https://doi.org/10.33472/AFJBS.6.11.2024.668-690

AFJBS
African Journal of Biological Sciences
Journal homepage: http://www.afjbs.com

Research Paper Open Access

GROUNDWATER QUALITY ASSESSMENT IN SELECTED POLLUTION-PRONE LOCAL GOVERNMENT AREA IN CROSS RIVER STATE, NIGERIA

Agbor R.B.[1], Asuquo[2], E.N., Ajang, Raymond Odey.[3], Idung, Joseph Udo.[4], Asor Joseph[5], Ekpe Glory[6]

[1,6]Department of Genetics and Biotechnology, University of Calabar, Calabar, Cross River State, Nigeria
[2]Department of Curriculum and Teaching, Educational Technology Unit, University of Calabar, Cross River State, Nigeria.
[3,5]Department of Zoology and Environmental Biology, University of Calabar, Calabar, Cross River State-Nigeria
[4]Department of Science Laboratory Technology, University of Calabar, Calabar, Cross River State-Nigeria
Email: [1]agborreagan@yahoo.com

Article Info

Volume 6, Issue 11, July 2024

Received: 22 May 2024

Accepted: 19 June 2024

Published: 08 July 2024

doi: 10.33472/AFJBS.6.11.2024.668-690

ABSTRACT:

Groundwater is an important natural resource that the majority of the human population depend on for drinking. Potable water is essential for good health and the socio-economic development of man. This research examined the quality of groundwater in selected pollution-prone towns in Cross River State. The study evaluated the level of contamination and quality of the groundwater from boreholes closed to dumpsites and abattoirs in six L.G.A in Cross River State. Borehole water samples were subjected to standard laboratory procedures.Physico-chemical (pH, temperature, electrical conductivity, total dissolved solids (TDS), heavy metals (nitrate, chloride, copper, zinc, aluminum, Fluoride, and ammonia) and microbiological examination of the borehole water samples were carried out. The results revealed that the pH for the groundwater samples ranged from 4.26 – 7.0 indicating acidity in some of the water samples. The value for conductivity ranged between 31.33 – 603.67 µs/cm and was above the WHO standard for drinking water, fluoride ranged between 0.10 – 0.68mg/L, and calcium with a range of 11.13 – 2.1.17mg/L which was within the WHO and NIS permissible limits. Standard BOD values were higher than all the controls. The microbial load of the underground water was significantly high in all the areas sampled. It was evident from the BOD values, that there is a high level of contamination of groundwater sources within the areas visited which makes the need for urgent health intervention.

Keywords: Contamination, Groundwater, Microbial, Dumpsites, Leachates

1. INTRODUCTION

Water pollution occurs when physical; biological and chemical substances change the physiology of the water body (Daniels *et al.,* 2013). Water pollution is a global problem, in Nigeria the rate of urbanization is characterized by a high population index, and a steady rise in industrial and agricultural activities affects the underground water table. Environmental pollution/degradation and indiscriminate disposal of wastes are perceived to pose serious pollution threats with all their concomitant health hazards on groundwater quality especially in urban areas (Eni *et al*., 2011). Polluted water is unsafe for drinking and swimming, and causes illnesses such as diarrhea, cholera, dysentery, typhoid, and polio. Some people who drink polluted water are exposed to hazardous chemicals that may make them sick. The provision of potable water to rural urban areas is necessary to prevent health issues. Access to safe drinking water is a prerequisite to the reduction in the spread of waterborne diseases (Gomez *et al.,* 2002).

In the past few decades, open dumpsites were the most common practice for municipal solid waste disposal in rural and most urban towns and it is the simplest method of solid waste disposal and provides the cheapest direct cost. The solid wastes both organic and inorganic are deposited in an open low-lying and often low-value land. However, the deposited and exposed wastes constitute aesthetic and odor nuisance, attract insects, and rodents, and pose a great hazard to the environment hence an alternative technique had been developed known as sanitary landfill (Nagendran *et al.,* 2006).

The decomposition and depression of the waste in the landfills drain-out leachate which consist of both biological and chemical substances such as inorganic salts, dissolved organic matter, and toxic metals, could seep down through the different soil layers to affect the underground water table. The different substances in the leachates appear in varying concentrations based on the physical, chemical, and microbiological processes taking place in the deposited waste (Aziz *et al.,* 2010). The availability of leachate in groundwater aquifers may present several dangers to human health and the environment. The impact of leachates on groundwater and other water resources has attracted a lot of attention worldwide. Because of its overwhelming environmental significance, leachate migrations from waste sites or landfills and the release of pollutants from sediments (under certain conditions) pose a high risk to groundwater resources if not adequately managed (Ikem *et al.,* 2002). The impact of pollutants on groundwater continues to raise concern and has become the subject of recent and past investigations (Ahmed and Sulaiman, 2001; Mor *et al.*, 2006). Wastes placed in dumpsites are subjected to groundwater underflow or infiltration from precipitation (Mor *et al.,* 2006).

Anthropogenic activities are also another source of groundwater pollution, due to the indiscriminate location of abattoirs and dumpsites around residential areas in developing countries. The main abattoir activities include butchering, removal of hide, intestine management, rendering, trimming, processing, and cleaning activities. The wastes generated from abattoirs usually comprise blood, oil, mineral and organic solids, salts, and chemicals added during handling operations (Hassan *et al.,* 2014; Akange *et al*., 2016). These wastes are sometimes poorly disposed of and are a major source of water pollution (Enoh *et al.,* 2012). Abattoir wastewater could significantly intensify the amounts of nitrogen, phosphorus, and total solids in the receiving water body (Akange *et al.,* 2016), (FAO, 1997; Okorafor *et al*., 2012). However, 25,000 children die every year from diarrhea caused by unsafe water and poor sanitation. A large percentage of the world's population depends on groundwater as their main source of drinking water (Shah *et al.,* 2021). The importance of potable water both for domestic and industrial uses, has created concern for water quality analysis (Mgbemna *et al*., 2014). Groundwater bodies are prone to contamination from anthropogenic and natural activities. This study was aimed at evaluating the underground water quality in pollution-prone areas in Cross River State

2. MATERIALS AND METHODS

Study area

The groundwater samples for the research work were collected from different sources in Yakurr, Ikom, Yala, Ogoja, Akamkpa, and Calabar municipality LGA of Cross River State. Yakurr and Ikom are located in the central senatorial district of Cross River State. The sampling sites (dumpsites and abattoirs) are all located at various village settlements within Yakurr and Ikom Local Government Area. Yakurr Local Government Area is located at Longitude 8°5'23" East and Latitude 5°45'34" North with a population of 262,700 according to the last census in 2016 with GPS coordinates of 05°48.682 North and 008°05.018 East. It is a populated place and made up of seven (7) villages. Ikom L.G.A is located at Latitude 5°57 North and Longitude 8°42 East. The main occupation of the people is farming. There are civil servants and a few are traders. They make use of this water though not minding whether the water is potable for consumption or not.
Akamkpa local government area and Calabar municipality are located in the Southern Senatorial District, Calabar Municipality lies geographically on Latitude 4°57'North and Longitude 8° 19 East. The area has both urban features as well as rural settings in the environs of the metropolis. Two ethnic groups Quas and the Efiks form the indigenous population. However, because of its cosmopolitan status there abound people from all parts of the State. Of its location, most of the indigenous populations are engaged in fishing, farming, and trading. Akamkpa lies between latitude 050 34'East and longitude 080 47'North. The temperature of both areas ranges from 21.0 5°C to 33.15 ^{0}C while rainfall ranges from 42.0 to 1401.0 (mm/month). Akamkpa shares a border with the Republic of Cameroon. Yala and Ogoja are located in the Northern Senatorial district of the State. Ogoja lies between Latitude 6°39 North and Longitude 8°47 East while Yala lies between latitude 6°35'North and Longitude 8°38 East and their major occupation is farming. Plate 1 shows the waste dumpsite at Yala local government area of Cross River State.

Groundwater sample collection from boreholes

Water samples were collected from boreholes in six (6) Local Government Areas of the State. Fifty-four (54) groundwater samples were collected in labeled sterile and acidified bottles, covered immediately to prevent contamination, and transported in an ice pack to the Cross River State Water Board laboratory for microbiological and physicochemical analysis. Groundwater samples for heavy metal analysis were collected and preserved in acidified bottles with 3 mL of HNO_3 acid. Special precautions were observed during sample collection, by sterilizing the mouth of the tap with methylated spirit and then turning on the tap for maximum flow for two minutes before collecting the water samples in the bottles.

Experimental design

The experimental design for the study was a 3x6 factorial in a Completely Randomized Design (CRD)
Factor 1: Sources (Control, Dumpsite, and Abattoir).
Factor 2: Six Local government Area (Yakurr, Ikom, Akamkpa, Ogoja, Yala and Calabar Municipality.

Microbiological analysis of samples

Qualitative microbiological analysis was applied to samples of water that should be representative of the objective under investigation and that should be well conserved to maintain all relevant properties constant until the time of analysis. Bacteriological water analysis was one of the methods of analyzing groundwater to estimate the number of bacteria colonies present.

Enumeration and identification of microorganisms

Determination of the viable plate count of isolates was done following the method of Iyakndue *et al.* (2017) and Rao *et al.* (2017). The pour plate technique was used for plating the samples, 1ml of the sample was transferred into Petri dishes (in triplicate) and the media used was potatoes dextrose agar (PDA) for fungal enumeration and nutrient agar (NA) for bacterial enumeration. An Aliquate of each sample was transferred into the plate for each sample and then mixed well and allowed to solidify, then incubated at room temperature for 24 hours (for NA) and 72 hours (for PDA). After incubation, the colonies were observed and then counted, and recorded, and then identification of pure cultures from each sample was done by studying colony characteristics, microscopy, and biochemical characteristics. Identification was accomplished by using a binocular microscope to view the isolate (Iyakndue *et al.,* 2017; Rao *et al.*, 2017).

