands (Baswinkel, 2000; Asonye *et al.*, 2000). Groundwater is often contained in aquifers. An aquifer is an underground water saturated stratum of formation that can yield usable amount of water to a well (Magnus, 2012). There are two different types of aquifers based on physical characteristics. These are a confined aquifer in which the saturated zone with water is sandwiched between layers of impermeable materials, and an unconfined aquifer in which there is no impermeable layer immediately above the saturated zone. As usual, an aquifer can produce an economically feasible quality of water to a well or spring (Okwueze, 1996; Dahunsi *et al.*, 2014).

The characteristics of water in a given aquifer are greatly influenced by formation strata and terrain type (Akpokodje and Etu-Efatebor, 1987). Therefore, the acquisition of viable deep water wells depends on the adequate and reliable empirical knowledge of the geology of the area and more so, the depth of aquifer (Okolie *et al.*, 2005; Okolie, 2011). Potable water is an essential ingredient for good health and the socio -

economic development of man (Udom *et al.*, 2002), though very scarce in many human societies. All natural waters contain many dissolved substances. Contaminants such as bacteria, viruses, heavy metals, nutrients, and salts have adversely affected water supplies as a result of inadequate treatment and disposal of water from humans, and livestock, industrial discharges and over - use of limited water resources (Singh and Mosley, 2003). Groundwater contamination could be avoided when borehole wells are located far from any source of potential pollution.

Good well design is also important in the prevention of underground water contamination. During the construction process of a borehole, drilling fluid, chemical castings and other materials may find their way into the well, thereby polluting the water (Akpoveta *et al.*, 2011). In Eket, which is an oil producing community, borehole water serves as the major source of drinking water and water for recreation in the local population, since only very few can afford the luxury and rely on purified and treated bottled water for consumption. Owners of boreholes capitalize on this opportunity to commercialize these boreholes. Therefore, this scenario gives impetus to this study, which is aimed at examining the water quality parameters of borehole water with special interest study on Eket Local Government Area with a view to assessing their level of purity. This study tends to estimate the levels of heavy metals, ion contents, including nutrients, biochemical oxygen demand (BOD), dissolved oxygen (DO), bicarbonate alkalinity, carbonate alkalinity, hydroxide alkalinity and salinity of the borehole water samples with a view to comparing them with international allowable standards as a guide to infer on the water quality index in the study area. In Eket, Akwa Ibom State (Figure 1), boreholes are drilled by private well owners using local drillers and also mini companies whose personnel do not keep careful record of the depths at which water from aquifer was obtained over time (Akpoveta *et al.*, 2011).

1.1. Review of Previous Studies

The major sources of pollution in streams, rivers and underground water arises from anthropogenic activities largely caused by the poor and uncultured living habit of people as well as the unhealthy practices of factories, industries and corporate bodies, resulting in the discharge of effluents and untreated wastes (Sunnudo-Wilhelmy, 1999).

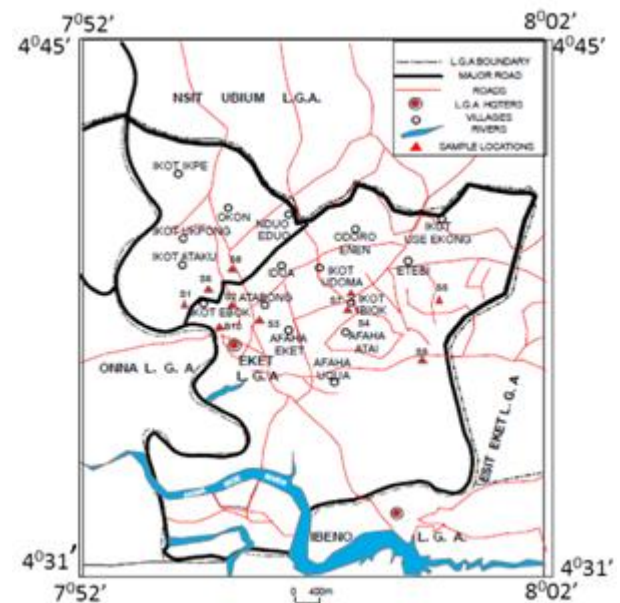


Fig. 1: Map showing the studied locations in Eket LGA

An open hole during the construction stage can be a direct route for contaminants from the surface to the aquifer, thereby providing an ideal opportunity for chemical and bacteriological contamination to occur. The possibility of well water contamination can be eliminated if the period of construction is reduced, assuming the sources of anthropogenic contamination do not exist. However, if there is a lengthy delay in construction and completing the well even if no sources of anthropogenic contamination exists, there is potential for natural levels of metals and other toxic chemicals to be harmful to human health (Akpoveta *et al.*, 2011). This scenario was highlighted in Bangladesh where natural levels of arsenic in ground water were found to be causing harmful effects on the population (Anawara *et al.*, 2002). The unfortunate situation of arsenic contamination arose because the ground water was extracted for drinking without a detailed chemical investigation. Monitoring the

quality characteristics of water from boreholes is very essential for environmental safety.

