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RESEARCH ARTICLE

# Groundwater Quality Assessment In Aka-Offot Industrial Layout, Uyo, Akwa Ibom State, Nigeria

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**Abstract**

Groundwater quality assessment was carried out on water samples from five boreholes collected through simple random sampling method during wet and dry seasons within Aka-Offot Industrial Layout, Uyo and a non-industrialized area (control site). The aim was to assess their quality by determining their physico-chemical properties and heavy metals for comparison with the control site and the world's threshold standards. Water samples were collected with polyethylene bottles that were initially rinsed with 10% hydrochloric acid then with sample water. Two samples were collected from each borehole. One was for physico-chemical properties determinations while the other one was for heavy metal analysis. $HNO_2$ was added in the samples for heavy metal analysis for preservation of the metals. The samples were stored in an ice-packed cooler kit to the laboratory for analysis. The results revealed that the temperature of the water was slightly above WHO standard but fell below FEPA standard; turbidity and electrical conductivity fell within the permissible limits. The water was acidic because the mean pH value was lower than the permissible limit; dissolved oxygen was significantly low while biological oxygen demand was higher than the permissible limit signifying high load of organisms and impurities in the water. The total dissolved solid, ammonium, nitrate and sulphate were below the permissible limits. The mean values of Fe, Pb, Zn, Cr and Co fell below the permissible limits. For Cd, it's dry season mean value was a little above WHO permissible limit but fell below FEPA standard while the dry season mean value of Mn was above FEPA's permissible limit but all of them fell within the WHO limit. However, industrial wastes disposed in this area have had adverse effects on the groundwater. Therefore, adequate waste management method is one of the recommendations prescribed for a healthy and sustainable environment.

**Keywords**: Groundwater quality; Physico-chemical properties; heavy metals; permissible limits

## Introduction

Water is one of the essential needs of man. Security access to potable water supply is a central issue of concern not only in urban areas but much more in rural areas (Atser and Akpabio, 2015). The importance of water supply for domestic use cannot be compromised not only because of its social and economic values (Atser and Udoh, 2014), but also, because water based sources of livelihood have become critical to the survival and health of both urban and rural households, providing valuable contributions to them (Bain *et al.*, 2014). Water is therefore a very strategic socio-economic asset especially in poor economies where wealth and survival are measured by the level of an access to water. Access to water supply is therefore one of the key factors that enhance the well-being of the households (Yange *et al.*, 2013). In Nigeria, water supply like in other developing countries is facing serious challenges many of which are economic and socio-political in nature (Alayande, 2005).

Groundwater is one of the earth's most widely distributed, replenishable resources. It is about 0.6% of the total global water resources and out of this, only 0.3% is being used for economic purposes (Raghunath, 2007). In most countries, people depend on groundwater as the only source of drinking water because, groundwater is comparatively much clean and free from pollution than the surface water (Mangukiya *et al.*, 2012). Contamination and over exploitation are the major reasons for groundwater deterioration (Yadav *et al.*, 2012). Though recent years shift in usage from surface water to groundwater has controlled problems of microbiological and trace elements to a certain extent, but the same has led to newer problems of fluorosis, arsenicosis and salinity due to over-exploitation of groundwater (Singh *et al.*, 2013). Moreso, the extensive use of fertilizers, pesticides, discharge of industrial effluents, domestic sewage and solid waste dump, landfills and many other anthropogenic activities are the major sources of groundwater contamination mostly in the third world countries. This is rising day by day across the world due to extreme residential, municipal, commercial, industrial and intensive agricultural practices because the rate of discharge of pollutants into the groundwater is higher than the rate of purification

(Murhekar *et al.,* 2012). Therefore, it has become important to protect the groundwater resource against contamination in recent time, because it has negative effects on human beings, plants and animals (Caliman *et al.,* 2011; Srinivas *et al.,* 2011). Above all, it is of great concern to act swiftly by carrying out this study since it may take years for the contaminated aquifer to be flushed out because of the rather slow flow (Esu and Amah, 1999).

## Materials and Methods

### Study Area

The study was carried out at Aka-Offot Industrial Layout in Uyo, Akwa Ibom State. It lies between longitudes 7° 55" E - 7° 56" E and latitudes 5° 00" N -5° 01" N (Figures 1). The area has a humid tropical climate with an annual rainfall ranging from 2500-3000mm and annual mean temperature of about 27°C and the relative humidity ranging from 75% to 79%. Ikot Ayan village, Ediene is in Ikono Local Government Area of Akwa Ibom State, which was considered as a non-industrialized area was chosen as the control site. It lies between longitudes 7°45'E - 8°00'E and latitudes 5°05'N -5°15'E (Figure 1). The topography of the study area is low-lying with coastal plain sand as parent material (Petters *et al.*, 1989).
The surface geology is unconsolidated sand formation ranging from coarse to fine sands (Tahal, 1979; Okoji, 1988). The soil is generally very porous and weakly structured with moderate nutrient and high water retention capacity, thus, the motivation in carrying out this study because of the fact that these boreholes which are sources of water supply to inhabitants of this area, are located within this Industrial Layout.