Isolation and purification of the isolates

The bacterial and fungal colonies were purified by repeated sub-culturing into nutrient agar using the pour plate method and potatoes dextrose agar using the spread plate method respectively, which were incubated at room temperature for 24 hours (for NA) and 72 hours for (PDA). From these pure cultures, stock cultures were prepared on agar slants in stock bottles (using nutrient agar for bacterial isolates and PDA for fungal isolates) for subsequent characterization and identification.

Physical analysis of water samples

Temperature

This was determined with the thermometer. The thermometer was inserted into the water sample in a beaker and the reading was noted (Okwute and Isu, 2007; Iyakndue *et al.,* 2017).

pH

The pH was determined with a pH meter (Model Hach Sension +). The pH meter probe was inserted into the water sample in a beaker, the read key was pressed and the pH reading was taken (Okwute and Isu, 2007; Iyakndue *et al.,* 2017).

Conductivity

A conductivity meter (Model: Orion 3 Star) was used. The conductivity meter probe was rinsed with distilled water and inserted into the sample in a beaker, the conductivity reading was displayed (Okwute and Isu, 2007; Iyakndue *et al.,* 2017).

BOD

A BOD meter (Model: HACH HQ40D) was used to determine this parameter. The meter probe was rinsed with distilled water and inserted into the sample. BOD reading was displayed on activation of the read key (Okwute and Isu, 2007; Iyakndue *et al.*, 2017).

Chemical analysis of the water sample

Total iron

The multi-cell adapter with the I-inch square cell holder was inserted into the electronic device after the "total iron" test was selected from a button on the electronic device. Then a clean square sample cell was filled with 10ml of the sample. Contents of one ferro-iron reagent powder pillow were added to the sample cell and swirled to mix. An orange color was formed indicating the presence of iron (Ogunmodede *et al.,* 2013; Iyakndue *et al.,* 2017).

Manganese

The multi-cell adapter with an I-inch square cell holder was inserted into the electronic device after the "manganese" test was selected from a button. Then a square sample cell was filled with 10ml of the sample. Contents of one buffer powder pillow and a citrate type of manganese stopper were added. Then contents of one sodium periodate powder pillow were added to the sample cell stopper and inverted to mix. A violet color indicated the presence of manganese (Ogunmodede *et al.,* 2013; Iyakndue *et al.,* 2017).

Copper

A square sample cell was filled with 10 ml of the sample. The blank was inserted into the cell holder with the fill line facing the user. Zero was pressed on the timer with the display showing 0.00 mg/l Cu. Within 30 minutes after the timer expired, prepared samples were inserted into the cell holder with the fill line facing the user. The results were taken in mg/l Cu (Ogunmodede *et al.,* 2013; Iyakndue *et al.,* 2017).

Nitrate

The "nitrate" test was selected from a button on the electronic device, and then the multi-cell adapter with an I-inch square cell holder was inserted facing the user. The square sample cell was filled with 10 ml of the sample. Contents of one Nitra Ver 5 nitrate reagent powder pillow were added. Then OK was pressed on the timer. A one-minute reaction period began, and then the cell was shaken vigorously until the time expired. The timer "OK" was pressed again. Then a five-minute reaction period began. An amber color developed showing the presence of nitrate (Iyakndue *et al.,* 2017).

Nitrite

The "nitrite" test was selected from a button on the device, and then the multi-cell adapter with an I-inch square holder was inserted. The square sample cell was filled with 10 ml of the sample. Contents of Nitri Ver 3 Nitrite reagent powder pillow were added and swirled to mix. A pink color developed showing the presence of nitrite (Iyakndue *et al.,* 2017).

Phosphorus

A square sample cell was filled with 10 ml of the sample. The blank was inserted into the cell holder. The ZERO was pressed on the button, with the display showing 0.00 mg/l PO_4^{3-}. The prepared sample was wiped and inserted into the cell holder with the fill line facing the user. The results were taken in mg/l PO_4^{3-} (Okwute and Isu, 2007; Iyakndue *et al.,* 2017).

Ammonia

The "ammonia" test was selected from a button on the electronic device and the multi-cell adapter with a one-inch square holder was inserted. The square sample cell was filled with 10 ml of the sample. Contents of one ammonia salicylate powder pillow were added to each cell stopper and then shaken to dissolve. Then the OK button was pressed, and a 15-minute reaction period began. A green color developed showing the presence of ammonia-nitrogen. When the timer expired, the blank was inserted into the cell holder with the fill line facing the user. Zero was pressed on the timer with the display showing 0.00 mg/l NH_3-N. The sample was wiped and inserted into the cell holder and results were taken in mg/l NH_3 (Iyakndue *et al.,* 2017).

Zinc

Ten milliliters of the sample solution were poured into a square sample cell. With the use of a plastic dropper, 0.5 ml of cyclohexanone was added to the solution in the graduated cylinder. Then OK was pressed on the timer. A 30-second reaction period began, during the period the prepared sample in the cylinder was shaken vigorously. A color change was observed, which depending on the zinc concentration could be reddish-orange, brown, or blue (Ogunmodede *et al.,* 2013; Iyakndue *et al.,* 2017).

Chromium

Multi-cell Adapter was inserted with the 1-inch square cell holder facing the user and the required test was selected. A square sample cell was filled with 10 ml of the sample. The contents of one ChromaVer® 3 Reagent Powder Pillow were added to the sample cell and swirled to mix. TIMER>OK button was pressed for a five-minute reaction period will begin. A purple color was formed to indicate the presence of hexavalent chromium. When the timer expired, a second square sample cell was filled with 10ml of sample, the blank was inserted into the cell holder with the fill line facing the user. ZERO buttons were pressed, and the display showed 0.000 mg/L Cr^{6+}

Statistical analysis

The collected data were subjected to a two-way Analysis of Variance (ANOVA) while significant means were separated using the Least Significant Difference (LSD) test at 5% and 1% probability levels.

3. RESULT

Physicochemical properties of groundwater

pH

The result as presented in Table 1 shows that the borehole located in the non-pollution-prone area in Yala LGA had the highest pH value and significantly higher ($P<0.05$) than the value obtained from other sources. This was followed by the pH obtained from Akamkpa (control, dumpsite), Calabar Municipality (control), Ikom (control, dumpsite), Ogoja (control, dumpsites, slaughter), Yala (dumpsite, slaughter) with no significant difference ($P>0.05$) in mean, the pH values obtained from these areas appears to be slightly acidic, which further reduces in areas like Akamkpa and Ikom (slaughter), Yakurr (control, dumpsite, slaughter) (Table 1).

The result revealed that the pH value in Calabar Municipality both in the dumpsite and slaughter areas was the lowest; meaning the boreholes in those areas had a strong acidic content. However, while comparing the pH in the borehole water samples from the different LGAs, excluding the source of collection, it was observed that the pH value from Yala and Ogoja was the highest, followed by Akamkpa and Ikom, also followed by the pH value from Yakurr while Calabar Municipality had the lowest pH value (Table 2). This result implies that the borehole water samples from the pollution-prone areas were acidic.

Electrical conductivity

The borehole located at Ikom (control), Ogoja and Yakurr (control, dumpsite), and Yala (control, slaughter) had significantly high levels of conductivity than the mean values obtained from Akamkpa (control), Cal. M (control), Ikom (dumpsite, slaughter), Yakurr (slaughter), and Yala (dumpsite) with no significant difference ($P>0.05$). This was followed by the conductivity value obtained from Cal.M (dumpsite), Akamkpa (dumpsite), and Ogoja (slaughter) while Cal. Slaughter had a lower conductivity level (Table 1). Table 2 shows that the boreholes from Yakurr and Yala had the highest conductivity level, followed by Ikom. The conductivity level from Akamkpa and Calabar municipalities was the lowest. This result implies that the conductivity levels in the borehole water samples from the different locations were lower than the WHO standard for drinking water and that the ionic concentration of the water was low.

Total Dissolved Solid (TDS)

The result as presented in Table 1 indicates that the TDS in the borehole located at Ogoja (dumpsite), had the highest TDS value than other boreholes. This was followed by the TDS values from Ikom and Yakurr (dumpsite), and Yala (control) with no significant difference (P>0.05) in mean. While, the TDS value from Akamkpa and Calabar municipal (control, dumpsite, slaughter), Ikom, Yakurr, and Ogoja (control, slaughter), and Yala (dumpsite and slaughter) was the lowest with no significant variation in mean. However, Table 2 shows that the TDS value from borehole water samples was the highest, followed by the TDS in boreholes from Ikom and Yakurr that shows no significant differences (P> 0.05) in mean values, while Akamkpa and Calabar municipalities had the lowest TDS in their borehole water. This result based on the WHO standard for drinking water implies that the level of TDS was below the WHO recommended standard.

Turbidity

The result obtained show that water samples from Ikom (dumpsite) had the highest turbidity level, followed by the turbidity level in borehole water samples from Ikom (slaughter), Ogoja (dumpsite), and Yala (control) with no significant difference (P>0.05). This was also followed by the turbidity level in borehole water samples in Akamkpa, Ikom, and Ogoja (control) with no significant difference (P>0.05) in the mean but significantly higher than the turbidity level Akamkpa (slaughter), Calabar Municipality and Yakurr (control), and Yala (dumpsite) while the lowest turbidity level was obtained from borehole water samples from Calabar Municipality (dumpsite, slaughter), and Yakurr (slaughter) with no significant variation in the mean values (Table 1). It was observed that the turbidity of borehole water in Ogoja and Yala was the highest, followed by the values obtained from Akamkpa, also followed the value obtained from Yakurr while the lowest turbidity value was obtained from the borehole water situated in Ikom (Table 2).

Aluminum

The result shows that high Al was detected in Akamkpa (dumpsite), followed by the Al content obtained from Calabar municipality (dumpsite, slaughter) with no significant difference (P>0.05) in mean, but significantly higher than the mean Al content found in other locations and sources (Table 1). However, the Al content in Akamkpa, Calabar municipality was higher than the Al content in Ikom, while Al content in the borehole water from Ogoja, Yakurr, and Yala was observed to be the lowest. This result implies that Akamkpa and Calabar municipalities had the highest Al content in their boreholes.

Ammonia and biochemical oxygen demand

The result as presented in Figures 1 and 2 signified that the ammonia and BOD levels in the borehole water samples from the different locations and sources show no significant difference (P>0.05) in the mean values obtained.