The natural water analyses for physical and chemical properties including trace element contents are very important for public health studies, which are the main part and contamination studies in the environment (Kot *et al.*, 2000). Water is the most essential nutrient for the survival of man as it is involved in every bodily function and constitutes up to about 75 per cent of total body weight of man (Shryer, 2007, Mack and Nadel, 2011; Offei-Ansah, 2012). The lack of this essential mineral can lead to serious health implications such as hypertension, high cholesterol, and heart diseases. Recently, there has been a reported link of lack of water to headache, arthritis and heartburn (Batmanghellij and Paje, 2012). On the strength of this, there is a recommendation that one should drink at least 64 ounces of water per day (Bellisio *et al.*, 2010). However, despite the need to ensure sufficient water quality, one of the critical development challenges is ensuring sufficient water quality (Gundry *et al.*, 2003).

As an African rural community, one of the most complex challenges is the source of safe drinking water. African continent is bedeviled with lack of sources of good quality drinking water, with a greater proportion of the populace lacking access to safe, drinkable water. According to WHO (2008) report, more than 3.8 million people die each year from water sanitation and hygiene related causes and majority of these are in Africa. The impact of the consumption of unsafe drinking water in Africa has been likened to death of children at a rate equivalent of a jumbo jet crashing every four hour (UNICEF, 2010). In a bid to redress the critical situation, programs such as the Millennium Development Goals (MDG), which aims at improving the quality of water are widely adopted (WHO, 2006). Emphasis has also been placed on diversification and water sources from reliance on surface water to include rain and groundwater. Presently, there has been increasing challenges and contamination of surface water sources resulting in

diseases such as bilharzia, sleeping sickness (Tripanosomiasis), river blindness, and guinea worm. Many societies are now adopting digging of boreholes as a source of water (Ncube and Scutte, 2005; Capenter *et al.*, 1998; Chigor *et al.*, 2012), with lot of funds expended to construct boreholes even though sometimes the purity of the drinking water from the borehole is questionable.

The quality of borehole water depends on such factors as local geology, hydrology, and geochemical characteristics of the aquifers (Bhattachanya *et al.*, 1997). However, Fourmer and Trusdell (1973) asserted that other factors that may impact on the quality of groundwater are activities of microorganisms, temperature, and pressure. Therefore, groundwater often contains dissolved mineral ions, which need to be removed, when present in excess by some type of treatment, before the water is fit for the intended usage. With the increasing anthropogenic activities, the quality of groundwater has deteriorated, becoming of serious public health concern (Fourmer and Trusdell, 1973). It is the knowledge of the composition and properties of water that is significant for the evaluation of its potential use and management.

On a global scale, (WHO) produces international standards and guidelines on drinking water quality (Table 4) as a basis for the regulation and standard setting, in both developed and developing countries (Ikem *et al.*, 2002; WHO, 2008). Various countries have also enforced drinking water standards for the maximum permissible levels of different chemical constituents. In United State of America (USA), guidelines are issued to ensure that drinking water standards set by United State Environmental Protection Agency (USEPA) are adhered to, and in Nigeria, the responsibility for good water standard is enforced by Standard Organisation of Nigeria (SON, 2007). According to report by UNICEF, Nigeria is one of the African Countries facing the problem of accessibility to safe drinking water; noting that only 47 per cent of the population can access safe drinking

water (UNICEF, 2010) and the situation is very critical in the rural north-eastern Nigeria region where over 70 percent of the population cannot access clean water (Voices, 2013).

The voluntary management of private wells is a problem as most health related pollutants in water are symptomless. As a result, private borehole water owners may be exposed unknowingly to health-related pollutants, unless they have their water tested for the correct water parameters. Several studies have documented the occurrence of various water contaminants in private water systems (Zimmerman *et al.*, 2001; New Jersey Department of Environmental Protection, 2004; IOWA, 2004; Liu *et al.*, 2005; Rowe *et al.*, 2007). A comprehensive study of 228 water borne illnesses in the 1970's by Craun, showed that residents with private or small semipublic wells were most vulnerable to waterborne illnesses. Recent research in Pennsylvania has further documented the occurrence of disease causing bacteria in private wells (Lindsey *et al.*, 2002; Swistock *et al.*, 2004; Swistock and Sharpe, 2005; Owamah *et al.*, 2013). Monitoring the quality of borehole or underground water is very essential for environmental safety. According to Kot *et al.*, (2000), the natural water analyses for physical and chemical properties, including trace element contents are very important to public health studies.

As far as South - South region of Nigeria is concerned, borehole water is popular in a region, which is entirely within the Niger Delta Zone, and where there is increased consumption of borehole water, there has equally been a growing concern for the quality of water from this source. It is on the strength of this concern that the physical properties and chemical contents in borehole water in Eket Local Government Area of Akwa Ibom State are investigated in this study. Therefore, this study aimed at assessing the potability of water in borehole and generating information that can serve as a guide in monitoring water contamination in the region. The data generated in this study in addition to other studies

can be used to create a baseline database of borehole drinking water quality in the region.