### Methods of Data Collection

With the aid of global positioning system (GPS) and measuring tape for establishment of points, groundwater samples were collected from five (5) boreholes selected through simple random sampling method within Aka-Offot Industrial Layout, Uyo during wet and dry seasons. Water samples were equally collected from a borehole at the control site.
The study sites were: (i) The Nigerian Security and Exchange Commission premises with Field Code (NSEP), which is located 640 metres away from Champion Breweries wastewater disposal site and 905 metres away from Plasto Crown waste disposal site; (ii) Central Bank of Nigeria premises with field code (CBNP) which is located 460 metres away from Champion Breweries wastewater disposal site and 902 metres away from Plasto Crown waste disposal site; (iii) private compound with field code (PC) which is located 310 metres away from Champion Breweries wastewater disposal site and 540 metres away from Plasto Crown waste disposal site; (iv) Champion Breweries premises with field code (CBP) which is located 210 metres away from Champion Breweries wastewater disposal site and 250 metres away from Plasto Crown waste disposal site and (v) Plasto Crown premises with field code (PCP) which is located 420 metres away from Champion Breweries wastewater disposal site and 110 metres away from Plasto Crown waste disposal site. New plastic bottles labelled with waterproof marker were used for collecting the water samples. They were first washed with 10 per cent hydrochloric acid (HCl), rinsed with tap water and finally rinsed with distilled water. At the sample collection point, the plastic bottles were rinsed twice with the water to be collected. The boreholes were pumped and allowed to run for some time (15-20 minutes) prior to the collection of the water.
The water samples were collected in clean 200 ml polyethylene plastic bottles from both the study area and the control site. Two samples were collected at each location; one for physico-chemical properties determinations, while the other one was for heavy metal analysis. Samples collected for heavy metal analysis were preserved by adding a drop of nitric acid ($HNO_3$) after collection so as to preserve the metals. Electrical conductivity, hydrogen ion concentration (pH) and temperature of the sampled water were determined at the field with the aid of the following equipment listed in Table 1. The samples were stored in an ice-packed cooler kit and transported to the laboratory for prompt analyses within 24 hours, using standard scientific methods (Table 1).

## Results and Discussion

The results of the physico-chemical properties, and heavy metal concentrations of the water samples collected from the boreholes of the study area as well as the control site are presented in Tables 2 & 3, for comparison with the control site and the world's permissible standards (FEPA, 1988 and WHO, 2006).

### Physico-chemical properties

### Physical parameters

### Temperature

The Temperature of groundwater from the study area varied from 25.3 – 26.2°C with a mean temperature of 26.10°C while the control site had 25.2°C during dry season (Table 2) and the wet season varied from 25.5°C – 26.0°C with a mean of 25.80°C and the control site had 25.0°C (Table 3). The temperature of water from the study area for both dry and wet seasons was higher than the one of the control site. The temperature of water from the study area was slightly above the 25.0°C permissible limit of WHO (2006) and significantly below the 30°C stipulated by FEPA (1988). Temperature affects the amount of dissolved oxygen in water, metabolic rate of aquatic animals and so on. Therefore, the temperature of water from the study area was slightly moderate.

**Turbidity**

The turbidity of water from the study area (mean) was 1 NTU during dry season and 1 NTU (mean) during wet season while the control site equally had 1 NTU for both dry and wet seasons (Table 2 and 3). There was no significant difference between the turbidity values of the water from the study area, the control site and the world's permissible limit of 1 NTU (FEPA, 1988). High turbidity in groundwater is usually caused by particulate matter in suspension which results from land surface erosion. Therefore, the average turbidity value in the groundwater of the study area was due to the fact that when water seeps downwards or percolates through the ground (mostly the coastal plain sands of the study area) most of the organic matter or suspended particles that are be picked near the ground surface have been gradually removed (Esu and Amah, 1999). This observation is explained by the "filti-plant function" of aquifers which states that "the unsaturated overlying an aquifers can act as a waste treatment system" (Fetter, 1980; Esu and Amah, 1999).