Calcium

The result as presented in Table 1 show that Akamkpa and Ikom (dumpsite), Calabar municipality (control, dumpsite), Ogoja and Yala (slaughter), had significantly high (P>0.05) levels of calcium in the borehole water, higher than the calcium level in other borehole water samples. Table 2 shows that the calcium levels in the borehole water from Calabar municipality were the highest, followed by the Ca level in Ogoja boreholes, followed by the Ca levels in Akamkpa and Ikom boreholes with no significant difference ($P>0.05$) in meanwhile the Ca level in Yakurr was the lowest.

Phosphate

It was observed from the result that the phosphate in boreholes from Ogoja (dumpsite) was the highest, significantly higher ($P<0.05$) than the $PO4^{2-}$ in Akamkpa and Ikom (dumpsite) with no significant difference in mean but significantly higher ($P<0.05$) than the $PO4^{2-}$ in Calabar Municipality (slaughter) and Yala (dumpsite) boreholes. The lowest $PO4^{2-}$ value was obtained in Akamkpa and Ogoja (control) boreholes. Table 2 shows that the $PO4^{2-}$ content in Ogoja boreholes was the highest, followed by the $PO4^{2+}$ content in Ikom boreholes while Akamkpa and Calabar municipality boreholes were the lowest.

Fluoride

The availability of fluoride in borehole water from Akamkpa (dumpsite), Calabar municipality (dumpsite, slaughter), Ikom (dumpsite), Ogoja (dumpsite, slaughter), and Yala (dumpsite) was the highest, with no significant difference ($P>0.05$) in the mean values obtained. This was followed by the fluoride content in borehole water from Calabar Municipality (control), significantly higher than the fluoride content in other borehole water samples, which equally showed no significant difference ($P>0.05$) in mean Table 1. The comparison between the fluoride levels among the different borehole locations shows that Akamkpa, Calabar municipality Ikom, Ogoja, and Yala had the highest fluoride content, while, Yakurr had the lowest (Table 2).

Nitrate

The result as presented in Table 1 show that Akamkpa and Yakurr (dumpsites) had the highest nitrate levels in their boreholes. This was followed by the nitrate levels in Calabar Municipality (dumpsite, slaughter) and Yala (dumpsite) with no significant difference ($P>0.05$) in the mean values obtained but significantly higher than the nitrate content in the boreholes situated at Akamkpa, Yala, and Yakurr (control and slaughter), Calabar Municipality (control), Ikom and Ogoja (control, dumpsite, slaughter) with no significant difference ($P>0.05$) in the mean values. It was also observed that the nitrate level in the Calabar municipality borehole was the highest, followed by the nitrate level in borehole water in Akamkpa and Yakurr that show no difference ($P>0.05$) in means while the nitrate level in Ogoja borehole had the lowest nitrate level (Table 2).

Heavy metal content in groundwater

Iron (Fe)

The result as presented in Table 3 show that the iron level in Calabar Municipality (dumpsite) borehole was the highest, followed by Akamkpa and Yala (dumpsite) boreholes with no significant difference ($P>0.05$) in the mean values. This was followed by the iron content in other borehole water samples in different locations and sources during the research.

Table 4 shows that the iron content in the Akamkpa borehole was the highest, followed by the iron content in borehole water from Calabar municipality and Yala while, Ikom, Ogoja, and Yakurr boreholes had the lowest iron content with no significant difference ($P>0.05$) in mean.

Zinc (Zn) content

It was observed from Table 3 that the zinc level in Ogoja (slaughter) groundwater was significantly low. While borehole water samples from other sources and locations were significantly high in zinc. Table 4 revealed that the zinc in Akamkpa and Ogoja water samples was significantly higher ($P<0.05$) than the zinc level in Calabar Municipality and Yala boreholes water samples, this was followed by the zinc level in Ikom borehole while Yakurr had the lowest zinc.

Chromium (Cr) content

The chromium level in Ogoja (slaughter) was significantly higher ($P<0.05$) than the Cr level in borehole water samples from other locations and sources which appears to be significantly low with no variation in mean (Table 3). The result as presented in Table 4 shows that the chromium content in Ikom and Yakurr boreholes was the highest with no significant difference ($P>0.05$) in the mean values. This was followed by the chromium content in borehole water from Akamkpa, Ogoja, and Yala with no variation in means. While the chromium content in Calabar Municipality was the lowest.

Copper and manganese

The results as presented in Tables 3 and 4 show that the copper and manganese content in groundwater samples from the different locations and sources were not significantly different ($P>0.05$).

Microbial populations in groundwater

Total heterotrophic bacterial counts of groundwater samples

Bacteria are ubiquitous; most of the bacteria are harmful to human health. Water sources meant for human consumption, containing disease-causing bacteria could be detrimental to the well-being of humans. The bacterial counts observed in the groundwater samples obtained from Calabar municipality (slaughter) were more than the counts obtained in other sources and locations. Though the bacterial population was high in the groundwater samples obtained from Calabar municipality (slaughter) indicating contamination of the water source, Ogoja (dumpsite) was next and significantly higher in the bacteria counts than that obtained from Akamkpa (dumpsite), Calabar municipality (control, dumpsite), Ikom (dumpsite, slaughter), Ogoja (slaughter) and Yala (dumpsite and slaughter) with no significant difference ($P>0.05$) in the mean bacterial counts. The lowest bacterial count was detected in the groundwater samples from Akamkpa (slaughter), Ikom, Yala, and Ogoja (control), and Yakurr (control, slaughter, dumpsite) with no significant difference ($P>0.05$) in the bacteria counts obtained. Akamkpa control had no bacteria growth in the borehole water samples (Table 5). However, among the different local government areas in which borehole water sampling was done, Ogoja water samples had the highest bacteria counts, followed by Ikom and Yala borehole water samples while Akamkpa, Calabar municipality, and Yakurr had the lowest bacterial counts with no significant variation in mean values. This result implied that the bacterial population in the water sample could cause a threat to human health and so a remediation approach should be taken.

Total fungal counts of groundwater samples

It was observed from the result as presented in Table 5 that the fungal counts in groundwater samples from Ikom (dumpsite) were the highest, followed by the groundwater samples from Yala (dumpsite and slaughter), This was also followed by the water sample from Calabar municipality dumpsites area. It was also observed that the controls in all the different locations had the lowest fungal counts in the drinking water source. Table 6 shows that the groundwater from Yala had the highest fungal counts, followed by Ikom, also followed by the borehole water sample in Calabar municipality and Ogoja while Akamkpa and Yakurr had the lowest fungal population in their drinking source.

Distinct Fungal isolates from sampling locations

Fungal isolates from Akamkpa were yeast and *Aspergillus* sp. The yeast had a percentage occurrence of 18.18% while the *Aspergillus* sp had a percentage occurrence of 9.09%. The fungal isolates from Ikom LGA were *Fusarium* sp., *Aspergillus* sp., *Penicillium* sp., and *Trichophyton* sp with percentage occurrence of 18.18%, 18.18%, 9.09%, and 9.09% respectively. Calabar Municipality fungal isolates were *Aspergillus* sp with 18.18% percent occurrence. Yala LGA fungal isolate was *Fusarium* sp. with 9.09% percentage occurrence. Yakurr LGA fungal isolates were *Candida albicans* and yeast with 9.09% percent occurrence each. The results for the percentage occurrence of fungi and distinct fungal isolates from sampling locations (Table 7).

Distinct bacterial isolates from sampling locations

The bacterial isolates from Akamkpa LGA were *Enterobacter* sp., *Klebsiella* sp., *Escherichia coli*, and *Streptococcus pyogenes* with a percentage occurrence of 5.56% each. Those from Ikom LGA were *Klebsiella* sp., *Bacillus* sp., *Staphylococcus aureus*, *E. coli*, *Citrobacter* sp, *and Enterobacter* sp with percentage occurrence of 11.11%, 11.11%, 5.56%, 5.56%, 5.56%, and 5.56% respectively. Bacterial isolates in Ogoja LGA were *Staphylococcus aureus* and *Klebsiella* sp with a percentage occurrence of 5.56% each while that of Yala LGA were *Streptococcus pyogenes* and *Enterococcus faccalis* with a percentage occurrence of 5.56% also. Bacterial isolates from Calabar Municipality were *Pseudomonas aeruginosa* and *E,coli* with a percentage occurrence of 5.56% each (Tables 8).

4. DISCUSSION

Effect of Pollutants on the physicochemical properties of Groundwater

The temperature values were within the range for a tropical aquatic system (<40°C). The pH quantifies the level of acidity and alkalinity of a particular substance or solution. Low pH (0-6.99) classifies the solution as acidic, a pH of 7.00 is said to be normal while a pH of 7.1 above is regarded as alkaline. The acidic pH values recorded from most of the dumpsites fall outside the recommended range suitable for drinking. pH is an indicator of water quality and the extent of pollution (Jonnalagadda and Mhere, 2001) thus, the acidic values at the discharge point suggest that the effluent negatively impacted the water quality and this could consequently affect organisms using the groundwater negatively because most of their metabolic activities are pH dependent.

The observed acidity may be a result of humic acid formed from decaying organic matter from leachate. Groundwater pH has been known to influence the dissolution of minerals in a groundwater system as well as affect the quality for various purposes. This is in line with reports from Rim-Rukeh *et al.*(2006) and Cleary & Devantier (2019), that decaying organic matter contributes to humic acid formation and leaching into groundwater with a resultant increased acidity or alkalinity of the groundwater. The present study revealed that fluoride which is distributed in the lithosphere and hydrosphere varied significantly among the dumpsites and abattoirs ranging from 0.14 mg/l in Yakurr to 0.57 mg/l in Calabar municipality. The concentration of fluoride in the water samples studied falls short of the WHO (2006) guideline value for fluoride concentration of 0.5 – 0.9 mg/l. This could be attributed to the high amount of total dissolved solids in the groundwater in the study area with a high volume of cations that combine with fluoride to form complexes, thus making fluoride unavailable in free form. This was in line with the position of Odukoya (2015).