2.2. The Study Area

Eket Local Government Area is one of the local government areas in Nigeria, playing host to major multinational oil company, Exxon Mobil. Eket is located between latitudes $4^{\circ}31'$ and $4^{\circ}45'$ and between longitudes $7^{\circ}52'$ and $8^{\circ}02'$ (Figure 1). The study area is underlain by Sedimentary Formation of Late Tertiary and Holocene ages (Magnus *et al.*, 2012). Deposits of recent alluvium and beach ridge sands occur along the coast and the estuaries of the Imo and Qua Iboe Rivers and also along flood plains of creeks. The study area consists of mainly of Coastal Plain sands. The sands are mature, coarse and moderately sorted. The Coastal Plain sands, otherwise known as the Benin Formation overlies the Bende-Ameki Formation and dips south-westward (Mbonu and Ebeniro, 1991; Akankpo and Igbokwe, 2011). The landscape of Eket comprises generally, low-lying plain and riverine areas with no portion exceeding 175 m above mean sea level. The physiography of Eket is that of a beach ridge complex characterized by a succession of sub parallel sand ridges (Figure 1).

3. Materials and Methods

3.1. Materials

Deionized water was used for preparation of all reagents. All the chemicals used were of analytical grade (Analar). Ten water samples were collected from selected boreholes in the study area (Table 2). The water samples were collected for a period covering July 2017 to October 2017 on a monthly basis. The water samples were collected in prewashed polyethylene bottles (with detergent, rinsed with deionized water and dilute mineral acid) and transported to the laboratory for analyses in ice-cooled coolers. Some of the physicochemical parameters that vary on storage like pH, conductivity, salinity, redox potential, dissolved oxygen, total dissolved solids, turbidity and temperature were determined at the sampling locations using portable meters.

3.2. Methods of Analysis

In the laboratory, other parameters were determined with less delay as was possible. Some other parameters determined in the laboratory were: Total alkalinity, Total hardness, calcium content, chloride content, sulphate, phosphate, trace metals and all other water parameters.

3.2.1. Total Alkalinity

Total alkalinity was determined by titrimetric method, according to method No.2320 B of APHA, AWWA.WEF (2005).

3.2.2. Total Hardness and Calcium Content

Total hardness and calcium content of the waters were determined by EDTA titration, according to method No.2340 C of APHA, AWWA.WEF (2005).

3.2.3. Chloride Content

Chloride content of the water was determined by argentometric titration according to method No. 4500 - Cl, B. of APHA, AWWA.WEF, 2005.

3.2.4. Sulphide Content

Sulphide content of the water was determined by iodometric titration in accordance with method No. 4500 F, of APHA, AWWA.WEF, 2005.

3.2.5. Sulphate Content

Sulphate content was determined by turbidimetric method, according to method No. 4500 SO₄²⁻ E of APHA, AWWA.WEF, 2005.

3.2.6. Nitrate Content

Nitrate was determined by spectrophotometric method, according to method No. 4500 NO₃,B of APHA, AWWA.WEF, 2005 .

3.2.7. Phosphate Content

Phosphate content of the water was determined by spectrophotometric method, according to method No. 4500 P, C of APHA, AWWA.WEF, 2005.

3.2.8. Acidity of the Water

Acidity of the water was determined by alkaline titration, according to method No. 3210 B of APHA, AWWA.WEF, 2005.

3.2.9. Total and Free Carbon Dioxide

As the total alkalinity of the waters from the study area were almost due to bicarbonate alkalinity, and the total dissolved solid of the waters were not more than 500 mg/L, total carbon dioxide and free carbon dioxide content of the waters were determined by calculations, according to Method No. 4500 CO₂ D of APHA, AWWA.WEF, 2005 .

3.2.10. Carbonate, Bicarbonate and Hydroxide Alkalinity

Carbonate alkalinity, bicarbonate and hydroxide alkalinity were determined by calculation after pH measurement, according to Method No. 4500 CO₂ D of APHA, AWWA.WEF, 2005.

3.2.11. Trace Metals

Selected trace / heavy metals that are very critical to public health safety in drinking water namely, Cadmium (Cd), lead (Pb), zinc (Zn), copper (Cu) and iron (Fe), were determined by flame atomic absorption spectrometer (ATI, Unicam 939) according to Method No 3111 A. of APHA, AWWA, WEF, 2005. The resultant concentrations of the determined parameters were compared with the WHO and SON guidelines values (USEPA, 1986; WHO, 2011). The values of the determined parameters were subjected to statistical analyses by the mean value test at 95 percent confidence limits.

4. Results and Discussion

4.1. Results of Analyses

In Table 1, is presented the description of the boreholes where water samples were taken from. Presented in Table 2, is the results of physico-chemical parameters of borehole water samples for stations 1 to 5, while Table 3, is a presentation of results of physico-chemical parameters of borehole water samples for stations 6 to 10.

