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ASSESSMENT OF GROUNDWATER QUALITY AROUND A PETROLEUM TANK FARM, IN IFIE COMMUNITY AND ENVIRONS, WARRI, SOUTHERN NIGERIA

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Abstract

Investigation of the physical and chemical properties of groundwater around a Petroleum Tank Farm was carried out between January and August, 2015 to assess the suitability of the borehole water for drinking and other domestic uses. The results show that pH of water was acidic with values ranging from 4.62 to 6.87, EC (33.00–206.00 µs/cm), TDS (15.00–115.00mg/L), DO (2.13-7.10mg/L), and BOD (0.71–2.28mg/L). Anionic concentrations varied thus: HCO_3^- *(2.42-15.11mg/L),* SO_4^{2-} *(0.67-10.54 mg/L),* NO_3^- *(0.15-4.71 mg/L),* PO_4^- *(0.04-0.81 mg/L) and* Cl^- *(8.03-35.82 mg/L). The cations had very low values:* Ca^{2+} *(1.29-10.17 mg/L),* Mg^{2+} *(0.19-4.82 mg/L),* Na^+ *(0.16-2.81mg/L),* Cu^{2+} *(0.02-0.20mg/L),* Zn^{2+} *(0.02-0.61mg/L) and Fe (0.02-0.31mg/L). Water Quality Index (WQI) revealed very poor water, suggesting that the heavy vehicular movements and gas flaring at the Petroleum Tank Farm impacted negatively on its surrounding groundwater with increased levels of pH, DO and BOD. Based on the findings in this study, the quality of the borehole water is unsuitable for drinking without adequate treatment. Improved energy efficiency performance of all utilities such as in means of transport and behavioural changes to reduce green house gases through the adoption of renewable energy should be encouraged and advocated.*

Key Words: *Borehole, Groundwater, Water quality, pH, BOD, Warri*

Introduction

Water is the most important natural resource without which life would be nonexistent (Adetoyinbo *et al*., 2010). Availability of safe and reliable source of water is an essential prerequisite for sustainable development. In the last few decades, there has been an increase in the demand for freshwater due to rapid growth of population as well as the accelerated pace of industrialization (Yisa and Jimoh, 2010). This demand has led to the use of groundwater not only for its wide spread occurrence and availability but also for its consistent good quality which makes it an ideal supply of drinking water (UNESCO, 2000).

Despite its abundance, groundwater may still be unusable when its quality is considerably degraded by chemical and bacteriological contamination with increasing human population, industrialization, urbanization and the

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consequent increase for the demand of water for both domestic and industrial uses (Paschal *et al*., 2014).

When groundwater becomes contaminated it is difficult and expensive to clean. Consumption of water contaminated by disease causing agents (pathogens) or toxic chemicals can cause health problems like diarrhea, cholera, typhoid, dysentery, cancer and skin diseases (Howard *et al*., 2003).

The quality of water for various purposes, such as, domestic, irrigation and industry, depends on the concentration of the physico-chemical composition and such water quality are usually compared with established international standards such as the World Health Organization (WHO) standard. (Omoboriowo *et al*., 2012).

Warri, a prominent centre of commercial activities in Southern Nigeria, has a port, a petroleum refining industry and several oil fields in its environs. It is a fast growing town faced with increasing demand for water resources due to high population growth rate and large scale industrial growth (Fashola *et al*., 2013). The Ifie community in Warri, where this study was carried out, houses a number of Petroleum Tank Farms; Matrix petroleum, Synop petroleum, A and E petroleum and the Warri Refinery; which supply petroleum products to almost the entire Delta state and neighbouring states. Inhabitants of this community and its environs depend largely on groundwater (borehole) as their major source of water for drinking and other domestic purposes. With the presence and activities of these oil companies and other associated industries, there are serious concerns regarding the susceptibility of groundwater contamination due to discharge of waste materials.

Water Quality Index (WQI) is an important technique for demarcating groundwater quality and its suitability for drinking purposes (Tiwari and Mishra, 1985). It is one of the most effective tools to communicate information on the quality of water to the concerned citizens and policy makers (Yisa and Jimoh, 2010).

The aim of this study therefore is to determine the suitability of borehole water for drinking and domestic purposes in Ifie community and environs, through various physico-chemical parameters and the application of the Water Quality Index (WQI).