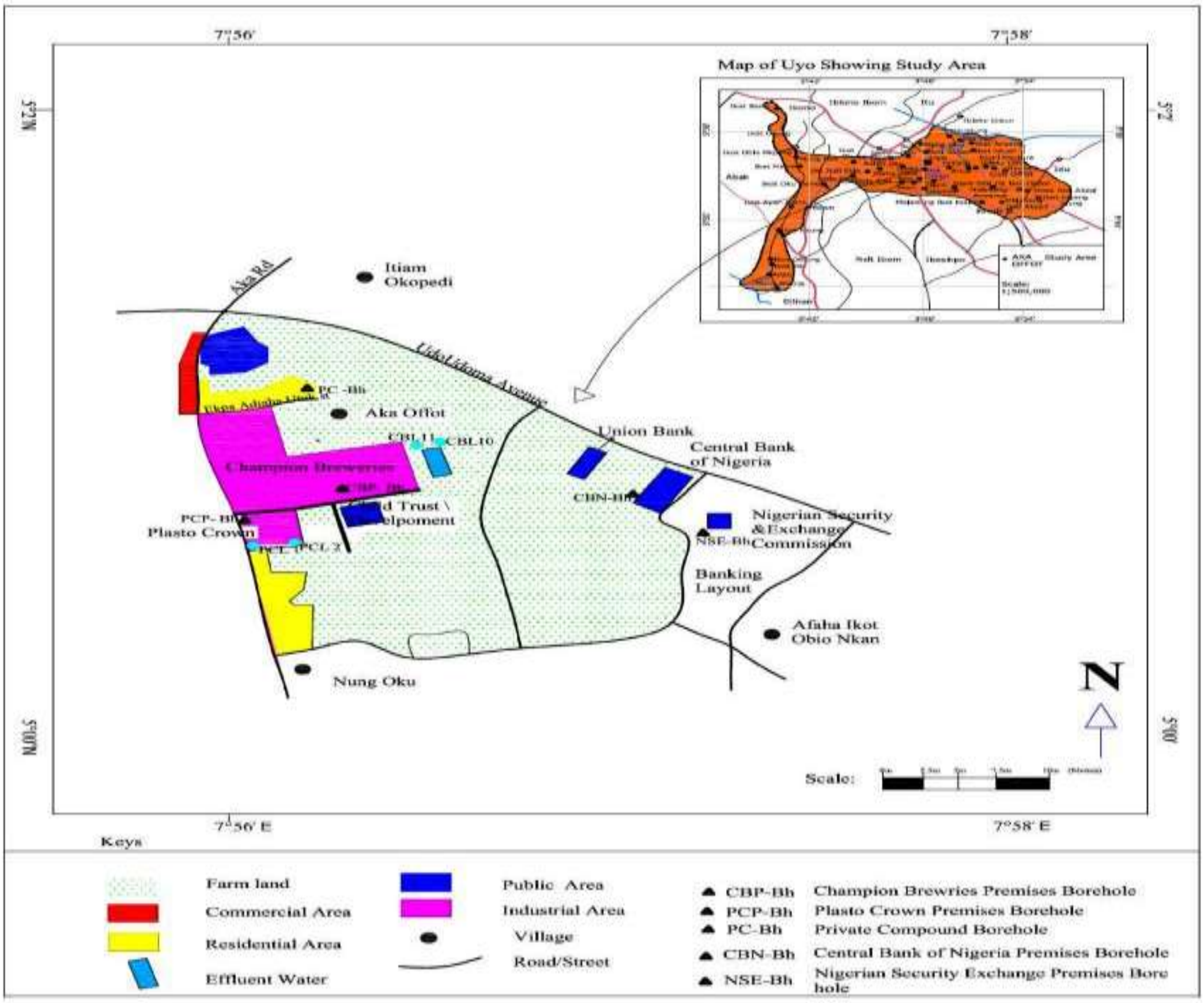


**Figure 1:** Map of Akwa Ibom State showing study area and control site.
Source: Agate Geographic Services (2008)

**Table 1:** Methods and equipment used for physico–chemical properties, nutrients and heavy metal analyses

| Analytical equipment/ Method of Reference | | Parameter |
|---|---|---|
| Cyberscan pH 20 meter | | pH |
| Cyberscan low 20 conductivity meter | | Conductivity, Temperature<br>Total Dissolved Solid (TDS) |
| Microprocessor Oximeter 196 | - | Dissolved Oxygen (DO) |
| Atomic absorption spectrophotometer (AAS) (Whitehead 1979, method) | - | Heavy metals |
| Spectrophotometrically by | | |

| | | |
|---|---|---|
| (a) Turbidimetry using baricum chloride (APHA, 1993) | - | Sulphate, So4 |
| (b) As nitrate after reduction in a reduction calcium system (Parsons et. al., 1984) | - | Nitrate ($No_3$) |
| (c) Formazine standards | - | Turbidity (NTU) |
| (d) Nesslerizaiton method | - | Ammonium ($NH_4$) |
| Difference between initial oxygen concentration in sample and concentration after 5 days incubation in dissolved oxygen (DO) bottles at 20°C (APHA, 1993) | - | Biochemical oxygen demand ($BOD_5$) |

Source: Adapted from Whitehead (1979); Parsons *et al.* (1984) APHA, (1993).