Biochemical oxygen demand (BOD) of dissolved oxygen concentration in natural waters depends on the physical, chemical, and biochemical activities in the water body. BOD values obtained from the polluted sites across the study area were lower than the WHO (2003) water quality standards but the values were higher than all the control. This could be attributed to the high levels of nutrients, organic loads, and total solids content of effluents from these dumpsites and abattoirs. BOD is very crucial for the survival of aquatic organisms (Yakub and Ugwumba, 2009). The depletion of BOD at these discharge points (DP) may also be attributed to the enormous amount of organic loads which required high levels of oxygen for chemical oxidation, decomposition of nutrients, or break down thereby depleting available oxygen required for respiration. Similar findings have been reported from abattoir effluent by Chukwu *et al*., (2008) and Arimoro *et al*., (2007).

The high BOD values of the dumpsites, as revealed in the present study could be attributed to the low available level of oxygen, since low oxygen level will result in high BOD and this is a strong indication of pollution (Chukwu *et al*., 2007) However, this could be attributed to the fact that most organic substances are ultimately broken down anaerobically or chemically; thus total dissolved solid (TDS) is the quantity of total ions present in solution. TDS measures all the oxidizable organics while BOD measures the oxygen available for biological activities. Also, the high TDS value of the groundwater could be due to the high organic load of the dumpsites and abattoirs. This could probably explain the linear relationship between solid wastes and biochemical oxygen demand (Osibanjo and Adie, 2007). Water's electrical conductivity depends on the amount of ions present. Potable drinking water has fewer ion concentrations while contaminated water or highly polluted water consists of high levels of ions capable of generating electricity.

The electrical conductivity was recorded at high levels at very few discharge points from the study area as presented in Table 1. The observed values could be attributed to the high levels of conducting elements such as aluminum, fluoride, and phosphate. (Fakayode, 2005) reported also that conducting elements contributed to the high electrical conductivity in a studied dumpsite. Aluminum is evenly distributed in nature because of its metallic properties. This element is served as a coagulant during the water treatment in the removal of turbidity, organic matter, and microorganisms. Al also appears as an impurity in other water treatment chemicals, which can leach into drinking water. The term fluoride originated from fluorine, which is a common, natural, and abundant element. The addition of fluoride to the water supply reduces the incidence of tooth decay. The report has shown that excess fluoride could lead to dental fluorosis or skeletal fluorosis, which can cause damage to bones and joints. Nitrate is formed naturally in nature when nitrogen reacts which oxygen or ozone. Nitrogen is vital to all living things, but the richness of nitrate in portable drinking water sources can be detrimental to health, especially in pregnant women and infants. Some nitrate values were above the 15mg/l values for good water quality standard specified by NIS in Calabar municipality (11.33mg/l), Akamkpa (10.04mg/l), and Yakurr (10.06 mg/l). Possible sources of nitrogenous wastes include partially digested food from the gut of slaughtered animals washed into the river, resulting in high-level pollution and contamination of the groundwater (Adesuyi *et al*, 2015).

Phosphates can get into water through anthropogenic sources, animal waste, phosphorus-rich bedrock, laundry, cleaning, industrial effluents, and fertilizer runoff. The presence of phosphates in high enough concentrations in water bodies causes eutrophication. The excess richness of the boreholes due to phosphate could result in the loss of life of aquatic organisms and excessive algae blooms. The present study also showed the presence of high levels of phosphates in the dumpsites and abattoirs. High phosphate levels ranging from 13.17mg/l to

16.38mg/l were obtained across the study areas. The high level of phosphate in the water samples could be due to the leaching of fertilizer residues from agricultural farmlands along the pathways and water bodies. This probably could be due to the enormous farming activities in the study areas which could also be responsible for the abundance of phytoplankton observed along the river banks, especially in Calabar municipality and Ikom. Other sources of phosphate may be from detergents used by the abattoir workers to wash roasted slaughtered animals (Osibanjo and Adie, 2007), laundry activities of surrounding residents, and run-off of household effluents into the river (Fakayode, 2005). Self-purification capacity of a water body is a good indicator of its ecological status and involves complex mechanisms which depend on several factors such as flow rate, time, temperature, serial dilution, chemical oxidation, biodegradation of organic materials, deposition of solid or particulate materials into the sediment, dilution of contaminants, presence of microorganisms, pH and dissolved oxygen content of the water.

Effect of Pollutants on heavy metals contamination of Groundwater

The relatively high concentrations of heavy metals may be attributed to the salt-contaminating nature in some of these locations like Akamkpa with limestone which easily dissolves in water and affects groundwater. The concentration of the studied heavy metals, iron, zinc, chromium, manganese, and aluminum in groundwater in all six locations are not above the typical international standards limits for drinking water and are seriously affected by a huge release of abattoir effluents and dumpsite leachates. Random distribution of heavy metal accumulation in the groundwater of industrial areas may occur. These low concentrations of heavy metals in groundwater depend on the optimum soil properties like the alkaline nature of the soil 7.9 pH, high active /total $CaCO_3$ 62.62%, high clay content 38.16% with SiCl texture, and presence of relatively high alkaline ions such as Ca, Mg, K, Na, and anions as bicarbonate, chloride, carbonate that makes the soil solution to be active in rendering most cationic heavy metals non-soluble and unavailable for plants absorption and protecting the groundwater from this hazardous contamination.

The accumulation of heavy metals was more in the groundwater around dumpsites compared to the groundwater obtained from a location hosting the abattoir as observed in this study. The dumpsites contain more heavy metals, especially the irons. The statistical analysis showed that almost all the heavy metals have much lower concentrations than typical standard levels of groundwater, and poor quality which means that the contamination by heavy metals is not very severe in the control and below risk levels Jonnalagadda and Mhere (2001) and Sarada (2016).

Iron remains the most abundant element by weight in the earth's crust and the second most abundant metal in the earth's crust. It is an essential element in human nutrition with a minimum daily requirement of iron ranging from 10 to 50 mg/day and a concentration of below 0.3 mg/l. (WHO, 2003). Natural water contains a variable amount of iron and in groundwater, it is present in the ferrous or bivalent form (Fe^{++}) according to Kumar and Puri (2012). The iron concentrations estimated in the groundwater sample collected from the dumpsites and abattoirs are more or less within the range of 0.3 mg/l with exceptions from Akamkpa, Calabar municipality, and Yala dumpsites which showed iron contents of 0.48, 0.99, and 0.49 mg/l respectively with relatively higher concentrations above the NIS regulation. This finding is also in collaboration with the reports of Kumar and Puri (2012).

Effect of pollutants on microbial loads of groundwater

The microbiological contamination of groundwater has profound and severe implications for public health, particularly in small communities and developing countries where groundwater is often the preferred source of drinking water (Jonnalagadda and Mhere, 2001). Although natural groundwater is usually of good quality, this can deteriorate rapidly due to inadequate source protection and poor resource management. Contaminated groundwater can contribute to high morbidity and mortality rates from diarrhoeal diseases and sometimes lead to epidemics. The disposal of excreta using land-based systems is a key issue for groundwater quality and public health protection. The use of inappropriate water supply and sanitation technologies in peri-urban areas leads to severe and long-term public health risks. The use of poorly constructed sewage treatment works and land application of sewage can lead to groundwater contamination close to water supply sources. Microorganism in particular, virus survival in these circumstances is not well understood, but there are indications of extended pathogen survival and therefore increased public health risk (Jonnalangadda and Mhere, 2001).

Contamination of the groundwater, as revealed in the present study, can result in poor drinking water quality, loss of water supply, degraded surface water systems, high cleanup costs, high costs for alternative water supplies, and/or potential health problems. The consequences of contaminated groundwater or degraded surface water are often serious. For example, estuaries that have been impacted by high nitrogen from groundwater sources have lost critical shellfish habitats. In terms of water supply, in some instances, groundwater contamination is so severe that the water supply must be abandoned as a source of drinking water. In other cases, the groundwater can be cleaned up and used again, if the contamination is not too severe and if the municipality is willing to spend a good deal of money. Follow-up water quality monitoring is often required for many years. Because groundwater generally moves slowly, contamination often remains undetected for long periods. Several microorganisms and thousands of synthetic chemicals have the potential to contaminate groundwater. Drinking water containing bacteria and viruses can result in illnesses such as hepatitis, cholera, or giardiasis. Methemoglobinemia or "blue baby syndrome," an illness affecting infants, can be caused by drinking water that is high in nitrates. Benzene, a component of gasoline, is a known human carcinogen (Jonnalagadda and Mhere, 2001). The serious health effects of lead are well known—learning disabilities in children; nerve, kidney, and liver problems; and pregnancy risks. Concentrations of these heavy metals in drinking water as revealed in this study and other substances are regulated by federal and state laws. Hundreds of other chemicals, however, are not yet regulated, and many of their health effects are unknown or not well understood. Preventing contaminants from reaching the groundwater is the best way to reduce the health risks associated with poor drinking water quality (Jonnalagadda and Mhere, 2001). The presence of fecal coliform bacteria in groundwater as revealed in the present study (is a collection of relatively harmless microorganisms that live in the intestines of warm- and cold-blooded animals and aid in the digestion of food such *as E. coli* which are present in groundwater. The presence of a coliform fecal contaminant is an indicator that a potential health risk exists for individuals exposed to the water (WHO, 2006).

5. CONCLUSION

Unhygienic water is detrimental to human health and affects the physiological features of humans. The result of this investigation shows clearly that the physical, chemical, heavy metal, and microbiological properties of the water in the different local government areas examined were high and could be injurious to human health. Therefore, Abattoirs and dumpsites should be sited in distant areas away from residential areas.