Materials and Methods

Description of Study Area

Ifie community is located in Warri-South Local Government Area, Delta State, and lies within the Niger-delta region of Nigeria. It is situated between latitudes 5º 31′ N and 5º 34′ N and longitudes 5º 41′ E and 5º 44′ E (Fig 1). Ifie community houses most of the Petroleum Tank Farms in Warri which supply petroleum products to almost the entire Delta state and neighbouring states. Neighbouring communities to Ifie includes; Ajatitor, Jalla Ubeji, Ugbokodo, Ogunu, Jeddo and Epkan.

The study area has a typical tropical climate, characterized by high temperature and humidity. Average annual temperature in the area is about 27ºC with maximum values in the months of March and April and lowest in July and August. This region has two major seasons; rainy and dry seasons. The rainy season occurs between April and October, while the dry season occurs between November and March. In recent years, however, a clear cut distinction between the two seasons appears very difficult due to climate change.

The study area is drained by the Ifie River and other Warri River tributaries into the Warri River which empties into the sea. The swamps at the bank of the Ifie River have largely been reclaimed for urban development and only patches of mangrove vegetation remain on the banks of the creeks. The vegetation comprises predominantly of mangrove plants, namely: *Rhizophora racemosa (*red mangrove) and *Avicenia africana* (white mangrove) (Wogu and Okaka, 2011).

Geologically, the Warri area is overlain by the Niger Delta sedimentary rocks with a thickness of about 8000 metres. The major lithologic formations include from bottom to top: Akata formation, Agbada formation, Benin formation and the Somebreiro-Warri Deltaic Plain Sands (Allen, 1965; Short and Stauble, 1967; Weber and Daukoru, 1975). The study area is directly underlain by Quaternary formation, the Somebreiro-Warri Deltaic Plain Sand (Wigwe, 1975). This formation consists of fine to medium and coarse-grained unconsolidated sands with occasional intercalations of gravely beds, peat or lenses of plastic clay. The formation generally does not exceed 120 metres in thickness and it is predominantly unconified. The water table is very close to the ground surface and varies from 0 to 4 metres (Olobaniyi and Owoyemi, 2004).

Samples Collection

Groundwater samples were collected from already sunk private boreholes for a period of seven months, January to August, 2015. Water samples were collected from three boreholes at different distances away from the Petroleum Tank Farm. Borehole 1 (BH1) is located approximately 500m from the Petroleum Tank Farm and 250m to the river. Borehole 2 (BH2) is located about 1000m from the Petroleum Tank Farm, while Borehole 3 (BH3) is located 1750m from BH1 and 1250m away from BH2.

The samples were collected in sterilized 2 litres white plastic containers. All plastics and glass wares utilized were pre-washed with detergent water solution, rinsed and soaked for 48 hours in 50% HNO_3, then rinsed thoroughly with distilled deionized water. They were then air-dried in a dust free environment. Groundwater samples were collected from the boreholes after 3 minutes of pumping to ensure the samples were true representative from the aquifer. Analytical procedures and determinations for physical and chemical parameters were carried out in accordance with the specifications of American Public Health Association, APHA (1998). Fast changing physicochemical parameters were determined *in situ* using digitized meters for pH (HANNA pH Meter, Model H128129), Electrical Conductivity (EC) and Total Dissolved Solids (TDS) (Conductivity Meter, HACH KIT, Model 44600).

