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Physico-Chemical Characteristics and Heavy Metals in Groundwater Bassambiri-Nembe, Bayelsa State, Nigeria

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Abstract

The study is focused on the post impact of oil spill contamination of groundwater in Bassambiri Nembe Bayelsa State. Groundwater samples were sampled from hand dug wells from eight stations including the control point for physico-chemical investigation using sterilized glass bottles. Standard methods were used for the analyses. The result of physico-chemical parameters analyzed shows that the values of the groundwater pH ranged between 5.90 - 6.35, electrical conductivity between 80.39 - 89.23 µS/cm, Salinity 23.3 - 28.69 mg/l, Turbidity 1.71 - 3.84 NTU, Biochemical Oxygen Demand (BOD) 1.12 - 1.36 mg/l, Alkalinity 8.56 - 12.12 mg/l, Total Hardness 11.8 - 14.47 mg/l and Temperature 26.1˚C - 27.3˚C. Analysis of cations shows that Na ranged from 7.38 - 10.34 mg/l, K 0.26 - 0.49 mg/l, Calcium ion levels 2.56 - 3.59 mg/l and Mg 0.88 mg/l - 1.23 mg/l. The anions showed Potassium ion levels ranged from 0.01 mg/l - 0.02 mg/l, Chloride ion levels 12.29 mg/l - 15.88 mg/l, Fluoride ion levels 0.01 mg/l and Nitrates from 0.27 mg/l - 0.48 mg/l. Total Heterotopic Fungi population ranged from 15.26 - 48.55 Coliform Forming units/ml. The maximum permissible value of total coliforms in drinking water was exceeded. However, the Total Hydrocarbon Concentration (THC) across the groundwater sample points was less than 0.01 mg/l. The concentration of PAH and BTEX was 0.01 mg/l across the study area. The heavy metal concentrations in the groundwater samples were negligible with levels of 0.01 mg/l observed in the study area except for iron ranging from 0.20 - 0.56 mg/l levels above the WHO permissible limit. The physico-chemical parameters of groundwater indicate that they fall below WHO permissible limits. The cations and anions concentration indicate a stable and healthy water system which is relatively good. The groundwater system has high levels of iron in groundwater and bacterial contamination. Treatment is required to avoid acute and chronic iron overload resulting from consumption from drinking groundwater within the study area.

Keywords

Groundwater, Physico-Chemical Parameters, Oil Spill Contamination

1. Introduction

The principal environmental problem associated with the petroleum industry in Nigeria is Oil spillage which occurs within on-shore and off-shore of the Niger Delta [1]. [2] has reported that there had been over 1500 abandoned oil spill sites located within the Central, Western and Eastern axis of the Niger Delta and according to their reports these spillages happened between 1976 and 1996 comprising 4674 incidents that spilled over 2,369,470 barrels of crude oil. 77% of the spills were lost to the environment. Spills on land accounted for 6%, swamps 25% and 69% offshore environments respectively [3]. Pollution from oil spills and industrial effluents has the potential to affect aquatic and terrestrial ecosystems [4]. Deforestation drives ecological changes such as climate change, erosion, water and soil pollution which in turn impacts on the long-term viability of ecosystem services. Globally, there is forest decline due to agricultural and demographic pressures [5]. Similarly, there is decline to vegetation resulting from petroleum related industrial activities including exploration and refining. Likewise, activities in the Oil Industry such as transportation and distribution are largely responsible for vegetation degradation as well as altering the chemical and physical properties of soil thereby reducing soil fertility. Deterioration of vegetation and agricultural soils can arise from deforestation, occasioned by burning of forests and farmlands [6]. Similarly, crude oil exploitation has resulted in environmental pollution and degradation of water quality and resources in the Niger Delta [7]. This research aimed at assessing the post spill impact of crude oil contamination on physicochemical parameters of groundwater resources within the spill location at Bassanbiri Nembe and its surroundings. The study area—Bassambiri, lies within South Brass and East Odiama Creeks of Nembe Southeast Bayelsa State, Nigeria. The Santa Barbara River and meanders through the thick brackish mangrove forest terrain of Bayelsa State of Nigeria, intersected by interconnected secondary tributaries which empty into the Atlantic Ocean (**Figure 1**).

2. Materials and Method

Groundwater Sample Collection

Samples of groundwater were collected from eight hand-dug wells in different locations in both the study and control area (see **Figure 1**) in three replicates each of each sample. Samples were collected upstream (3), midstream (3) and