Acknowledge

I sincerely acknowledge every source cited in this article. Thanks so much

6. REFERENCES

1. Adesuyi, A. A., Nnodu, V. C., Akinola, M. O., Njoky, L. & Joluso, A. O. (2015). Groundwater Assessment Quality in Eliozu community, Port Harcourt, Niger Delta, Nigeria. International Journal of Scientific and Technology, 4(12): 149 – 156.
2. Ahmed, A. M. & Sulaiman, W. N. (2001) Evaluation of groundwater and soil pollution in a landfill area using electrical resistivity imaging survey. Environmental Management Journal, 28(5): 655-663.
3. Akange, E. T., Chaha, J. A. & Odo, J. I. (2016). Impact of Wurukum abattoir effluent on River Benue and Niger using macroinvertebrates as Dio-indicators, International Journal of Aquaculture, 6(22): 1 – 11.
4. Arimoro, F. O., Chukwudi, M. A. & Ogheneghalome, O. (2007). Effect of industrial wastewater on the physical and chemical characteristics of a tropical coastal river. Research Journal of Environmental Sciences, 2, 209-220.
5. Aziz, S. Q., Aziz, H. A., Yuso, M. S., Bashir, M. J. & Umar, M. (2010). Leachate characterization in semi-aerobic and anaerobic sanitary landfills: a comparative study. Journal of Environmental Management, 91(12): 2608 – 2614.
6. Chukwu, O. (2008). Analysis of groundwater pollution from abattoir waste in Minna, Nigeria. Research Journal of Dairy Sciences, 2: 74-77.
7. Cleary, D.F. & Devantier (2019). Industrial effluent encyclopedia of environmental health Second Edition, 2019.
8. Daniels, T. & Daniels, K. (2003). The Environmental planning handbook for sustainable communities and Regions. New York: McGraw Hill.
9. Eni, D. I., Obiefuna J. N, Oko, C. & Ekwok I. (2011). Impact of urbanization on subsurface water quality in Calabar Municipality Nigeria.International Journal of Humanities and social science, 1(10): 167-172.
10. Enoh, C. & Abaraogu, J. (2012). Investigation of a borehole water system in Nigeria. Journal of Medical Sciences, 3: 312 – 318.
11. Fakayode, S. O. (2005). Impact assessment of industrial effluent on water quality of the receiving Alaro stream in Ibadan, Nigeria. Journal Ajeam-Ragee, 10:1-13.
12. Food and Agriculture Organization (FAO) (1997).Chemical Analysis Manual for Food and Water 5th Edition, FAO ROME, 20-26.
13. Gomez, J. D. & Naket, A. C. (2002). Community participation in water and sanitation, Journal of Water International, 27:343 – 353.
14. Hassan, I., Campbell, C. & Ademola, T. (2014). Effect of abattoir effluents on surroundings underground water. International Journal of Advance in Pharmacy, Biology, and Chemistry, 6(1):522 – 529.
15. Ikem, A., Osibanjo, O., Sridhar, M. K. C. & Sobande, A. (2002). Evaluation of Groundwater Quality Characteristics Near Two Waste Sites in Ibadan and Lagos, Nigeria. Journal of Water, Air, and Soil Pollution, 140**:** 307–333
16. Iyakndue, M. L., Brooks, A. A., Unimke, A. A. & Agbo, B. E. (2017). Effects of palm oil mill effluent on soil microflora and fertility in Calabar–Nigeria, Asian Journal of Biology, 2(3): 1-11.
17. Jonnalagadda, S. B. and Mhere, G. (2001). Water quality of the Odzi River in the eastern highlands of Zimbabwe. Water Resources, 35, 2371-2376.
18. Kumar, S., Saha, M., Takada, H., Bhattacharya, A., Mishra, P. & Bhatta Charya, B.(2006). Water quality management in the lower stretch of the River Ganges, east Coast of India: An approach through environmental education. Journal of Cleaner Production, 15(16): 1559-1567.

19. Mgbemena, N. M., Obodo G, A., Okonkwo, N. A. & Onwukeme, B. I. (2014). Physiochemical Assessment of Borehole Waters in Ovim, Isiukwuato LGA, Abia State, Nigeria Journal of Applied Chemistry 7, 31-33.
20. Mor, S., Ravindra, K., Dahiya, R. P. & Chandra, A. (2006). Leachate characterization and assessment of groundwater pollution near municipal solid waste dumpsite site.
21. Nagendran, R., Selvam, A., Joseph, K. & Chiemchaisri, C. (2006). Phytoremediation and rehabilitation of municipal solid waste landfills and dumpsites. A brief review waste management, 26:1357 – 1369.
22. Odukoya A. M. & Abimbola, A. F. (2010). Contamination assessment of surface and groundwater within and around two dumpsites. International Journal of Environmental Science and Technology, 2(2):367-376
23. Ogunmodede, O. T., Ajayi, O. O., Amoo, I. A. & Adewole, E. (2013). Characterization of Dumpsite: A case study of Ado-Ekiti and Ijero Ekiti, Nigeria, Journal of Environmental Science, Toxicology and Food Technology, 3(6): 43-50.
24. Okorafor, K. A., Agbo, B. E., Johnson, A. M. & Chiorlu, M. (2012). Physico-chemical and Bacteriological Characteristics of Selected Streams and Boreholes in Akamkpa and Calabar Municipality, Nigeria, Archives of Applied Science Research, 4 (5): 2115-2121
25. Okwute, L. O. & Isu, N. R. (2007). The environmental impact of palm oil mill effluent (POME) on some physicochemical parameters and total aerobic bio-land of soil at a dump site in Anyigbe, Kogi State, Nigeria, African Journal of Agricultural Research, 2(12): 656-662.
26. Osibanjo, O. & Adie, G. U. (2007). Impact of effluent from Bodija abattoir on the physicochemical parameters of Oshunkaye stream in Ibadan City, Nigeria. African Journal of. Biotechnology, 6, 18061-811.
27. Rao, A. P., Agbo, B. E., Udoekong, N. S. & Etuk, H. A. (2017). Evaluation of the antagonistic potential of soil bacteria against plant pathogenic fungus: Aspergillus niger, Journal of Advances in Microbiology, 3(2): 1-7.
28. Rim-Rukeh, A., O.G. Ikhifa & A.P. Okokoya, (2006). Effects of agricultural activities on the water quality of Orogodo River, Agbor Nigeria. Journal of. Applied Scientific. Resources, 2, 256-259.
29. Shah, S. F. H., Ahmad, L., Sherwani R. A. & Aslam M. (2021). A Study on various pollutants in water and their effect on the blood of the consumers. Applied Water Science Journal, 11, 164.
30. WHO (2006) International Standards for Drinking Water (3rd ed.) Geneva, 346 385.
31. Yakub, A.S. & Ugwumba, A.A.A (2009). A study on the macroinvertebrate fauna of lower Ogun River at Ishasi, Ogun state, south-west Nigeria. Zoologist, 7: 65-74.

Table 1: Physicochemical properties of underground water in pollution-prone areas in Cross River State

Location	**Source**	**pH**	**Conductivity (µS/cm)**	**TDS(mg/L)**	**Turbidity(NTU)**	**AL(mg/L)**	**Calcium(mg/L)**	**Phosphate(mg/L)**	**Fluoride(mg/L)**	**Nitrate(mg/L)**
Akamkpa	Control	6.70^{b}±0.12	203.33^{b}±7.17	64.33^{c}±4.26	7.33^{c}±0.38	0.09^{c}±0.01	14.43^{b}±1.35	5.90^{h}±0.78	0.26^{c}±0.04	5.04^{c}±0.20
	Dumpsite	6.23^{b}±0.20	139.67^{c}±7.13	71.0^{c}±4.36	3.31^{f}±0.44	0.46^{a}±0.02	18.57^{a}±080	24.49^{b}±2.73	0.62^{a}±0.09	17.73^{a}±0.90