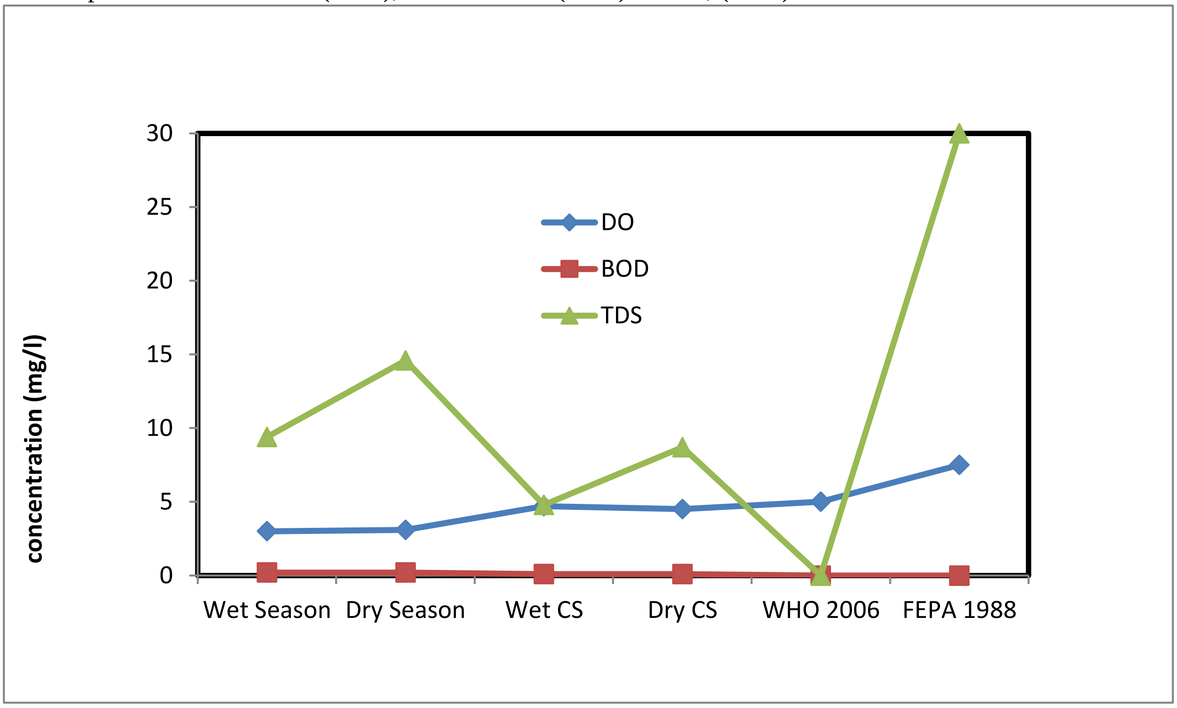


**Figure 2:** DO, BOD and TDS levels of the water collected from boreholes within Aka-Offot Industrial Layout, Uyo versus the one from the control site (CS) and the world's threshold standards.

**Electrical conductivity (EC)**

Electrical conductivity of water from the study area varied from 11-29 µs/cm with a mean of 21µs/cm while the control site had 16µs/cm for dry season and the wet season varied from 10-27 µs/cm with a mean of 20µs/cm from the study area and 15µs/cm for the control site (Table 3). The EC mean value that of the control site, and equally the same situation during the wet season. However, the electrical conductivity permissible limits for groundwater were not supplied by WHO (2006) and FEPA (1988). But from the TDS values of water from the study area, the amount of dissolved salts in the water did not constitute any danger to human health and aquatic life implying that the electrical conductivity derived from the water of this area was in order (Olasoji et al., 2015).

**Chemical parameters pH**

The pH of water from the study area varied from 4.91-5.71 with a mean of 5.35 while the control site had 6.02 for dry season (Table 2) and wet season varied from 5.16 – 5.91 with a mean of 5.54 from the study area and 6.08 for the control site. As indicated in the water from the study area, there was significant level of acidity as compared to the control site for both dry and wet seasons, likewise the world's threshold standard of 6.5-8.5 pH for drinking water (FEPA, 1988 and WHO, 2006). This range of pH may impair the potable state of groundwater from the study area. Low pH and high content of carbon dioxide in water suggest that the natural state of water in such areas are corrosive to iron and steel and could attack carbonate minerals (Esu and Amah, 1999).