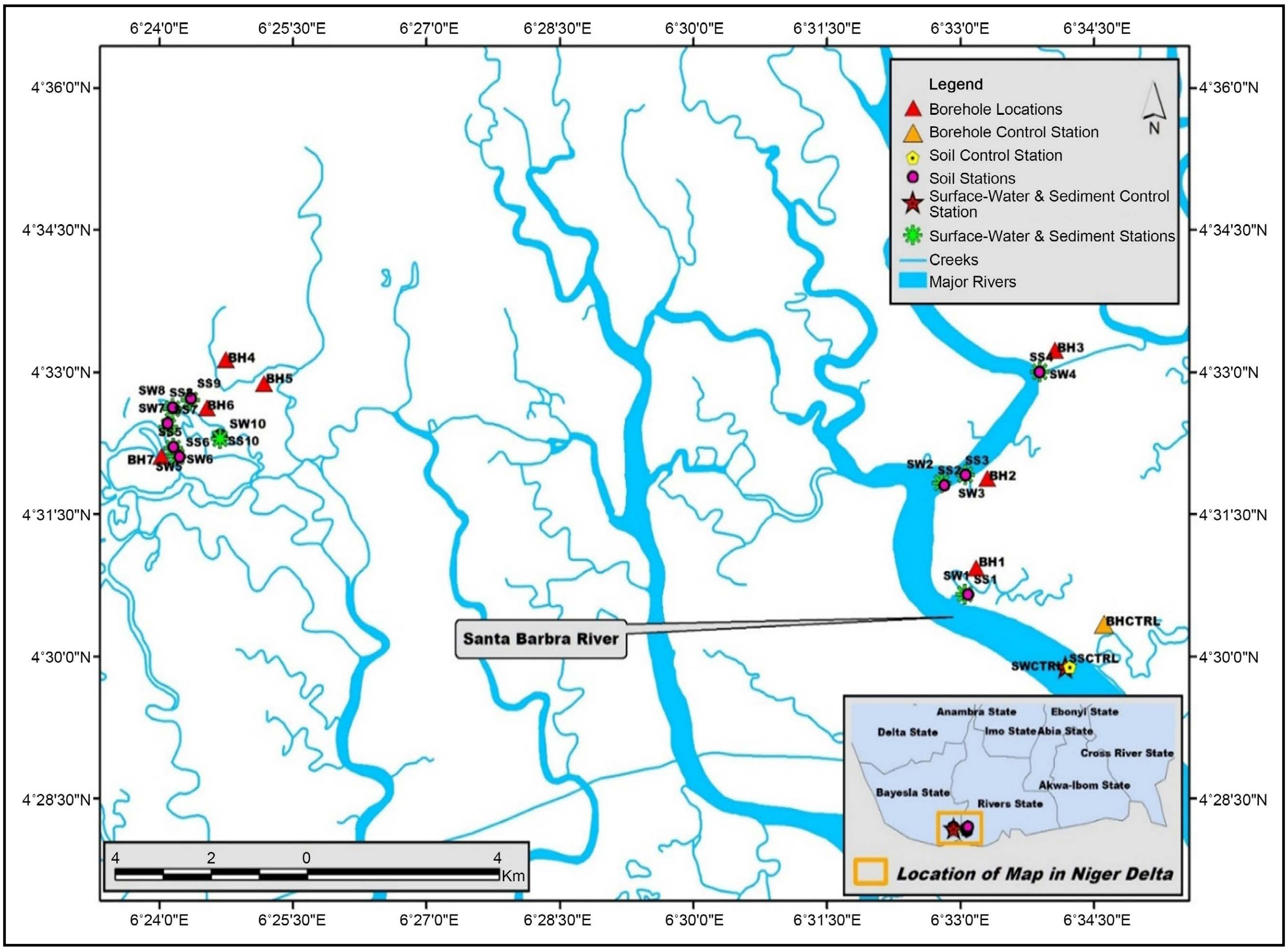


Figure 1. Map of study area showing sampling points (after [8]).

downstream (4). The groundwater samples were transferred into sample bottles and carefully labelled with the appropriate identification codes. In addition, the sample bottles were rinsed three times with the groundwater samples. Samples for total hydrocarbon content were acidified with 2 ml concentrated sulphuric acid using 1-liter bottles. The labeled groundwater samples were taken to the laboratory in coolers of ice for analysis within 24 hours. The groundwater samples from the study area and the control area were subjected to laboratory analysis to determine their properties and heavy metal composition.

Analysis of Physicochemical Parameters

The physical and chemical parameters studied (some of which were in situ and laboratory analyses) comprise temperature, hydrogen ion concentration (pH), electrical conductivity, salinity, Turbidity, Dissolved Solids, (TDS), Dissolved Oxygen (DO), and Biochemical Oxygen Demand (BOD). The methods used were as described by [9].

Turbdity

Test Method: Nephelometric Method

Standard Reference: APHA 2130B: Apparatus used: HACH 2100P Turbidimeter

Calculation:

$$\text{Nephelometric turbidity units }(\text{NTU}) = \frac{A \times (B + C)}{C}$$

where A = NTU found in the diluted ample;

B = Volume of dilution water, ml;

C = sample volume taken for dilution, ml.

TDS

Test Method: Total Dissolved Solids; Dried At 180˚C (Gravimetric Method)

Standard Reference: Apha 2540 C

Calculation:

$$\text{Total Dissolved solids}(\text{mg/L}) = \frac{(W_1 - W_2) \times 1000}{\text{Sample volume}(\text{ml})}$$

where:

W_1 = Weight of dried residue + dish;

W_2 = Weight of empty dish.

Total Suspended Solids (TSS)

Test Method: Total Suspended Solids Dried at 103˚C - 105˚C (Gravimetric method)

Standard Reference: APHA 2540 D

Calculation:

$$\text{Total Suspended solids}(\text{mg/L}) = \frac{(W_1 - W_2) \times 1000}{\text{Sample volume}(\text{ml})}$$

where:

W_1 = Weight of dried residue + dish;

W_2 = Weight of empty dish.

Alkalinity

Test Method: - Titrimetric method

Standard Reference: - APHA 2320B

Calculation:

$$\text{Phenolphthalein Alkalinity, as mg CaCO}_3/\text{L} = \frac{A \times N \times 50000}{\text{ml sample}}$$

where:

A = mL of standard acid used;

N = normality of standard acid.

Total Alkalinity

$$\text{Phenolphthalein Alkalinity, as mg CaCO}_3/\text{L} = \frac{B \times N \times 50000}{\text{ml sample}}$$

where:

B = total mL of titrant used to methyl orange or bromcresol green end point;

N = normality of standard acid.

Hardness

Standard Reference: APHA 2340C

Method: EDTA Titrimetric method

Calculation:

$$\text{Hardness}(\text{EDTA})\text{ as mg CaCO}_3/\text{L} = \frac{A\times B\times 1000}{\text{mL sample}}$$

where:

A = mL titration for sample and;

B = mg $CaCO_3$ equivalent to 1.00 mL EDTA titrant.

Calcium

Standard Reference: APHA 3500-Ca-B

Method: EDTA Titrimetric method.