	Slaughter	$5.60^{c}\pm0.13$	$39.0^{d}\pm14.64$	$14.0^{c}\pm4.58$	$5.28^{d}\pm0.24$	$0.081^{c}\pm0.04$	$12.5^{b}\pm1.00$	$9.13^{g}\pm0.61$	$0.35^{c}\pm0.05$	$7.35^{c}\pm1.59$
Cal. M	Control	$6.23^{b}\pm0.12$	$241.0^{b}\pm4.93$	$85.67^{c}\pm3.84$	$5.70^{d}\pm0.07$	$0.08^{c}\pm0.02$	$20.93^{a}\pm0.81$	$8.02^{g}\pm1.34$	$0.45^{b}\pm0.03$	$7.03^{c}\pm0.07$
	Dumpsite	$4.26^{e}\pm0.09$	$117.0^{c}\pm13.05$	$57.67^{c}\pm6.39$	$1.58^{h}\pm0.07$	$0.40^{b}\pm0.09$	$20.73^{a}\pm0.82$	$12.18^{f}\pm3.34$	$0.58^{a}\pm0.02$	$12.96^{b}\pm2.43$
	Slaughter	$4.83^{d}\pm0.18$	$31.33^{d}\pm6.76$	$16.00^{c}\pm3.61$	$1.93^{h}\pm0.23$	$0.39^{b}\pm0.08$	$16.35^{b}\pm0.10$	$20.16^{c}\pm4.64$	$0.68^{a}\pm0.09$	$14.04^{b}\pm0.77$
Ikom	Control	$6.50^{b}\pm0.12$	$603.67^{a}\pm51.33$	$157.0^{c}\pm12.74$	$7.10^{c}\pm0.12$	$0.063^{c}\pm0.01$	$11.67^{b}\pm0.18$	$9.06^{g}\pm0.58$	$0.21^{c}\pm0.06$	$3.97^{c}\pm0.44$
	Dumpsite	$6.03^{b}\pm0.09$	$286.67^{b}\pm35.67$	$225.0^{b}\pm13.61$	$8.94^{a}\pm1.06$	$0.16^{c}\pm0.03$	$18.07^{a}\pm1.61$	$23.43^{b}\pm0.94$	$0.54^{a}\pm0.01$	$5.85^{c}\pm0.31$
	Slaughter	$5.50^{c}\pm0.02$	$283.33^{b}\pm29.87$	$113.0^{c}\pm47.70$	$8.15^{b}\pm1.19$	$0.16^{c}\pm0.05$	$16.37^{b}\pm0.67$	$15.85^{e}\pm5.47$	$0.36^{c}\pm0.10$	$6.08^{c}\pm0.07$
Ogoja	Control	$6.70^{b}\pm0.12$	$501.33^{a}\pm44.82$	$161.67^{c}\pm3.84$	$7.28^{c}\pm0.14$	$0.02^{c}\pm0.002$	$13.57^{b}\pm0.41$	$4.59^{h}\pm0.69$	$0.22^{c}\pm0.01$	$1.34^{c}\pm0.28$
	Dumpsite	$6.43^{b}\pm0.20$	$486.67^{a}\pm29.81$	$336.0^{a}\pm73.76$	$8.20^{b}\pm0.09$	$0.08^{c}\pm0.01$	$15.1^{b}\pm1.66$	$27.73^{a}\pm11.42$	$0.55^{a}\pm0.07$	$7.37^{c}\pm2.87$
	Slaughter	$6.47^{b}\pm0.20$	$144.33^{c}\pm7.88$	$69.00^{c}\pm2.08$	$3.30^{f}\pm0.7$	$0.07^{c}\pm0.02$	$21.17^{a}\pm1.39$	$18.17^{d}\pm0.43$	$0.74^{a}\pm0.04$	$2.78^{c}\pm0.62$
Yakurr	Control	$5.67^{c}\pm0.23$	$420.67^{a}\pm41.95$	$152.67^{c}\pm20.03$	$5.45^{d}\pm0.25$	$0.07^{c}\pm0.03$	$9.97^{b}\pm0.27$	$8.30^{g}\pm0.03$	$0.10^{c}\pm0.00$	$5.24^{c}\pm0.44$
	Dumpsite	$5.27^{c}\pm0.23$	$578.67^{a}\pm84.23$	$272.67^{b}\pm10.17$	$2.79^{g}\pm0.23$	$0.12^{c}\pm0.02$	$19.18^{a}\pm0.48$	$18.17^{d}\pm0.78$	$0.19^{c}\pm0.01$	$17.31^{a}\pm2.89$
	Slaughter	$5.13^{c}\pm0.09$	$217.00^{b}\pm45.79$	$68.33^{c}\pm0.88$	$2.02^{h}\pm0.16$	$0.06^{c}\pm0.01$	$12.80^{b}\pm0.91$	$13.70^{f}\pm2.30$	$0.14^{c}\pm0.03$	$7.64^{c}\pm0.33$
Yala	Control	$7.00^{a}\pm0.15$	$541.0^{a}\pm10.69$	$223.67^{b}\pm11.70$	$7.97^{b}\pm0.49$	$0.03^{c}\pm0.001$	$11.13^{b}\pm0.85$	$8.63^{g}\pm0.26$	$0.20^{c}\pm0.01$	$3.11^{c}\pm0.17$
	Dumpsite	$6.37^{b}\pm0.60$	$232.0^{b}\pm5.51$	$105.33^{c}\pm10.41$	$5.26^{d}\pm0.31$	$0.09^{c}\pm0.02$	$12.73^{b}\pm0.69$	$20.89^{c}\pm2.62$	$0.61^{a}\pm0.03$	$12.27^{b}\pm0.32$
	Slaughter	$6.30^{b}\pm0.12$	$469.33^{a}\pm60.76$	$139.0^{c}\pm44.19$	$4.80^{e}\pm0.15$	$0.05^{c}\pm0.01$	$20.10^{a}\pm1.00$	$15.50^{e}\pm1.26$	$0.29^{c}\pm0.04$	$2.98^{c}\pm1.16$
LS		0.23	56.80	46.86	0.43	0.04	1.26	1.64	0.07	1.85

D WHO NIS		6.5-8.5 6.5-8.5	500 1000	250 500		0.02 0.2	0.1 50	5.0	0.5-0.9 1.0	15

Means with the same superscript along the vertical arrays indicates no significant difference (P>0.05).

Table 2: Physicochemical Properties of groundwater collected from different Local Government Area in CRS

Location	pH	Conductivity **(µS/cm)**	TDS **(mg/L)**	Turbidity **(NTU)**	AL **(mg/L)**	Ammonia **(mg/L)**	Calcium **(mg/L)**	Phosphate **(mg/L)**	Floride **(mg/L)**	Nitrate **(mg/L)**	BOD **(mg/L)**
Akamkpa	$6.18^{b}\pm0.18$	$127.33^{d}\pm24.46$	$49.78^{d}\pm9.26$	$5.31^{c}\pm0.61$	$0.209^{a}\pm0.06$	0.023 ±0.001	$15.17^{c}\pm3.15$	$13.17^{d}\pm8.96$	$0.41^{a}\pm0.19$	$10.04^{b}\pm6.07$	$0.89^{c}\pm0.02$
Calabar Municipal	$5.11^{d}\pm0.30$	$129.78^{d}\pm30.76$	$53.11^{d}\pm10.40$	$3.07^{e}\pm0.66$	$0.289^{a}\pm0.06$	0.02±0.001	$19.34^{a}\pm2.46$	$13.45^{d}\pm0.08$	$0.57^{a}\pm0.13$	$11.33^{a}\pm3.94$	$0.70^{c}\pm0.06$
Ikom	$6.01^{b}\pm0.15$	$391.22^{b}\pm68.18$	$165.0^{b}\pm21.97$	$0.07^{f}\pm0.53$	$0.13^{b}\pm0.02$	0.02±0.001	$15.37^{c}\pm3.25$	$16.11^{b}\pm2.01$	$0.37^{a}\pm0.17$	$5.29^{c}\pm1.10$	$1.32^{a}\pm0.82$
Ogoja	$6.53^{a}\pm0.10$	$377.44^{c}\pm89.30$	$188.89^{a}\pm44.57$	$6.26^{a}\pm0.75$	$0.06^{c}\pm0.01$	0.02±0.01	$16.61^{b}\pm3.97$	$16.83^{a}\pm0.89$	$0.50^{a}\pm0.24$	$3.83^{d}\pm0.74$	$1.12^{b}\pm0.44$
Yakurr	$5.36^{c}\pm0.11$	$405.44^{a}\pm76.74$	$164.5^{b}\pm42.12$	$3.42^{d}\pm0.53$	$0.09^{c}\pm0.01$	0.01±0.001	$13.98^{e}\pm0.19$	$13.39^{d}\pm0.76$	$0.14^{b}\pm0.05$	$10.06^{b}\pm0.09$	$0.82^{c}\pm0.99$
Yala LSD WHO NIS	$6.56^{a}\pm0.21$ 0.17 6.5-8.5 6.5-8.5	$415.11^{a}\pm60.76$ 10.57 500 1000	$156.0^{c}\pm22.20$ 6.78 250 500	$6.01^{a}\pm0.52$ 0.27	$0.06^{c}\pm0.01$ 0.05 0.02 0.2	0.02±0.01 NS 0.05	$14.66^{d}\pm0.33$ 0.21 0.1 50	$15.01^{c}\pm0.89$ 0.38 5.0	$0.36^{a}\pm0.19$ 0.09 1.0	$6.12^{c}\pm0.72$ 0.93 15	$0.79^{c}\pm0.80$ 0.06 5.0

Mean with the same superscript along the vertical arrays indicates no significant difference (P>0.05).

Table 3: Heavy metal contents of underground water in pollution-prone areas of Cross River State.

Location	**Source**	**Fe (mg/L)**	**Zinc (mg/L)**	**Chromium (mg/L)**	**Copper (mg/L)**	**Manganese (mg/L)**
Akamkpa	Control	$0.02^{c}\pm0.01$	$1.10^{a}\pm0.06$	$0.01^{b}\pm0.01$	0.007±0.003	0.003±0.003
	Dumpsite	$0.48^{b}\pm0.02$	$1.19^{a}\pm0.01$	$0.10^{b}\pm0.01$	0.127±0.02	0.01±0.01
	Slaughte	$0.07^{c}\pm0.02$	$1.30^{a}\pm0.02$	$0.01^{b}\pm0.03$	0.007±0.003	0.003±0.003

	r					
Calabar municipal	Control	0.02^{c}±0.01	0.76^{a}±0.04	0.003^{b}±0.003	0.01±0.00	0.01±0.003
	Dumpsite	0.99^{a}±0.39	1.22^{a}±0.22	0.047^{b}±0.04	0.07±0.03	0.073±0.04
	Slaughter	0.09^{c}±0.01	0.99^{a}±0.08	0.001^{b}±0.00	0.243±0.05	0.100±0.01
Ikom	Control	0.01^{c}±0.003	0.47^{a}±0.09	0.01^{b}±0.00	-	-
	Dumpsite	0.01^{c}±0.003	1.44^{a}±0.38	0.04^{b}±0.03	0.003±0.003	0.14±0.04
	Slaughter	0.18^{c}±0.08	0.20^{a}±0.06	0.16^{b}±0.08	-	0.07±0.03
Ogoja	Control	0.007^{c}±0.003	0.43^{a}±0.15	0.003^{b}±0.003	0.0067±0.003	0.003±0.003
	Dumpsite	0.04^{c}±0.01	0.94^{a}±0.13	0.05^{b}±0.04	0.11±0.001	0.0067±0.003
	Slaughter	0.031^{c}±0.003	0.013^{b}±0.003	2.20^{a}±0.06	0.003±0.001	0.0067±0.003
Yakurr	Control	0.017^{c}±0.01	0.30^{a}±0.12	0.013^{b}±0.003	-	0.013±0.003
	Dumpsite	0.043^{c}±0.003	0.88^{a}±0.21	0.12^{b}±0.004	0.06±0.03	0.16±0.03
	Slaughter	0.03^{c}±0.01	0.47^{a}±0.19	0.14^{b}±0.02	0.01±0.003	0.013±0.003
Yala	Control	0.017^{c}±0.01	0.56^{a}±0.08	0.007^{b}±0.003	0.003±0.001	-
	Dumpsite	0.49^{b}±0.01	0.56^{a}±0.21	0.01^{b}±0.00	0.044±0.04	0.16±0.06
	Slaughter	0.06^{c}±0.01	0.93^{a}±0.08	0.08^{b}±0.01	0.007±0.003	0.10±0.001
	LSD	0.05	0.17	0.04	NS	NS
	WHO	2.5			1.5	0.5
	NIS	0.3	5.0	0.01	1.0	0.5

Means with the same superscript along the vertical arrays indicates no significant difference (P>0.05)

Table 4: Heavy metal content of ground water collected from different Local Government Area in CRS

Location	Fe (mg/L)	Zinc(mg/L)	Chromium(mg/L)	Copper(mg/L)	Manganese(mg/L)
Akamkpa	0.91^{a}±0.07	1.20^{a}±0.03	0.04^{b}±0.02	0.05^{b}±0.02	0.006±0.002
Calabar municipal	0.37^{b}±0.19	0.99^{b}±0.08	0.0001^{c}±0.00	0.243^{a}±0.06	0.10±0.001
Ikom	0.07^{c}±0.04	0.70^{c}±0.22	0.07^{a}±0.03	0.001^{b}±0.001	0.07±0.02
Ogoja	0.02^{c}±0.01	1.19^{a}±0.27	0.02^{b}±0.01	0.04^{b}±0.02	0.006±0.001
Yakurr	0.03^{c}±0.00	0.55^{d}±0.12	0.09^{a}±0.02	0.02^{b}±0.01	0.06±0.03

	4				
Yala	0.19^{b}±0.08	0.89^{b}±0.07	0.04^{b}±0.01	0.04^{b}±0.01	0.05±0.001
LSD	0.05	0.18	0.02	0.04	NS

Means with the same superscript along the vertical arrays indicates no significant difference (P>0.05)

Table 5: Microbial populations of underground water in pollution-prone areas of Cross River State.