4.1.1. PH

The mean results of the pH of the borehole water samples obtained ranged between 4.12 – 5.33 (Table 2 and Table 3), as compared to the WHO permissible limit of 6.5 – 8.5 (Table 4). The pH values obtained were lower, than the permissible limits, indicating that the considered water samples were acidic.

4.1.2. Temperature

The temperature recorded for the water samples ranges between 21.5°C and 24.7 (Table 2 and Table 3) compared to the WHO permissible limits of less than 40°C for potable water (Table 4). The values obtained in all the stations were far below the permissible limits of less than 40°C.

4.1.3. Conductivity

The results of the mean electrical conductivity obtained were in the range of 51.42 uS/cm – 170.8 uS/cm (Tables 2 and 3). However, the values were far lower than the permissible limit of 200 uS/cm (Table 4).

4.1.4. Total, Hydroxide, Carbonate and Bicarbonate Alkalinity

Hydroxide alkalinity determined was less than 0.001 mg/l in all the stations, carbonate alkalinity was less than 0.001 mg/l in all the stations, and bicarbonate alkalinity was the only dominant alkalinity in the borehole water samples and gave values between 39.99 mg/l – 75 mg/l (Table 4). The total alkalinity in all the water samples far less than the permissible limits, but was predominantly bicarbonate alkalinity. The implication here is that the water samples in the study area is prone to scaling in boilers and other heating utensils (Etesin *et al.*, 2013).

4.1.5. Dissolved Oxygen and Redox Potential

The dissolved oxygen gave mean results of between 3.05 mg/l to 5.42 mg/l, as compared to the permissible limits of greater than 5.0 mg/l for potable water (Tables 2 - 4). While, the redox potential determined gave values of between 40 mV in station 9 and 196 mV in station 6 (Tables 2 and 3) the results of

dissolved oxygen indicated a low value of 3.05mg/l in Station 9 and a low redox potential of 40 m V for the same station 9. The two correlated results point to a depletion of DO in the water, probably due to biochemical activities.

4.1.6. Salinity

The results of the salinity determination gave values of 0.00% to 0.01% (Table 2 and Table 3), indicating fresh water from the boreholes without salt water intrusion. The results are compared to the WHO permissible limit of 0.0 percent salinity for potable water (WHO, 2011).

4.1.7. Total Dissolved Solid (TDS)

The results of the borehole water samples gave mean total dissolved solids of 25.6 mg/l to 85.1 mg/l (Tables 2 and 3), compared to a permissible limit of less than 500 mg/l (Table 4). The results indicate that all the stations had total dissolved solids that are far less than the permissible limit for potable water (WHO, 2011).

4.1.8. Total Hardness, Calcium and Magnesium Content

The water samples gave mean total hardness of 9.02 mg/l to 50.0 mg/l, compared to the permissible limit of 80 mg/l for potable water (Tables 2 - 4). The level of hardness obtained was low, which correlates with the negligible values of carbonate alkalinity in the borehole waters. The borehole water samples gave mean calcium content of between 3.01 mg/l and 20.0 mg/l (Table 2), compared to the permissible limit of less than 200 mg/l. The low calcium content correlates with the low total hardness and low total alkalinity of the borehole water. The borehole water samples also gave magnesium content of between 0.002 mg/l and 0.397 mg/l (Tables 2 and 3), compared to a permissible limit of less than 150 mg/l magnesium (WHO, 2011). The low concentration of magnesium correlates with low total hardness. The low concentration of calcium and magnesium may be attributed to no source of pollution of ground water from anthropogenic activities and also due to the

geological formation of the study area (Owamah *et al.*, 2013).

4.1.9. Chloride, Sulphate, Phosphate, Nitrate and Sulphite Contents

The borehole waters gave mean chloride contents of between 12.05 mg/L to 24.11mg/L, compared to a permissible limit of less than 250 mg/L of chloride for potable water (WHO, 2011). The low chloride content of the borehole waters correlates with the negligible content of salinity of water in the study area.

The low chloride content of the borehole waters is an indication of no saline water intrusion into the ground water of the study area. Sulphate contents of the borehole waters determined, gave values between 0.03mg/l to 2.034 mg/L, compared to the permissible limit of less than 250 mg/l sulphate in potable water. Phosphate contents of the water determined had values between 0.018mg/L to 0.219 mg/L, compared to the permissible limit of less than 5 mg/L for potable water (Tables 2 - 4).