Calculation:

$$\text{mg Ca/L} = \frac{A\times B\times 400.8}{\text{mL sample}}$$

$$\text{Calcium hardness as mg CaCO}_3/\text{L} = \frac{A\times B\times 1000}{\text{mL sample}}$$

where:

A = mL titrant for sample and;

B = mg $CaCO_3$ equivalent to 1.00 mL EDTA titrant at the calcium indicator end Point.

Magnesium

Standard Reference: APHA 3500-Mg-B

Method: Calculation from total hardness and calcium.

Calculation:

mg mg/L = [total hardness (as mg $CaCO_3$/L) − calcium hardness (as mg $CaCO_3$/L)] × 0.243

Biological Oxygen Demand (BOD_5)

Standard Reference: APHA 5210 B

Test Method: 5-Day BOD Test.

Calculation:

$$BOD_5\ (\text{mg/L}) = [\text{DO1} - \text{DO0}]/B$$

where:

DO0 = initial dissolved oxygen (immediately after preparation);

DO1 = final dissolved oxygen (after 5 days of incubation);

B = Fraction of sample used.

Chemical Oxygen Demand

Standard Reference: APHA 5220 C

Test Method: Closed Reflux—Titrimetric method.

Calculation

$$\text{COD}(\text{mg/l, as O}_2) = \frac{(\text{Blank Titer} - \text{Sample Titer})\times \text{Molarity of FAS}\times 8000}{\text{Sample Volume}}$$

where:

A = mL FAS used for blank;

B = mL FAS used for sample;

M = molarity of FAS, and;

8000 = milli equivalent weight of oxygen × 1000 mL/L.

Chloride

Test Method: Argentometric Titrimetric Method

Standard Reference: APHA 4500 Cl^-- B

Calculation:

$$\text{mg Cl}^-/\text{L} = \frac{(A-B)\times N\times 35450}{\text{mL sample}}$$

where:

A = mL titration for sample;

B = mL titration for blank;

N = normality of $AgNO_3$.

Determination of Heavy Metals

Standard Reference: APHA 3111B

Air-acetylene Flame Atomic Absorption Spectroscopy Method was used for heavy metal determination. 100 ml of water sample was measured with a measuring cylinder into a conical flask. Then 1 ml of concentrated HNO_3 and 2 - 3 g of anti-bump was added. Heat was applied on the electro-thermal heater to about 30 - 50 ml volume. The aqueous sample solution was allowed to cool and then filtered. The sample solution was transferred into a volumetric flask (100 ml) and measured to mark with distilled water. Calibration analysis was carried out by diluting 1000 ppm stock solution of the individual elements (Pb, Fe, Cu, Zn, Ni, Co and Mn). A minimum of three standard working solutions were prepared from the stocks, the solution ranged between 0.1 mg/L to 10 mg/L. External calibration was used by running de-ionized water and a suit of calibration standards for each element. The calibration curve was then generated for each metal.

3. Results and Discussion

The results of the Physico-chemical analysis of groundwater in the study area are presented in **Figures 2-5**.

pH of Ground Water

The pH values of ground water samples were acidic, range 5.90 - 6.35 across the sampling points in the study area (**Figure 2**). The highest pH value of 6.35 was recorded from borehole 3 (BH3) while the lowest pH value of 5.93 was recorded from borehole 2 (BH2). There was no significant difference ($p > 0.5$) between the various sampling points in relation to the control. The pH values of groundwater samples are acidic, ranging from 5.90 and 6.35 across the sampling points in the study. Similarly other studies have found pH values of 3.84 in Bassambiri Nembe and ranging to 7.72 in other parts of the Niger Delta [9]. The values recorded falls below the guideline for ground water pH according to US

Environmental Protection Agency (US EPA) and WHO standards for pH range is 6.5 - 8.5. According to [10] pH is an important ecological factor that has strong connection with the physiology of most aquatic organisms. The low pH recorded in this study tends to favour solubility and leaching of heavy metals when present and can enhance toxicity through the groundwater into aquifers. [11] attributes mild acidity in groundwater to organic acids resulting from decomposition of vegetation in swampy environments and further argues that decomposition is a natural acidification process through which CO_2 is produced and roots respire in soils in swampy terrains. Low pH and acidity in groundwater in the Niger Delta are also associated with gas flaring. [9] argue that gas flaring releases carbon dioxide which reacts with atmospheric precipitation to form carbonic acid, infiltrating into the groundwater system, lowering the pH and increasing acidity. Although, no heavy metal of interest was detected in the groundwater samples collected but heavy metals contained in hydrocarbon spills have the potential to intersect the groundwater through the soil and create an imbalance in the natural water pH of 7. World Health Organization [12] recommends a pH value of 6.5 for drinking water but, this result shows that the pH values fall below permissible limits.