Location	**Source**	**THBC (cfu/ml)**	**THFC (cfu/ml)**
Akamkpa	Control	ND	0.10^{f}±1.0
	Dumpsite	0.33^{c}±1.29	0.67^{d}±0.94
	Slaughter	0.07^{d}±0.6	0.22^{f}±0.60
Calabar municipal	Control	0.27^{c}±0.03	0.012^{f}±0.10
	Dumpsite	0.31^{c}±0.87	0.82^{c}±0.10
	Slaughter	0.90^{a}±0.17	0.41^{e}±0.36
Ikom	Control	0.01^{d}±0.00	0.08^{f} ±0.01
	Dumpsite	0.39^{c}±0.06	1.20^{a}±2.00
	Slaughter	0.27^{c}±0.05	0.52^{e}±0.07
Ogoja	Control	0.05^{d}±0.03	0.17^{f}±0.03
	Dumpsite	0.74^{b}±0.10	0.69^{d}±0.09
	Slaughter	0.20^{c}±0.03	0.51^{e}±0.01
Yakurr	Control	0.02^{d}±0.03	0.07^{f}±0.03
	Dumpsite	0.14^{d}±0.01	0.68^{d}±0.01
	Slaughter	0.10^{d}±0.01	0.09^{f}±0.01
Yala	Control	0.04^{d}±0.01	0.18^{f}±0.01
	Dumpsite	0.32^{c}±0.02	1.04^{b}±0.06
	Slaughter	0.27^{c}±0.01	1.02^{b}±0.05
	LSD	0.05	0.10

Means with the same superscript along the vertical arrays indicates no significant difference (P>0.05)

Table 6: Microbial populations of ground water samples collected from different local government area in Cross River State

Location	**THBC (cfu/ml)**	**THC(cfu/ml)**
Akamkpa	0.11^{c}±0.09	0.33^{d}±0.09
Calabar municipal	0.14^{c}±0.01	0.45^{c}±0.02
Ikom	0.22^{b}±0.07	0.60^{b}±0.05
Ogoja	0.33^{a}±0.03	0.46^{c}±0.02
Yakurr	0.09^{c}±0.02	0.28^{d}±0.03
Yala	0.21^{b}±0.14	0.75^{a}±0.04
LSD	0.06	0.08

Mean with the same superscript along the vertical arrays indicate no significant difference (P>0.05).

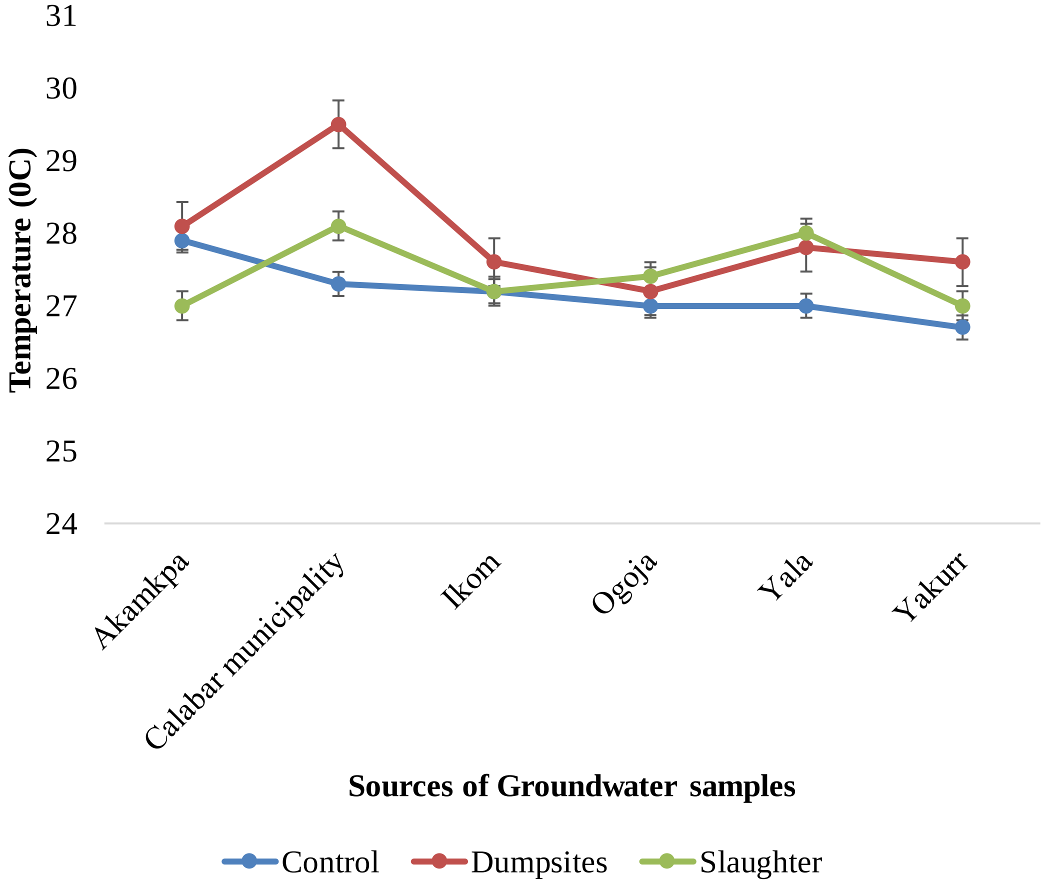


FIG. 1: Temperature (^{C}C) of various groundwater sample obtained from pollution-prone town of Cross River State.

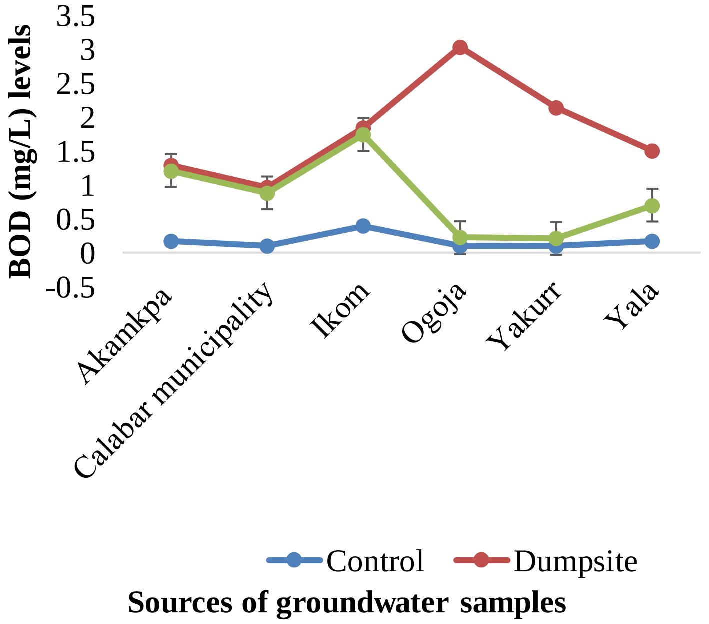


FIG. 2: Biochemical Oxygen Demand values of various Groundwater samples obtained for pollution-prone town in Cross River State.