Table 1: Description of borehole locations

Station	Location	Coordinates
ST 1	NO. 11 Ekpeyu ST, Eket	Latitude 4. 64139 ° N Longitude 7.91583 ° E
ST 2	Nung Uso ST, Eket	Latitude 4. 64167 ° N Longitude 7.91556 ° E
ST 3	30 Etebi ST, Eket	Latitude 4.648687 ° N Longitude 7.928333 ° E
ST 4	12 Etebi ST, Eket	Latitude 4.645953 ° N Longitude 7.928447 ° E
ST 5	Hospital Road , Eket	Latitude 4.64083 ° N Longitude 7.91639 ° E
ST 6	No. 12 Ofon Mbuk St, Eket	Latitude 4.642880 ° N Longitude 7.922180 ° E
ST 7	Iseyeriudua, Ikot Ibiok, Eket	Latitude 4. 64194 ° N Longitude 7. 92555 ° E
ST 8	Iqita Street, Ikot Ibiok, Eket	Latitude 4. 64250 ° N Longitude 7.92500 ° E
ST 9	Iko Ewak, Eket	Latitude 4. 64111 ° N Longitude 7. 92611 ° E
ST 10	79, Liverpool Road, Eket	Latitude 4. 64056 ° N Longitude 7.91639 ° E

The borehole waters gave mean nitrate contents of between 0.011mg/L to 0.081 mg/L, compared to a permissible limit of 10 mg/L for potable water (Tables 2 and 3). The low contents of nitrate, phosphate and sulphate are an indication that there is no source of pollution of the groundwater from anthropogenic activities. A comparative evaluation of the sulphate, nitrate and phosphate levels in the water, in this study with those reported by Akpofure *et al.* (2007) in Warri borehole water samples which had elevated levels of these nutrients are greater than those reported in this study.

4.1.10. Biochemical Oxygen Demand (BOD₅) and Chemical Oxygen Demand (COD)

The borehole water samples in the study area had (BOD₅) of between 0.611mg/L to 1.618mg/L, compared to the WHO permissible limits of 6mg/L for potable water. The borehole water samples in the study area gave COD content of between 1.672 mg/L and 3.961 mg/L, compared to the WHO permissible limit of 10mg/L for potable water (Tables 2 - 4). However, the BOD₅ determined in this study were comparable to that reported by Apoveta *et al.* (2011), in Benin potable water.

Table 2: WHO permissible limits for potable water (Source: WHO, 2011)

S/N	Parameter	Unit	WHO Limits
1	p H		6.5 - 8.5
2	Temp (o C)	o C	< 40
3	Cond (uS/cm)	u S/cm	< 2000
4	OH Alkalinity	mg CaCO ₃ /l	< 500
5	Dissolved oxygen	mg/l	> 5.00
6	Salinity	%	0
7	TDS	mg/l	< 500
8	Redox Potential	m V	
9	Total Hardness	mg CaCO ₃ /l	80 - 100
10	Calcium	mg CaCO ₃ /l	< 200
11	Magnesium	mg CaCO ₃ /l	< 150
12	Bicarbonate Alkalinity	mg CaCO ₃ /l	< 500
13	Acidity	mg CaCO ₃ /l	
14	Carbonate Alkalinity	mg CaCO ₃ /l	< 500
15	Chloride	mg/l	< 250
16	Iron	mg/l	< 0.3
17	Sulphide	mg/l	
18	Sulphate	mg/l	< 250
19	Phosphate	mg/l	
20	Nitrate	mg/l	< 10.0
21	Free CO ₂	mg/l	
22	Total CO ₂	mg/l	
23	BOD ₅	mg/l	6
24	COD	mg/l	10

4.1.11. Free Carbon Dioxide and Total Carbon Dioxide

The water samples from the study area had free carbon dioxide of between 8.36 mg/L and 19.36 mg/L, while total carbon dioxide had values of between 43.11 mg/L and 87.98 mg/L. Free carbon dioxide is an indication of the aggressive nature of water towards metal substrates APHA, AWWA, WEF (2005).

4.1.12. Trace Metals

The borehole water samples gave zinc concentration of between 0.518 mg/L and 1.06 mg/L, compared to the permissible limit of 5.0 mg/L. Lead (Pb) was determined in the water samples with values between 0.005 mg/L and 0.064 mg/L, compared to a permissible limit of 0.05 mg/L. Copper concentration was 0.014 mg/L to 0.267 mg/L (Tables 2 - 4). Cadmium concentrations were between 0.002 mg/L to 0.013mg/L compared to a permissible limit of 0.01 mg/L, while manganese contents determined were between 0.002 mg/L and 0.032 mg/L, compared to a permissible limit of 0.05 mg/L (Tables 2-4).

4.2. Discussion

The results obtained in this study for the trace metals in the borehole water samples are comparable with that reported by Apoveta et al. (2011), in the Benin Water. However, the results for manganese were lower than those reported by Apoveta *et al.*, (2011); in the Benin water, and the results reported by Adekola *et al.*, (2015), for Borehole water samples from Crassol, Taraba State, Nigeria. Total hardness of the borehole water samples gave values between 9.02 mg/L to 50 mg/L, with stations 1 to 5 having values that fall within the hardness classification range of 17.5 – 59.5 mg/L, (Tables 2,3 and 10). Water samples from stations 6, 7, 8 and 10, had total hardness that falls within the hardness classification range of 17.5 mg/L to 59.5 mg/L, which is slightly hard. However, station 9 had total hardness of 9.02 mg/L, which falls within the hardness classification that is soft. The total hardness recorded in this study was significantly lower than the values reported by Adekola *et al.*, (2015), for borehole water samples from Gassol, Taraba State.