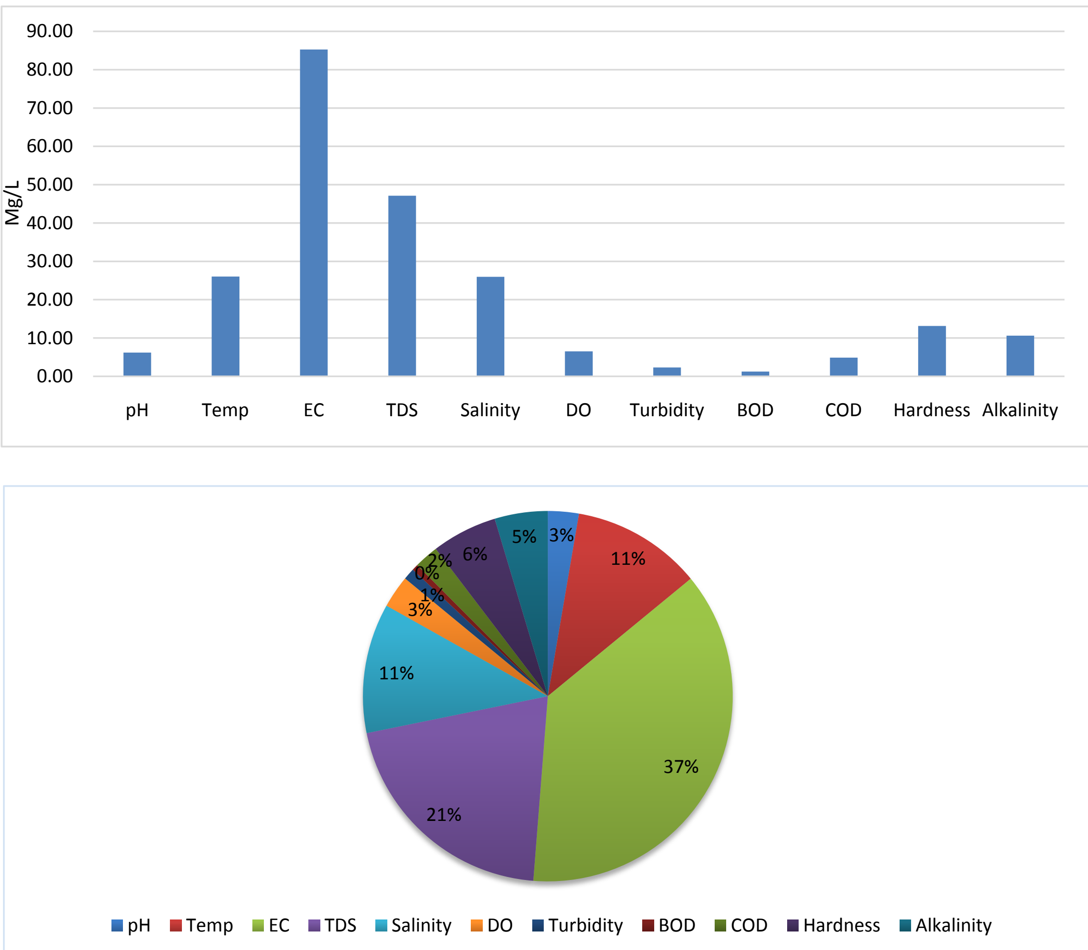


Figure 2. Physico-chemical properties of groundwater.

Electrical Conductivity (μS/cm)

Electrical conductivity; a measure of the dissolved ionic components in water values of the ground water samples from study area ranged from 80.39 μS/cm - 89.23 μS/cm in BH6 and BH2 respectively (Figure 2). Electrical conductivity

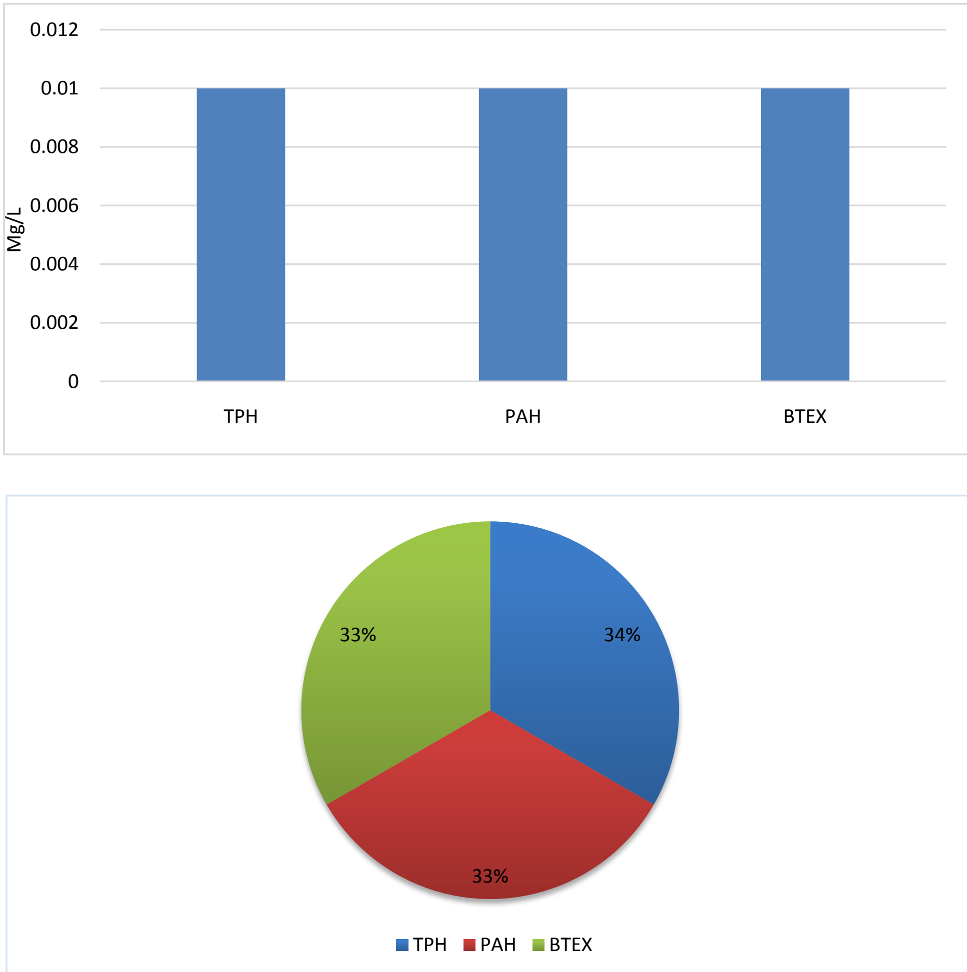
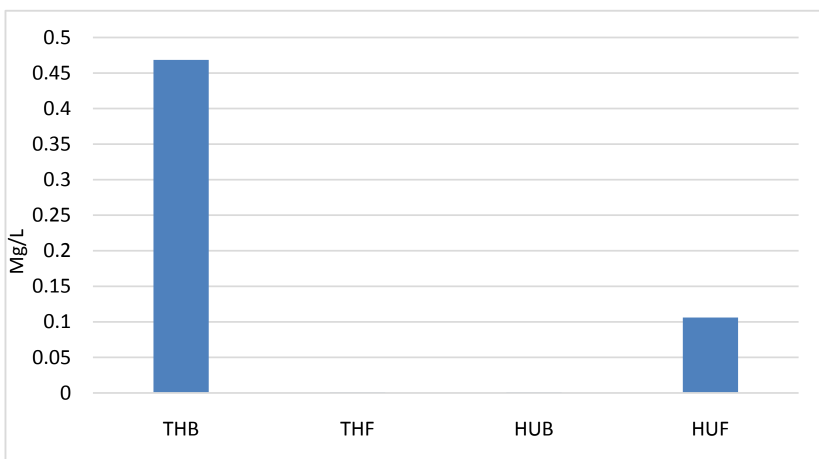