**Dissolved oxygen (DO)**

The dissolved oxygen of water from the study area varied from 3.0 – 3.20 mg/l with a mean of 3.10 mg/l while the control site had 4.5 mg/l for dry season and the wet season had 3.0 -3.1 mg/l with a mean of 3.0 mg/l for the study area and 4.7 mg/l for control site. The result shows that the DO values of the water from the study area for both dry and wet seasons were lower than that of the control site. Equally when compared to 5.0 mg/l recommended by WHO (2006) and 7.5 mg/l recommend by FEPA (1988) for drinking water, implies that the amount of DO of water from the study area was significantly low; (low oxygenation) which could be attributed to the load of impurities and organisms in the groundwater occasioned by industrial effluent. This is also evident in the result of the biological oxygen demand (BOD).

**Biological oxygen demand (BOD)**

The biological oxygen demand of water from the study had a mean of 0.2 mg/l while the control site had 0.05 mg/l for dry season and the wet season varied from 0.1-0.2 mg/l with a mean of 0.2 mg/l and the control site had 0.5 mg/l. The BOD values from the study area were higher than that of the control site for both dry and wet seasons and significantly higher than the world's permissible limit of 0 mg/l by FEPA (1988) and WHO (2006) for drinking water, signifying high level of algae and other organisms in the groundwater with attendant decrease of oxygen in this water.

**Total dissolved solid (TDS)**

The total dissolved solid of water from the study area varied from 10.60-17.80 mg/l with a mean of 14.60 mg/l while the control site had 8.7 mg/l for dry season and the wet season varied from 5.8 – 14.7 mg/l with a mean of 9.40 mg/l from the study area and the control site had 4.8 mg/l. The TDS values of the water from the study area were a bit higher than that of the control site but significantly lower than the FEPA (1988) and the Nigerian Standard for Drinking Water Quality (2015) permissible limit of 500 mg/l. Total dissolved solid is a measure of the amount of dissolved salts in water. Salty water conducts electricity more readily than pure water. The values of TDS of the water from the study area indicate that the amount of dissolved salts in the water was not up to the level that constitutes danger to human health and aquatic life (Olasoji et al., 2019). TDS just like electrical conductivity, serve as tool for assessing the purity of water (United States Environmental Protection Agency, 2022).

**Ammonium ($NH_4^+$)**

The ammonium ($NH_4^+$) content of water from the study area varied from 0.031 – 0.045 mg/l with a mean of 0.039 mg/l while the control site had 0.025 mg/l for dry season and the wet season varied from 0.031 – 0.041 mg/l with a mean of 0.036 mg/l and the control site had 0.023 mg/l (Table 3). The mean contents of both dry and wet seasons from the study area were a bit higher than the ones from the control site but fell below the permissible limits of 0.2 – 0.3 mg/l by WHO (2006) and 1.0 mg/l by FEPA (1988). Ammonium is a source of nitrogen in water. There is need to control the way effluent is being disposed in this area to avoid water pollution from ammonium because its high concentration in water is toxic to aquatic life (Olasoji et al., 2019).

**Nitrate ($NO_3$)**

The nitrate content of water from the study area varied from 1.982 – 2.086 mg/l with a mean of 2.029 mg/l while the control site had 1.893 mg/l for dry season and the wet season varied from 1.980 – 2.081 mg/l with a mean of 1.890 mg/l and the control site had 1.890 mg/l. The mean content of nitrate in water from the study area during dry season was higher than the one from the control site while the mean value of nitrate in water from the study area, during wet season was the same with one from the control site but all of them fell below the 50 mg/l WHO (2006) permissible limit and 10.0 mg/l stipulated by FEPA (1988). Nitrate is a source of nitrogen in water but its high concentration causes excessive growth of algae and eutrophication in aquatic ecosystem (Olasoji et al., 2019).

**Sulphate ($S_4^2$)**

The sulphate content of water from the study area varied from 0.853 – 1.458 mg/l with a mean of 1.130 mg/l for dry season while the control site had 0.883 mg/l and the wet season varied from 0.824 – 1.433 mg/l and the control site had 0.798 mg/l (Table 3). The mean contents of sulphate from the study area was higher than the ones from the control site but fell below the permissible limits of 400 mg/l by WHO (2006) and 500 mg/l by FEPA (1988). Sulphate is a source of sulphur in water, but its high concentration can impair photosynthesis and increase respiration (Olasoji et al., 2019).

**Heavy metal concentration**

**Iron (Fe)**

The iron content of water from the study area varied from 0.042 – 0.182 mg/l with a mean of 0.104 mg/l while the control site had 0.025 mg/l for dry season and the wet season varied from 0.020 – 0.173 mg/l with a mean of 0.034 mg/l from the study area and 0.024 mg/l for the control site. The mean values of Fe from the study area for both dry and wet seasons were a bit higher than the control site but fell below the permissible limit by 0.30 mg/l (WHO, 2006) and 1.0 mg/l for (FEPA, 1988) for drinking water.