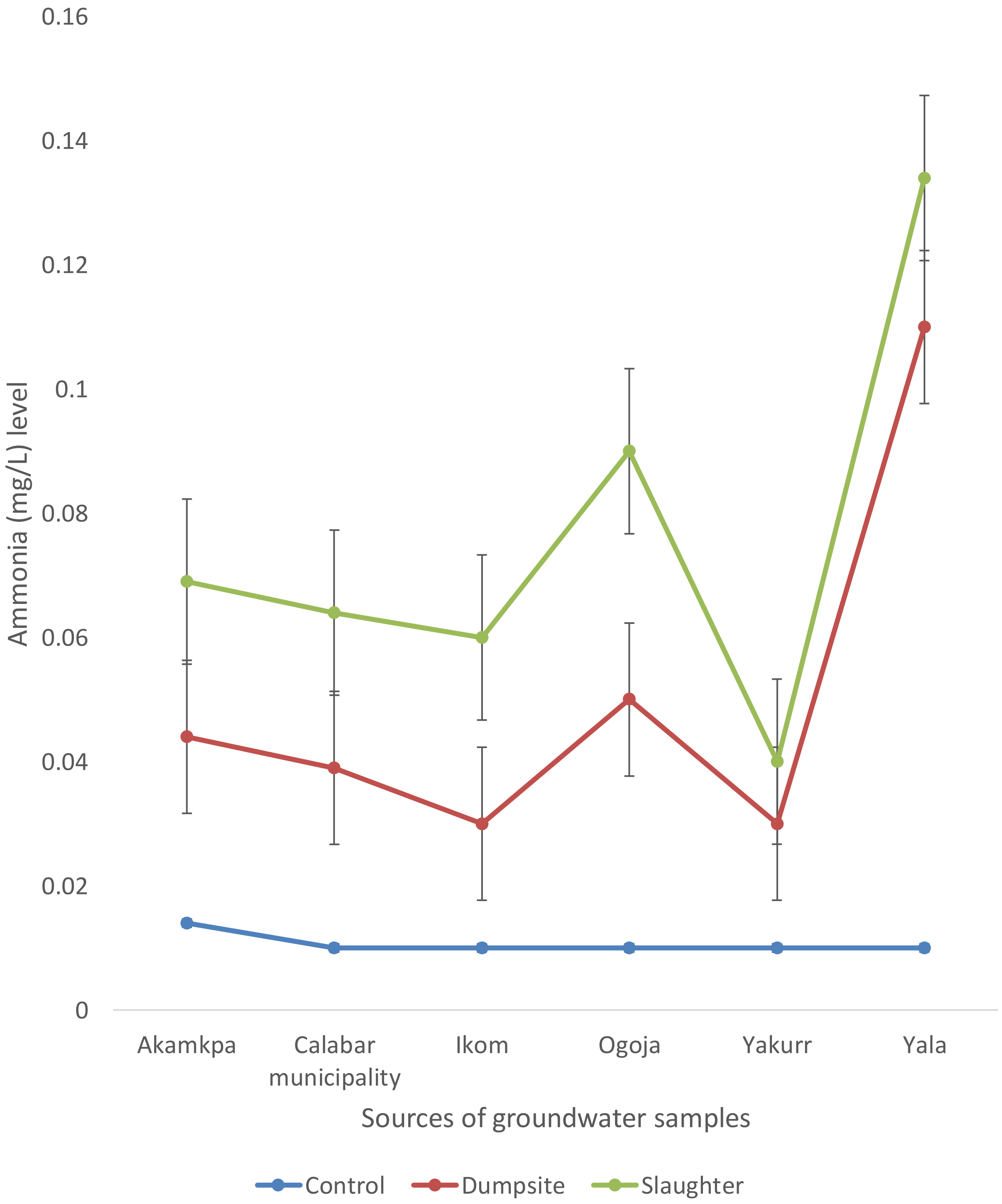


FIG 3: Ammonia values of various Groundwater samples obtained for pollution- prone towns in Cross River State.

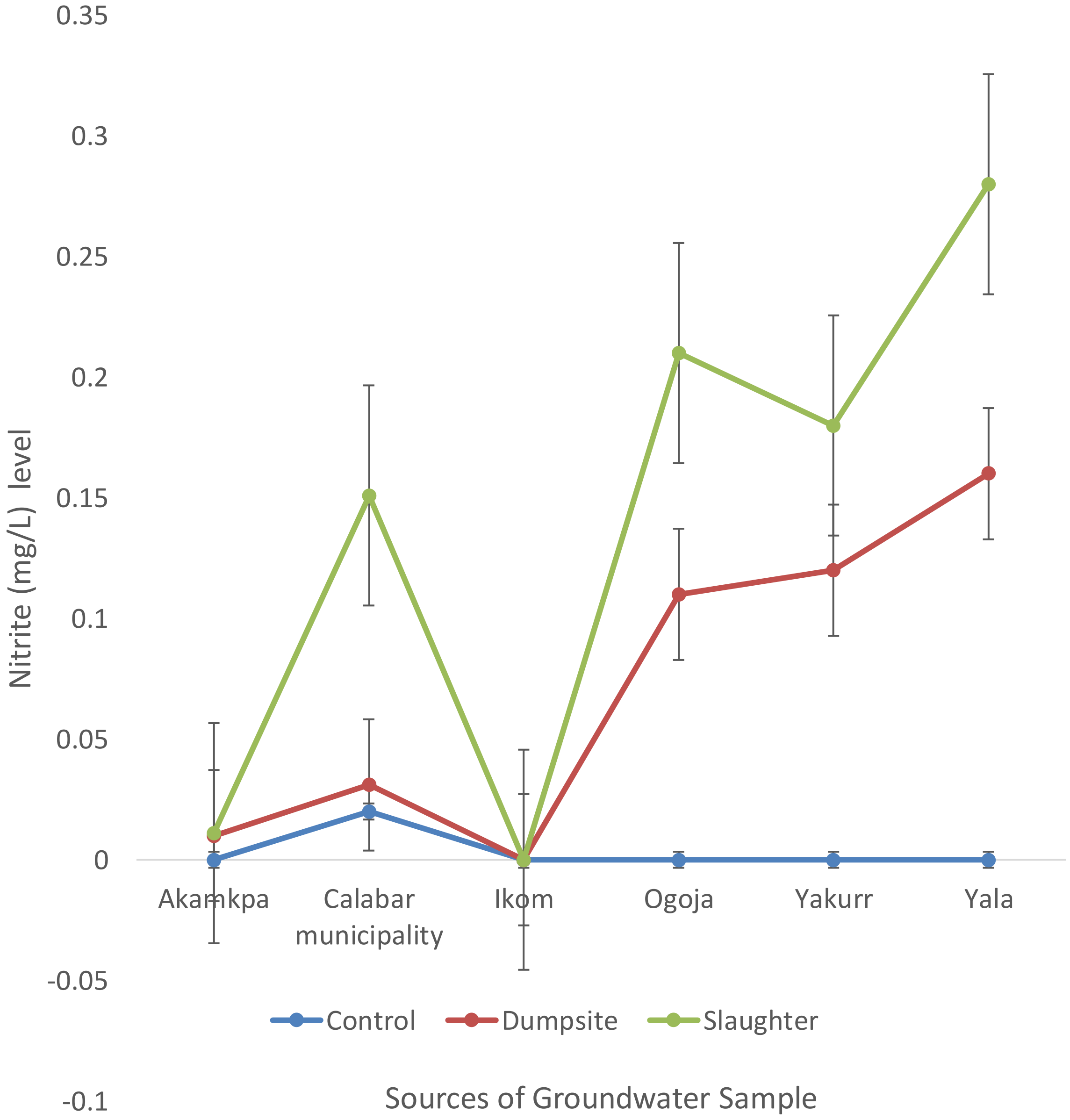
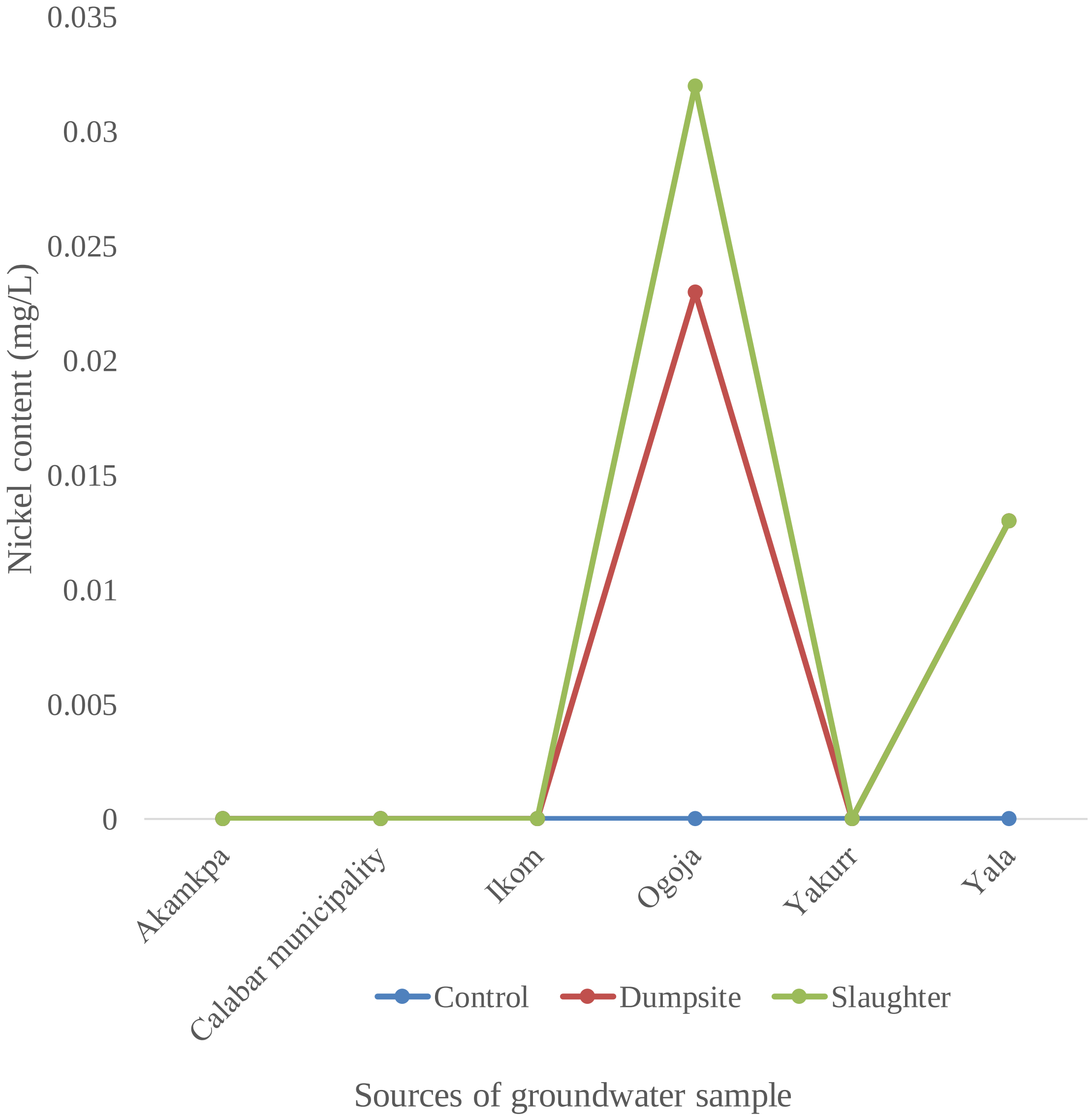


FIG. 4: Nitrites values of various Groundwater samples obtained for pollution- prone towns in Cross River State.



.

FIG. 5: Nickel content of groundwater samples obtained from pollution-prone areas of Cross River State.