Figure 3. Total hydrocarbon concentration in groundwater.



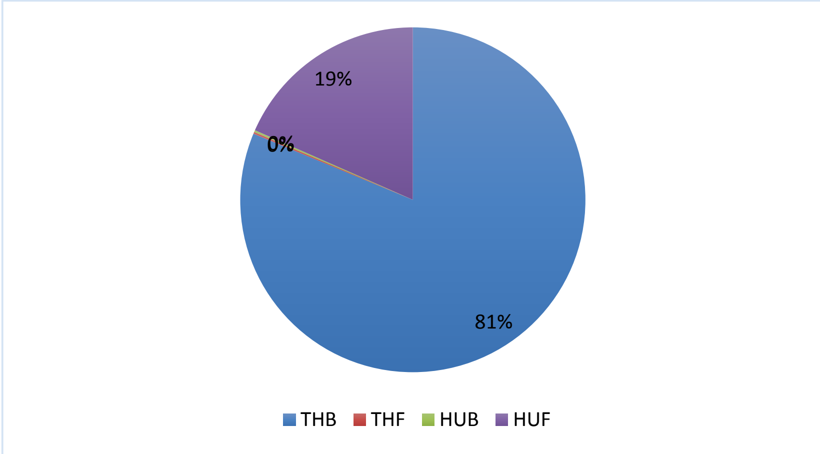
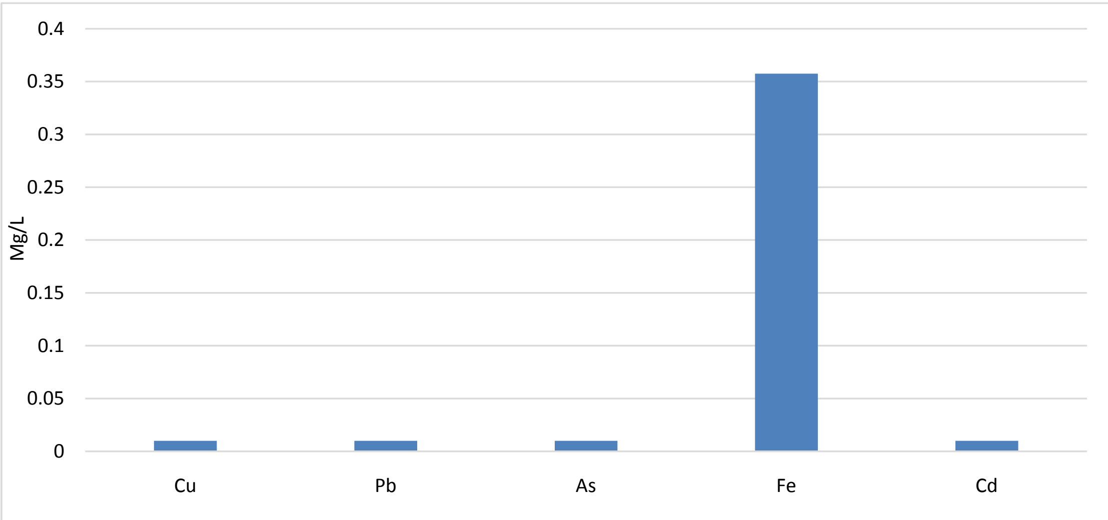


Figure 4. Microbial population in the groundwater of the study area.



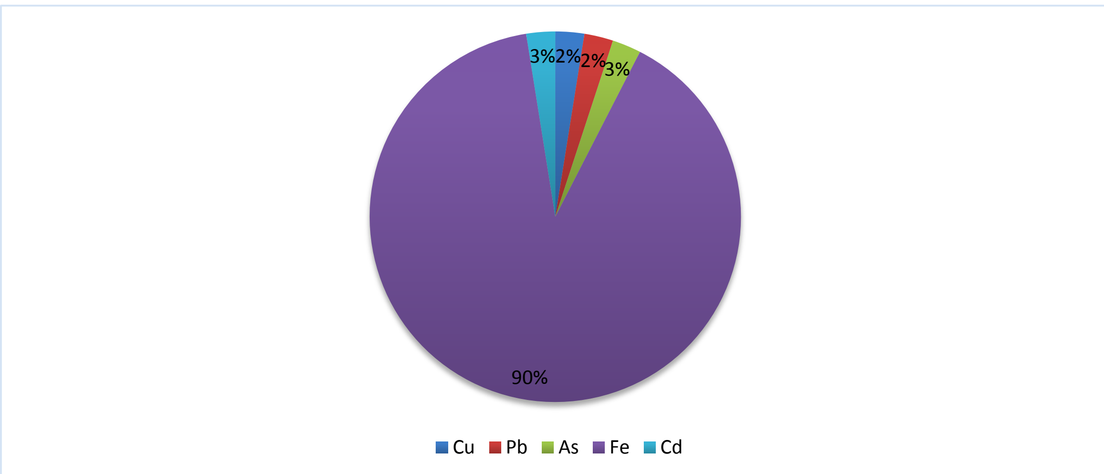


Figure 5. Heavy metal concentrations in groundwater.