**Lead (Pb)**

The Pb content of water from the study area varied from 0.002- 0.008 mg/l with a mean of 0.004 mg/l while the control site had 0.002 mg/l for dry season and the wet season varied from 0.001 – 0.004 mg/l with a mean of 0.002 mg/l from the study area and 0.001 mg/l for the control site. The mean value of Pb for dry season was a bit higher than that of wet season but fell below the permissible levels of 0.01 mg/l (WHO, 2006) and 0.05 mg/l stipulated by FEPA (1988).

**Zinc (Zn)**

The Zn content of water from the study area varied from 0.105- 0.343 mg/l with a mean of 0.207 mg/l while the control site had 0.043 mg/l for dry season and the wet season varied from 0.057–0.340 mg/l a mean of 0.192 mg/l from the study area and 0.039 mg/l for the control site (Table 3). The mean contents of zinc from the study area were higher than the ones from the control site for both dry and wet seasons but fell below the FEPA (1988) permissible limit of 1.0 mg/l for drinking water.

**Cadmium (Cd)**

The cadmium content of water from the study area varied from 0.002 – 0.007 mg/l with a mean of 0.004 mg/l while the control site had 0.002 mg/l for dry season (Table 2) and the wet season varied from 0.001 – 0.003 mg/l with a mean of 0.002 mg/l and the control site had 0.001 mg/l (Table 3). The mean concentration of Cd in the dry season was higher than the one of the wet season. Moreso, the mean values of Cd in water from the study area for both dry and wet seasons were higher than the control site. It is observed that the mean Cd value of 0.004 mg/l of the study area during dry season was above the WHO (2006) permissible limit of 0.003 mg/l but all of them fell below the FEPA (1988) limit of 0.01 mg/l for drinking water.

**Chromium (Cr)**

The chromium content of water from the study area varied from 0.001 – 0.004 mg/l with a mean of 0.002 mg/l while the control site had 0.001 mg/l for dry season (Table 2) and the wet season varied from 0.001- 0.002 mg/l with a mean of 0.002 mg/l and the control site had 0.001 mg/l (Table 3). The mean values of Cr in water from the study area were above the values of the control site for both dry and wet seasons but fell below the WHO (2006) and FEPA (1988) permissible limit of 0.05 mg/l for drinking water.

**Cobalt (Co)**

The cobalt content of water from the study area varied from 0.011-0.038 mg/l with a mean value of 0.020 mg/l while the control site had 0.004 mg/l for dry season (Table 2) and the wet season varied from 0.009 – 0.019 mg/l with a mean of 0.013 mg/l and the control site had 0.003 mg/l (Table 3). The mean values of Co in water from the study area were above the values from the control site. Though the Co permissible limit in drinking water was not supplied by WHO (2006) and FEPA (1988), the value of Co from the study area was the same with the United States Environmental Protection Agency (2022) limit of 0.02 mg/l for surface water.

**Manganese (Mn)**

The manganese content of water from the study area varied from 0.014 – 0.073 mg/l with a mean of 0.33 mg/l while the control site had 0.013 mg/l for dry season (Table 2) and the wet season varied from 0.009 - 0.061 mg/l with a mean of 0.026 mg/l and the control site had 0.009 mg/l (Table 3). The mean values of Mn in water from the study area were above the values of the control site for both dry and wet seasons but fell within the 0.4 mg/l permissible limit of WHO (2006) while the value from the study area during dry season was above the FEPA (1988) limit of 0.05 mg/l for drinking water. However, strict measures in controlling wastes from this area should be applied. For instance, the implication for areas with high concentrations of $Fe^{2+}$ and $Mn^{2+}$ is that the waters will not only have taste but will stain laundry and plumbing fixtures and cooking utensils. Incrustation of well screens and plugging of pipes are other adverse effects. Apart from the problem of taste, manganese also enhances growth in reservoir filters and distribution systems (Todd, 1980; Esu and Amah, 1999).

**Conclusion/Recommendations**

The study submits that the temperature of water from the study area was slightly moderate because it was a little above WHO permissible limit but below FEPA limit. The turbidity of water from the study area fell within the permissible limit as well as the electrical conductivity. The water from the study area was acidic because the pH was lower than the permissible level. The dissolved oxygen in the water was significantly low which was attributed to high load organisms which equally manifested in the higher biological oxygen demand value which was above the permissible limit. This was attributed to high level of algae and other organisms with attendant decrease of oxygen in the water. The total dissolved solid of water from the study area was below the permissible limit as well as ammonium, nitrate and sulphate. In terms of heavy metals, the values of iron, lead and zinc fell below the permissible limits. For cadmium, it was observed that its mean value during dry season in the study area was a little above the WHO permissible limit but all of them fell below the FEPA allowable limit. Equally, the chromium and cobalt values of water from the study area fell below the permissible limits while manganese mean value of water from the study during dry season was above the FEPA permissible limit but all of them fell within the WHO limit.