Table 3: Result of physico-chemical parameters of borehole waters for stations 1 – 5

S/N	Parameter	Unit	Station 1	Station 2	Station 3	Station 4	Station 5	WHO Limits
1	p H		4.69	4.71	4.25	4.32	4.52	6.5 - 8.5
2	Temp (°C)	°C	21.5	24.3	23.9	24.1	24.5	< 40
3	Cond (uS/cm)	u S/cm	153.8	150.7	124	170.8	129	< 2000
4	OH Alkalinity	mg CaCO ₃ /l	0.001	0.001	0.001	0.001	0.001	< 500
5	Dissolved oxygen	mg/l	4.11	4.57	4.79	5.42	4.22	> 5.00
6	Salinity	%	0.01	0.01	0.01	0.01	0.01	0
7	TDS	mg/l	80.3	75.2	61.1	85.1	64.6	< 500
8	Redox Potential	m V	160	152	162	165	153	
9	Total Hardness	mg CaCO ₃ /l	42	50	34.02	26.03	38.0	80 - 100
10	Calcium	mg CaCO ₃ /l	16.8	20	13.6	10.4	15.2	< 200
11	Magnesium	mg CaCO ₃ /l	0.351	0.397	0.27	0.207	0.302	< 150
12	Bicarbonate Alkalinity	mg CaCO ₃ /l	49.98	49.99	64.99	49.99	75	< 500
13	Acidity	mg CaCO ₃ /l	66	70	58.02	122	70	
14	Carbonate Alkalinity	mg CaCO ₃ /l	0.002	0.001	0.001	0.001	0.001	<500
15	Chloride	mg/l	14.18	17.02	12.05	20.56	13.49	< 250
16	Iron	mg/l	0.738	0.005	0.126	0.147	0.154	< 0.3
17	Sulphide	mg/l	11.6	9.03	11.08	13.11	8.87	
18	Sulphate	mg/l	2.034	0.031	0.087	0.107	0.761	< 250
19	Phosphate	mg/l	0.108	0.086	0.211	0.074	0.018	
20	Nitrate	mg/l	0.032	0.072	0.011	0.062	0.019	< 10.0
21	Free CO ₂	mg/l	13.08	10.22	12.04	11.75	14.96	
22	Total CO ₂	mg/l	43.11	43.99	57.19	87.98	86.01	
23	BOD ₅	mg/l	1.411	0.811	0.726	1.051	0.917	6
24	COD	mg/l	3.092	2.177	2.096	3.053	1.672	10

Pollution index (Pi) is expressed as a function of the value of individual parameter as against the baseline standard or the permissible limits, given as:

$$Pi = \text{Concentration Value} / \text{Standard Value}$$

The pollution index showed the relative pollution contributed by each item. The critical value is 1.0, values greater than 1.0 indicates significant degree of pollution, while values less than 1.0 show no pollution (Udom et al, 2002). Pollution index for the different parameters as determined in the borehole water samples for stations 1 to 3 are presented in Tables 5, stations 4 to 6 are presented in Table 6, and values for stations 7 to 10 are presented in Table 7. Pollution index for all the parameters in the study area had values that were below 1.0 the critical value, except for iron (Pi = 2.46) and cadmium (pi = 1.3) in water from station 1, which is the borehole at Ekpeyu

Street. The source of the two trace metals may be attributed to underground contaminations which are localized.

The values of BODs and COD of the water samples determined in this study are significantly lower than the BOD₅ and COD reported elsewhere for surface waters (Young *et al.*, 1981). The mean pollution index for a given sampling station was calculated as the sum of the pollution index (SPI) for each parameter divided by the number of parameters considered (United Environment Agency, 2012; Etesin *et al.*, 2013).

$$\begin{aligned} \text{Mean pollution index (MPI)} \\ = (\text{Sum of Pi}) / \text{Number of items.} \end{aligned}$$

$$\begin{aligned} \text{Overall Pollution Index (OPI)} \\ = \left[(\text{Sum of pollution index})^2 + (\text{MPI})^2 \right] / 2. \end{aligned}$$

Table 4: Result of physicochemical parameters of borehole waters for stations 6 – 10