gives a hint of the amount of total dissolved substance in water [13]. Generally, an increasing trend was observed whereby conductivity peaked at BH2 (89.23

μS/cm) while the least value (80.39 μS/cm) was recorded at BH6. Spatial results show a significant difference ($p < 0.05$) between BH6 and BH2 when compared with the control while no significant difference ($p > 0.05$) was observed between BH3, BH4, BH5 and BH7 when compared with control. The trend of conductivity values below 1000 μS/cm indicates fresh water and higher above 1000 μS/cm as brackish and above 40,000 m μS/cm as marine. The value of conductivity obtained in the study indicates that the water is fresh water. The results from the research show that electrical conductivity across the sample points is below the WHO limit of 2500 μS/cm [14]. Higher values of electrical conductivity are an indication of the presence of dissolved substances, chemicals and mineral released from oil spillage. The result suggests a very little solute dissolution generally in the ground water, fast ion exchange between the soil and the water or mainly a poor and rather insoluble geologic rock and mineral type. Higher values of electrical conductivity are an indication of the presence of inorganic dissolved solids such as chloride, nitrate, sulphate, and phosphate anions or sodium, magnesium, calcium, iron, and aluminium cations [15]. Similarly, in groundwater higher conductivity may also be attributed to high salinity and high mineral percentage due to the ion exchange and solubilization process taking place within the aquifers [16].

Total Dissolved Solids (mg/L^{-1})

Total Dissolved Solids (TDS) result presented in **Figure 2** shows that TDS varied from 43.51 mg/l - 51.73.19 mg/l (**Figure 2**) within the study area. The highest total dissolved solids values was observed in BH1 (51.73 mg/l) and the lowest (43.51 mg/l) recorded at the control sample point. The values of TDS recorded in the ground water samples across the sample points is far below the WHO recommended guideline value of 1000 mg/L^{-1}. Water containing TDS less than 1000 mg/L^{-1} could be considered as fresh water and good enough both for drinking, industrial and agricultural purposes as this will not affect the osmotic pressure of the soil solution [17]. According to [18] ground water physiochemical characteristics are influenced directly by precipitation patterns of which Total hardness and alkalinity always increase with rainfall. Santabarbara is a region of high precipitation such the variability in its physiochemical parameters, however, this is also impacted by the leakages of oil into the water resource of this region.

Salinity (mg/l) +

The salinity value of the ground water recorded across the sample points ranged between 23.31 ± 1.2 ppt - 28.69.30 ± 4.3 ppt (**Figure 2**). Salinity was low for all the sampling stations and the maximum permissible limit of 200 g/l was not exceeded. Salinity levels ranging from 10 to 661 (mg/l) have been found in boreholes in Eastern Niger Delta [17] and further argue that the increased anthropogenic activities relating to the petrochemical industry may have amplified abstraction rates of ground water resources in the Niger Delta. Salinity trends in the Niger Delta show vertical salinity gradient development within estuarine environment which points to the penetration of saline water inland through creeks and estuaries [16]. According to [19] In places where the lateritic cover is thin or non-existent, undesirable pollutants from the various potential sources (including leaking hydrocarbon pipelines/storage tanks, farmlands, waste dump pits and soak-aways) can readily result in the contamination and seriously degrading groundwater quality.

Dissolved Oxygen (mg/l)

The results of DO show that dissolved oxygen values ranged 6.26 mg/l - 6.85 mg/l. The highest DO value was recorded in BH2 (6.85 mg/l) while, the lowest value was recorded in BH1 (6.26 mg/l). However, the recorded values were not significantly different ($p < 0.05$) in relation to the values of the control. DO values of 6.3 - 8.3 mg/l as reported by [17] in a study of the Niger Delta. The minimum acceptable DO value of 5 mg/l [20] was exceeded in all the groundwater samples. This indicates that the water surface is sufficiently oxygenated and lacks aerobic and putrefying organisms that absorb. Reduction in Dissolved Oxygen concentration in a water body can be associated to the breaking down of organic matter by aerobic microorganisms linked with organic pollution. Dissolved oxygen is a useful indicator of water quality, ecological standing, efficiency and health of a river [21]. The concentration of dissolved oxygen at any point in time may be due to the existence of microorganisms that breakdown organic matter that utilizes oxygen to the disadvantage of the stream biota. According to [21], the concentration of dissolved oxygen is affected by plant activity, temperature, decaying organic matter in water, stream flow, altitude as well as atmospheric pressure and anthropogenic activities such as industrial processes causing increase in water temperature and lowering of dissolved oxygen capacity. This agrees with another research. [22] argues that the level of dissolved oxygen varies depending on factors such as temperature, time of the day, depth, altitude and rate of flow.

Turbidity (NTU)

Turbidity values in the study area ranged 1.71 - 3.84 NTU in the groundwater samples (**Figure 2**). The spatial variation showed steady increase in turbidity values across the sample points. The results show a significant difference ($p < 0.05$) at the boreholes; BH2, BH3, BH4 and BH5, in relation to the control, the highest turbidity value of 3.84 NTU was recorded in BH3 while, the lowest turbidity value of 1.71 NTU was obtained at borehole; BH6. Turbidity consists of suspended particles in the water and may be caused by organic or inorganic materials. The WHO limit of 5 NTU for turbidity was not exceeded in the groundwater samples across the sampling points [19]. The low turbidity values recorded in the study is an indication that the groundwater is relatively clear of debris (clean water). The implication of this that the water body is adequately illuminated from top to bottom a dynamic that aids photosynthetic processes and oxygen circulation throughout the water column. This characteristic may be why the DO is high [23].