In summary, some of the parameters of water from the study area were above the ones from the control site as well as the world's threshold standards. It is concluded that industrial wastes from industries in this layout, have had adverse effects on the groundwater of this area. Therefore, to safeguard the health and safety conditions of the inhabitants of this area and to operationalize a functional policy framework for industries in this Industrial Layout, the following recommendations are prescribed:

The management of industries operating in this area should as matter of urgency, install anti-pollution equipment for the treatment of their effluent in line with FEPA Act (Cap 131 of 1991), which states that "every industry shall install anti-pollution equipment for the detoxification of the

**Table 2:** Physio-chemical properties nutrients and heavy metal concentrations in water sampled from existing boreholes around Champion Breweries and Pasto Crown **Company**

| | | | | | Dry season | | | Tolerable limits |
|---|---|---|---|---|---|---|---|---|
| Parameters | **Range** | **Mean** | **SD** | **CV (%)** | **SE** | **Control site** | **WHO (2006)** | **FEP (1988)** |
| **A. Physical properties** | | | | | | | | |
| Temperature (°C) | 25.3 – 26.2 | 26.10 | 0.2160 | 0.8275 | 0.0881±26.0666 | 25.2 | 25.0 | 30.0 |
| Turbidity (NTU) | - | 1 | 0 | 0 | 0±1 | 1 | NS | 1.0 |
| Conductivity(μs/cm) | 11 -29 | 21 | 6.0221 | 28.6766 | 2.4558±21.3333 | 16 | - | - |
| **B. Chemical properties** | 4.91 – 5.71 | 5.35 | 0.3395 | 6.3457 | 0.1386±5.3533 | 6.02 | 6.5 – 8.5 | 6.5-8.5 |
| pH | 3.0 – 3.20 | 3.10 | 0.0752 | 2.4258 | 0.0307±3.0833 | 4.5 | 5.0 | 7.5 |
| Dissolved Oxygen (mg/l) | | | | | | | | |
| BODS (mg/l) | - | 0.2 | 0.0417 | 0.6725 | 0.0224±0.2010 | 0.05 | 0 | 0 |
| TDS(mg/l) | 10.60-17.80 | 14.60 | 2.3978 | 16.4232 | 0.9789±14.6166 | 8.7 | NL | 500 |
| $NH^{+}_{4}$ (mg/l) | 0.031-0.045 | 0.039 | 0.0048 | 12.3076 | 0.0019±0.0386 | 0.025 | 0.2- 0.3 | 1.0 |
| $NO_{3-}$ (mg/l) | 1.982-2.086 | 2.029 | 0.0437 | 2.1537 | 0.0178±2.0286 | 1.893 | 50 | 10.0 |
| $SO_4^{2-}$ (mg/l) | 0.853-1.458 | 1.130 | 0.2084 | 18.4424 | 0.0836±1.1301 | 0.883 | NS | 500 |
| **C. Heavy Metals** | | | | | | | | |
| Fe (mg/l) | 0.042-0.182 | 0.104 | 0.0584 | 56.1538 | 0.0238±0.1043 | 0.025 | 0.30 | 1.0 |
| Pb (mg/l) | 0.002-0.008 | 0.004 | 0.0020 | 50.00 | 0.0008±0.0041 | 0.002 | 0.01 | 0.05 |
| Zn (mg/l) | 0.105-0.343 | 0.207 | 0.0784 | 37.8743 | 0.0320±0.2066 | 0.043 | NS | 1.0 |
| Cd (mg/l) | 0.002-0.007 | 0.004 | 0.0019 | 47.50 | 0.0007±0.0038 | 0.002 | 0.003 | 0.01 |
| Cr (mg/l) | 0.001-0.004 | 0.002 | 0.0010 | 50.00 | 0.0004±0.0023 | 0.001 | 0.05 | 0.05 |
| Co (mg/l) | 0.011-0.038 | 0.020 | 0.0095 | 47.50 | 0.0039±0.0200 | 0.004 | NS | NS |
| Mn (mg/l) | 0.014-0.073 | 0.033 | 0.0248 | 75.1515 | 0.0111±0.0326 | 0.013 | 0.4 | 0.05 |

**premises and control site for wet season**

**Note:** WHO – World Health Organization (2006). FEPA = Federal Environmental Protection Agency (1988);
ND = not detected; NL= no limit; NS= not supplied; SD = standard deviation; Cv = Coefficient of variability SE= standard error.