S/N	Parameter	Unit	Station 6	Station 7	Station 8	Station 9	Station 10	WHO Limits
1	p H		4.42	4.25	4.12	5.33	4.11	6.5 - 8.5
2	Temp (°C)	°C	25.7	27.4	26.2	26.6	26.4	< 40
3	Cond (uS/cm)	u S/cm	165.6	51.42	68.2	62.8	102.8	< 2000
4	OH Alkalinity	mg CaCO ₃ /l	0.001	< 0.001	< 0.001	< 0.001	< 0.001	< 500
5	Dissolved oxygen	mg/l	3.32	4.43	3.45	3.05	3.59	> 5.00
6	Salinity	%	0.01	0.00	0.00	0.00	0.01	0.00
7	TDS	mg/l	83.2	25.6	31.7	30.1	51.5	< 500
8	Redox Potential	m V	196	113	110	40	113	
9	Total Hardness	mg CaCO ₃ /l	40.02	20.01	10.05	9.02	20.03	80 - 100
10	Calcium	mg CaCO ₃ /l	15.4	8.00	4.11	3.01	8.05	< 200
11	Magnesium ⁴	mg CaCO ₃ /l	0.186	0.01	0.052	0.002	0.013	< 150
12	Bicarbonate Alkalinity	mg CaCO ₃ /l	54.99	49.99	39.99	49.99	69.99	< 500
13	Acidity	mg CaCO ₃ /l	96.02	60.01	72.02	60.01	62.51	
14	Carbonate Alkalinity	mg CaCO ₃ /l	0.001	< 0.001	< 0.001	0.001	< 0.001	< 500
15	Chloride	mg/l	24.11	14.19	14.18	7.09	16.31	< 250
16	Iron	mg/l	0.214	0.019	0.175	0.211	0.097	< 0.3
17	Sulphide	mg/l	12.38	16.01	15.96	20.4	16.04	
18	Sulphate	mg/l	0.521	1.027	1.316	0.855	1.006	< 250
19	Phosphate	mg/l	0.218	0.096	0.103	0.083	0.219	
20	Nitrate	mg/l	0.029	0.048	0.081	0.053	0.071	< 10.0
21	Free CO ₂	mg/l	12.04	8.36	18.49	19.36	10.12	
22	Total CO ₂	mg/l	48.39	52.36	53.67	63.35	71.71	
23	BOD ₅	mg/l	0.611	0.812	1.533	0.891	1.618	6
24	COD	mg/l	2.054	3.117	3.961	1.866	3.017	10

Mean pollution index for stations 1 to 10 are presented in Table 5 and also represented in Figure 2. Station 1 had the highest mean pollution index of 0.417, station 2 had the mean pollution index of 0.277, station 3 had a mean pollution index of 0.256, station 4 had a value of 0.288, station 5 had a value of 0.265, station 6 had a value of 0.258, station 7 had a value of 0.225, station 8 had a value of 0.234, station 9 had a value of 0.248, while station 10 had a value of 0.248.

Comparatively, station 7 had the lowest mean pollution index of 0.225, though all the stations had the mean pollution index far less than one, which is

the critical value. The variations in the mean pollution index were not significant when subjected to student - t statistical analysis at $P = 0.01$. What could be established from this study is that in terms of physico-chemical compositions, water from the boreholes from the study area, may require minor or no treatment to be put into some specific use, mostly as a source of drinking water without adverse health implications. Comparatively, the borehole water samples from the study area has a higher quality index as a source of drinking water than the water reported by Adekola *et al.*, (2015), in a similar study in terms of turbidity, iron content, pH and chloride content,

which had values greater than their guideline values and also in a similar study by Akpoveta *et al.*, (2015), for water from boreholes in Benin and its environs, which had high values of calcium and manganese than their guideline values. The enhanced iron content

in water from station 1 (Table 5) is not a surprise, but agrees with an observation by Chilton, 1996, that high iron content in ground water is widely reported from developing countries, which is a major water quality issue (Quagraine and Adokoh, 2011).

Table 5: Standard pollution index for stations (ST) 1 – 10

Parameter	ST 1	ST 2	ST 3	ST 4	ST 5	ST 6	ST 7	ST 8	ST 9	ST 10
	SPI	SPI	SPI	SPI	SPI	SPI	SPI	SPI	SPI	SPI
pH	0.721	0.725	0.654	0.665	0.695	0.68	0.654	0.634	0.82	0.632
Temp (o C)	0.538	0.608	0.598	0.603	0.613	0.643	0.685	0.655	0.665	0.66
Cond (uS/cm)	0.077	0.075	0.062	0.085	0.065	0.083	0.026	0.034	0.031	0.051
OH Alkalinity	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001
Dissol. oxygen	0.822	0.914	0.958	1.084	0.844	0.664	0.886	0.69	0.61	0.718
Salinity	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001
TDS	0.161	0.15	0.122	0.17	0.129	0.166	0.051	0.063	0.061	0.103
Total Hardness	0.525	0.625	0.425	0.325	0.475	0.50	0.25	0.126	0.113	0.25
Calcium	0.084	0.1	0.068	0.052	0.076	0.077	0.04	0.021	0.015	0.04
Magnesium	0.002	0.003	0.002	0.001	0.002	0.001	< 0.001	< 0.100	< 0.001	< 0.001
Bicarb. Alk.	0.1	0.1	0.13	0.1	0.15	0.11	0.25	0.08	0.10	0.14
Carbonate Alk.	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001
Chloride	0.057	0.068	0.048	0.082	0.054	0.096	0.057	0.057	0.028	0.065
Iron	2.46	0.017	0.42	0.49	0.513	0.713	0.063	0.583	0.703	0.323
Sulphate	0.008	0.002	0.002	0.002	0.006	0.002	0.004	0.006	0.004	0.004
Phosphate	0.022	0.017	0.042	0.015	0.004	0.044	0.019	0.021	0.017	0.044
Nitrate	0.003	0.007	0.001	0.006	0.002	0.003	0.005	0.008	0.005	0.007
BOD5	0.235	0.135	0.001	0.175	0.153	0.102	0.135	0.256	0.149	0.27
COD	0.309	0.218	0.21	0.305	0.167	0.205	0.312	0.396	0.187	0.302
Average SPI	0.383	0.235	0.234	0.261	0.247	0.256	0.229	0.242	0.234	0.241