Biochemical Oxygen Demand (BOD) (mg/l)

The results of BOD vary from 1.12 mg/l - 1.36 mg/l across the ground water samples from the various points (**Figure 2**). BOD had a maximum value of 1.36 mg/l at BH1 and lowest value of 1.12 mg/l at borehole; BH4. There was no significant difference ($p < 0.05$) in groundwater obtained from the various sampling sites in the study. The maximum value of 1.9 mg/l for BOD was not exceeded in the study in all the points sampled for ground water in the study area [19]. Lower values of BOD signify the absence of organic contaminants and relatively higher level of microbial activities resulting in the reduction of the ambient oxygen content. Values of BOD was highest (5.33 mg/l) in boreholes; BH1, BH2, and BH3 in groundwater and lowest in borehole; BH4 (4.27 mg/l) in this research. However, [24] recorded relatively low BOD in their study which they attributed to the discharge of organic pollutants into the water body. [25] reported that when waste deeply loaded with pollutants and dissolved solids gain entry into water bodies; a large volume of oxygen and microorganisms are required for their decomposition.

Temperature (˚C)

Temperature of the groundwater ranged 26.1˚C - 27.3˚C across the sampled points in the study area (**Figure 2**). Spatially, the ground water temperature had a maximum value of 27.3˚C at borehole; BH7 while, the lowest temperature of 28.04˚C was recorded in borehole; BH3. There was no significant difference ($p > 0.05$) in groundwater temperature from the various sampling points in the study. The observed range of temperature values in the study is in consistent with several studies in the Niger Delta ([26] [27] [28]).

Total Alkalinity (Mg/l)

Alkalinity is a measure of the capability of water to neutralize acids and it largely occurs owing to the presence of carbonates and bicarbonates in the water [29]. There was variability in total alkalinity (ranged 8.56 mg/L - 12.12 mg/L) in the groundwater samples obtained from the various sampling points in the study area (**Figure 2**). The highest value of alkalinity (12.12 mg/L) was recorded in the control sample while, the least alkalinity (8.56 mg/L) was recorded in water from borehole; BH2. The result shows an increase in alkalinity across the sampled points ($p < 0.05$) which was significantly different from that obtained from the control. Alkalinity in groundwater has been found to range 9.3% - 18.6% in Afam Rivers State [29]. The derived alkalinity of groundwater from the various sampling points was below measured values of total alkalinity in all the samples were below the permissible limit of 120 mg/L by the WHO. The results indicate a healthy groundwater system in the study area. The derived alkalinity of groundwater from the various sampling points was below measured values of total alkalinity in all the samples were below the permissible limit of 120 mg/L by the WHO.

Total Hardness (mg/l)

Hardness of water is caused by the occurrence of dissolved polyvalent metallic ions, mostly calcium ions (Ca^{2+}) and magnesium ions (Mg^{2+}). The values of total hardness concentrations recorded in the groundwater samples across the sampled points ranged 11.8 mg/L - 14.47 mg/L (**Figure 2**). The result shows no significant difference at $p > 0.05$ across the stations when compared with the control. The recorded total hardness concentrations in the study were below the maximum limit of 300 mg/L by the WHO for drinking water [13]. Soft groundwater with an average value of 14 mg/l has been found in Bassambiri Nembe [30]. The recorded total hardness concentrations in the study were below the maximum limit of 300 mg/L by the WHO for drinking water [13]. Increase in the total hardness concentration is not a health risk [31] but an indication of high amounts of calcium and magnesium which can provide a significant supplementary contribution to total calcium and magnesium intake for the aquatic life [32].

Cations (mg/l)

The results of calcium ion concentration in the groundwater ranged 2.56 mg/l - 3.59 mg/l (**Figure 2**). Calcium metal forms when charge particles in water and these could be seen in groundwater from various geological settings [33]. There was no significant difference ($p > 0.05$) across the sampled points when compared to the control. Its level in natural water depends upon the type of rocks the geological and proximity to the coast. The range reported for this research is below WHO minimum value of 28.10 for groundwater. High level of calcium in drinking water has been associated with cardiovascular diseases, prenatal mortality and various type of cancer. However, the result show safe limits for calcium. The magnesium level of ground water samples ranged between 0.88 in the control point to 1.23 mg/l in borehole; BH1 and BH7 37 - 150 mg/l respectively. These values of calcium and magnesium ions indicated that all the samples were below the limit of 50 mg/l for drinking water [34]. The concentration of sodium ions varied from 7.38 mg/L in BH2 - 10.34 mg/L in BH1 across the groundwater samples. Similarly, potassium ions level across the groundwater samples ranged between 0.26 - 0.54 mg/l. In this research, the cations levels in the groundwater stations met the WHO standard for good quality drinking water.

Anions (mg/l)

Chloride level of the groundwater samples in the study ranged 12.29 - 15.88 mg/l (**Figure 2**). The result showed concentrations of CI^- were below the WHO limits of 200mg/l for groundwater. Elevated CI^- concentrations in drinking water have significant health hazards. Consumption of chlorinated water has been associated with increased risk colorectal and bladder cancer in numerous epidemiological studies ([35] [36]). Phosphate concentration in groundwater ranged 0.01 to 0.02 mg/l. Phosphate concentrations of 0.010 mg/l have been recorded in Nembe and Twon Brass respectively [9]. Fluoride concentration in ground water was 0.01 across all stations. Concentrations of 0.2 mg/l or less were also found in groundwater from the eastern Niger Delta [37]. The values recorded in this research are within acceptable limits [38]. The anions in groundwater indicate a healthy groundwater system.

Total Hydrocarbon Content

The average concentration of PAH was 0.01 mg/l (**Figure 3**). The result suggests that any contamination found in the groundwater was not caused by hydrocarbon contaminants. The PAH concentration were below the intervention values set by the Nigeria Upstream Regulatory Commission [39] for groundwater (40 mg/l for PAH, other pollutants THC 600 mg/l). Similarly, the BTEX concentration in groundwater across all stations was 0.01 mg/l. The BTEX levels were below the intervention values of the [39] which ranges from 30 - 2000 mg/l for various BTEX compounds.