**Source**: Author's Fieldwork (2021)

**Table 3:** Physico-chemical properties, nutrients and heavy metal concentrations in water sampled from existing boreholes around Champion Breweries and Plasto Crown Company premises and control site for wet season

| Parameters | Range | Mean | SD | CV% | SE | Control site | WHO (2006) | FEPA (1988) |
|---|---|---|---|---|---|---|---|---|
| **A. Physical properties** | | | | | | | | |
| Temperature (°C) | 25.5 –26.0 | 25.80 | 0.2097 | 0.8127 | 0.0856±25.800 | 25 | 25.0 | 30.0 |
| Turbidity (NTU) | | 1 | 0 | 0 | 0±1 | 1 | - | 1.0 |
| Conductivity (µs/cm) | 10-27 | 20 | 5.8793 | 29.3965 | 2.4002±20.1666 | 15 | - | - |
| **B. Chemical properties** | | | | | | | | |
| pH | 5.16 –5.91 | 5.54 | 0.3101 | 5.5974 | 0.1266±5.5433 | 6.08 | 6.5 – 8.5 | 6.5 – 8.5 |
| TDS(mg/l) | 5.8 –14.7 | 9.54 | 3.2234 | 34.2914 | 1.359±9.3666 | 4.8 | NL | 500 |
| Dissolved Oxygen(mg/l) | 3.0-3.1 | 3.0 | 0.0516 | 1.7200 | 0.0210±3.0333 | 4.7 | 5.0 | 7.5 |
| BODs (mg/l) | 0.1 –0.2 | 0.2 | 0.0516 | 0.6339 | 0.0210±0.1666 | 0.05 | 0 | 0 |
| $NH^+_4$ (mg/l) | 0.031-0.041 | 0.036 | 0.0034 | 9.4444 | 0.0014±0.0361 | 0.023 | 0.2 – 0.3 | 1.0 |
| $NO_{3-}$ (mg/l) | 1.980–2.081 | 2.025 | 0.0431 | 2.1283 | 0.0176±2.0246 | 1.890 | 50 | 10.0 |
| $SO_4^{2-}$ (mg/l) | 0.824-1.433 | 1.097 | 0.2196 | 20.0182 | 0.0896± 1.0968 | 0.798 | 400 | 500 |
| **C. Heavy Metals/ Toxic Substances** | | | | | | | | |
| Fe (mg/l) | 0.020-0.173 | 0.034 | 0.0683 | 200.8823 | 0.0278±0.0840 | 0.024 | 0.30 | 1.0 |
| Pb (mg/l) | 0.001-0.004 | 0.002 | 0.0011 | 55.00 | 0.0004±0.0021 | 0.001 | 0.01 | 0.05 |
| Zn (mg/l) | 0.057–0.340 | 0.192 | 0.0923 | 48.0729 | 0.0376±0.1916 | 0.039 | NS | 1.0 |
| Cd (mg/l) | 0.001-0.003 | 0.002 | 0.0009 | 45.00 | 0.0004±0.0018 | 0.001 | 0.003 | 0.01 |
| Cr (mg/l) | 0.001-0.002 | 0.002 | 0.0005 | 25.00 | 0.0002±0.0016 | 0.001 | 0.05 | 0.05 |
| Co (mg/l) | 0.009-0.019 | 0.013 | 0.0034 | 26.1538 | 0.0014±0.0133 | 0.003 | NS | NS |
| Mn (mg/l) | 0.009-0.061 | 0.026 | 0.0175 | 67.3076 | 0.0078±0.0132 | 0.009 | 0.4 | 0.05 |

**Note:** WHO – World Health Organization (2006). FEPA = Federal Environmental Protection Agency (1988);
ND = not detected; NL= no limit; NS= not supplied; SD = standard deviation; Cv = Coefficient of variability SE= standard error.

**Source**: Author's Fieldwork

effluent and chemical discharges emanating from their industries". The installation of such equipment shall be based on Best Available Technology (BAT), the Best Practical Technology (BPT) or the Uniform Effluent Standard (UES).
Further studies should be carried on the groundwater of this industrial complex, most especially the microbial studies.
Appropriate treatment should be given to water from boreholes in this area before drinking. For instance, consumers of borehole water should always boil such water before drinking.

**Declarations**

**Ethics approval and consent to participate**

Not applicable

**Consent for publication**

Not applicable

**Availability of data and material**

All data are contained within the manuscript and electronic supporting information (ESI)

**Competing interests**

All authors declare zero financial or inter-personal conflict of interest that could have influenced the research work or results reported in this research paper.

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