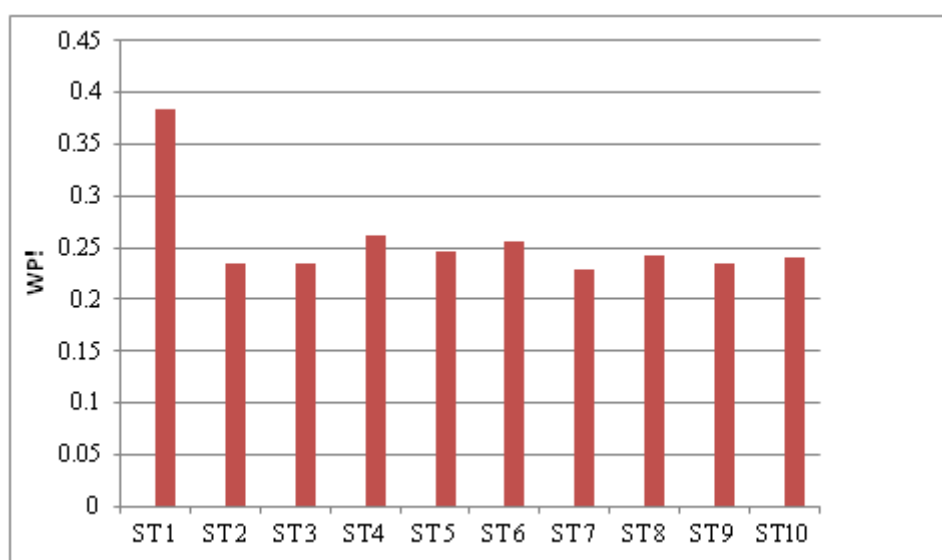


Fig. 2: WPI of stations 1 - 10

5. Conclusion and Recommendation

5.1. Conclusion

Water quality parameters from boreholes in Eket Local Government Area were assessed in this study, to evaluate the quality index of the borehole water. The parameters such as pH, temperature, dissolved oxygen, total dissolved solid, total suspended solid were within the permissible limits of the World Health Organization. Parameters such as chloride, nitrate, phosphate and sulphate had pollution indices that were far below the critical value of 1, indicating that water from the boreholes are safe for drinking in terms of the physico-chemical constituents. Also, the low chloride level and near zero salinity level indicated that there is no saline water intrusion in the study area, even though it is a coastal area. Based on the values of the total hardness of the water determined, the borehole waters in Eket could be said to be slightly hard of between 17 mg/L and 59.5 mg/L in the hardness classification (Table 10). From the alkalinity analyses of the borehole water samples the hydroxide alkalinity was negligible; carbonate alkalinity was negligible, while bicarbonate alkalinity was dominant and contributed mainly to the total alkalinity. The implication is that the water from the study area will form scales and may require minor treatment for drinking and domestic purposes.

The values of the trace metals such as iron, zinc, lead, cadmium, manganese were all below the critical pollution index of one, except in station 1 (Ekpeyu) where the water had enhanced iron content that was a little above the critical pollution index of one. However, on the overall, the iron content of the water samples analysed were negligible, implying that the water can be subjected to minor water treatment for drinking and domestic purposes.

Acidity of the water, total carbon dioxide and free carbon dioxide were detected in the water, but were within the acceptable limit for drinking and domestic purposes. However, the water may require some further treatment for use as processed water for industrial purpose. The BOD₅ and COD of the water samples were below the permissible limits of the WHO, even though the study area has a shallow aquifer, indicating no contamination of the water from the aquifer. It is worth noting that the presence of these contaminants of water below the WHO permissible limits, do not pose any serious health effect to the population.

5.2. Recommendation

In this study, only the physico - chemical parameters and trace metals in the borehole water samples from the study area were considered, on which the judgment of the water is based. However, it is recommended that considering the shallow nature of the aquifer in the study area, microbiological and biochemical examinations should be carried out in the water samples from the study area as a matter of public health concern. This concern is borne out of the fact that, there is a reported case of poor water quality in the north eastern Nigeria that has been suspected for causing outbreak of typhoid fever, cholera and bilhazias, especially where water from boreholes are not appropriately treated.

It is noteworthy, to recommend that the water quality guidelines by the National Regulatory Agencies like Standard Organization of Nigeria should be revised regularly, in line with World Health Organization water guidelines, which are updated regularly. Considering the fact that the major source of drinking water in the state is from private boreholes, there is need for the government agencies to monitor the operation

and management of these private boreholes regularly for public health.

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