Microbial

THF population ranged from 15.26 - 48.55 Coliform (**Figure 4**). Forming units/ml. The maximum value of total coliforms in drinking water is 1 per 100 ml (ICMR, 1975) and 10 per 100 ml [40]. The results show that the groundwater is highly contaminated. The bacterial contamination in the ground water is mainly caused sewage effluents and faecal defecation from anthropogenic activities within the Santa Barbra River over a period.

Heavy Metal Content

The iron concentration in groundwater in the study area ranged from 0.20 mg/l - 0.56 mg/l (**Figure 5**). Several studies have been carried out on iron concentration in the Niger Delta ([9] [41] [42]). [43] carried out extensive studies on occurrence and distribution of Fe^{2+} in groundwater in the Niger Delta with concentrations ranging from 0.0 - 10 mg/l. The research found that in Bassambiri Nembe boreholes drilled at depths of 250 m had Fe concentrations of 0.02 while other areas of Nembe having Fe concentrations of 0.6 at 193 m depth and highest concentrations recorded in Idama of 10 mg/l in (salt water swamps) of Rivers State at depths of 100 m. [9] have also recorded exceptionally high concentrations of Fe ranging from 0.1 - 0.8 in Twon Brass, Kolo, Nembe, Swali and Etegwe in Bayelsa State as well as Degema Town and Bonny in Rivers State. The occurrence of Fe is linked to geologic history and source rocks that make up the Niger Delta sediments [43]. Similarly, the presence of elevated iron concentrations in confined groundwater aquifers may be attributed to the buildup of dissolved iron under anaerobic conditions (British Geological Survey 2003). Iron levels in groundwater were above the WHO limit of 0.3 mg/l for drinking water. Water with a high concentration of iron may cause the staining and scaling of plumbing fixtures or laundry [9]. Iron contamination owes its origin to the presence of origin fixing bacteria associated with sedimentary organic matter [44] as well as low pH values causing corrosion of iron, clogging of distribution pipes and an objectionable odour [45]. The occurrence of iron in water distorts the appearance of water, making it turbid with a unique colour that is yellow brown to black [46]. Iron discolouration and the metallic taste occur at concentrations that exceed 1.0 mg/l [44]. Health problems can arise from the consumption of water with high iron content over a prolonged period leading to iron overload otherwise known as haemochromatis. Excess iron is toxic causing serious damage such as vomiting, diarrhea and destruction to the intestine [47]. The ground water in the Santa Barbra River is unsuitable for drinking and should be treated before its use for human consumption. Cu concentration across all sampled locations was 0.01. Similar results have been reported in Bomadi Creek Niger Delta [48]. The levels of copper in groundwater were below the intervention and target values (0.3 and 0.05) set by the [39]. High concentrations of copper have been found in groundwater in Delta State Niger Delta. [49] reported high copper concentrations ranging from 1.01 mgl to 2.105 mgl. The high level of copper is attributed to waste dumps, septic tanks and other laboratory waste indiscriminately discharged into the environment. Similarly, concentration of copper has been found to range between 0.03 mg/l to 0.15 mg/l with a mean of 0.08 mg/l in Eastern Niger Delta [41]. The elevated concentration of copper observed is linked to leaching from industrial waste, dumpsites and machinery used in oil production [41]. Elevated concentration of copper in drinking water may cause gastrointestinal disorders [50] (NSDWQ, 2017). The arsenic levels in groundwater water samples analyzed were within the WHO acceptable limit of 0.01mg/l. Arsenic is a trace metal found in variable concentrations in the atmosphere, soils, rocks, natural waters, and its abundance in the environment is linked to natural processes and industrial activities such as agriculture and mining [51]. In Bayelsa state arsenic levels have been reported to range from 0.00 to 0.03 below the permissible limit of 0.01 [9] and [52]. Elevated concentrations of arsenic ranging from 0.006 to 0.424 have been reported in ground waters in Biu Volcanic in the North-East and concentrations of 0.01 to 0.7 in Igun-Ijesha South-West Nigeria ([53] [54] [55]). Widespread groundwater contamination often arises from desorption/dissolution of host rock arsenic naturally present [56]. High concentrations of arsenic in surface and groundwater is associated with bedrock sulphide mineralization [57]. Arsenic is highly toxic in its inorganic form and long-term exposure to drinking water and food can cause cancer and skin lesions [58]. Cadmium levels in water samples anaylsed showed that the values were below the WHO acceptable limit of 0.01 mg/l [59]. The cadmium levels in the groundwater in Santa Barbra River presents no danger or health concern as the background levels are below acceptable guideline values and limits. Cadmium is present in the environment at low concentrations and increased levels linked to anthropogenic activities [60]. Cadmium is toxic at extremely low concentrations, with a low sorption affinity that enables easy mobilization and rapid accumulation in groundwater [61]. Exposure to low levels of cadmium in air, food, water, and particularly in tobacco smoke over time may build up cadmium in the kidneys, causing kidney disease and fragile bones including cancers [62].

4. Conclusion

The values of physico-chemical parameters of groundwater in the study area indicate that the pH, electrical conductivity, temperature, hardness, DO, BOD and salinity are below WHO limits whereas the cation and anion concentrations indicate a stable and healthy water system. The anions and cations concentrations in the study area groundwater are relatively good. In addition, the concentrations of heavy metals in groundwater were low except for iron that is high and occurring at levels above the WHO limit and the maximum value of total coliforms in drinking water was exceeded this may have health implications for human consumption. The groundwater system is relatively good but due to high levels of iron in groundwater and bacterial contamination it should be treated to avoid acute and chronic iron overload from drinking groundwater within the study area.

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Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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