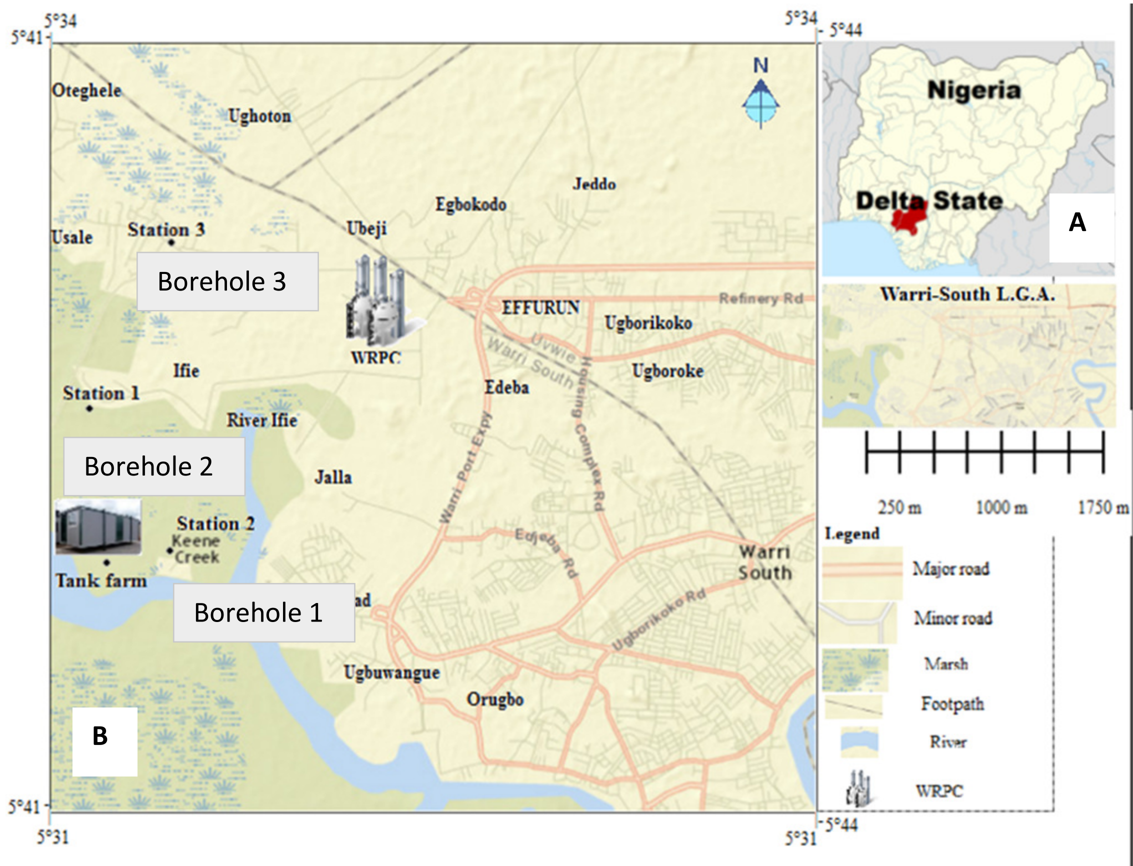

Figure 1: (A) Map of Nigeria showing Delta State (B) Study area showing borehole locations in Ifie community and environs

Analysis of variance (ANOVA) was used for comparisons between sampling locations to test for significant differences; and the source of significant difference was located using the Duncan's Multiple Range (DMR) test. All statistical analyses were computed using SPSS statistical package (version 16.0) and Microsoft Excel statistical Tool pack.

Water Quality Index (WQI) was calculated using the Weighted Arithmetic Water Quality Index Method (Shweta et al; 2013). WQI was calculated by using the following equation:

$$WQI = \sum Q_i W_i / \sum W_i$$

The quality rating scale (Qi) for each parameter is calculated by using this expression:

$$Q_i = 100(V_i - V_0 / S_i - V_0)$$

V_i = Estimated Concentration of the ith parameter of interest in the analysed water.

V_o = The ideal value of the ith parameter in pure water.

V_o = 0 (except pH = 7.0; and DO = 14.6 mg/l)

S_i = Recommended Standard value of the ith parameter

The unit weight (Wi) for each water quality parameter is calculated by using the following formula:

$$W_i = K/S_i$$

Where,

K = proportionality constant and can also be calculated by using the following equation:

$$K = 1/(\Sigma 1/S_i)$$

Results and Discussion

The results of the physical and chemical properties of borehole water samples determined in Ifie Community and environs are summarized in Tables 1 and 2.

The pH was generally acidic. It ranged from 4.62 to 6.87 at BH1, 4.85 to 5.81 at BH2 and 4.86 to 5.93 at BH3 (Table 1). The values varied throughout the sampling period with the lowest value (4.62) recorded in January at BH1, while the highest value (6.87) was recorded in August also at BH1. There was no significant difference ($P>0.05$) across the three locations. However, ANOVA ($p<0.05$) showed pH to be statistically higher during the wet season than in the dry season (Table 2). The pH values all fell within the acidic range, and were below the recommended ranges by NSDWQ (2007) and WHO (2010) for domestic and drinking water. The observed acidity is believed to be due to the presence of CO_2 and other gases in the atmosphere from heavy vehicles that frequent the Petroleum Tank Farm for petroleum products, and also gas flaring in the study area. Free CO_2 from the atmosphere can enter the groundwater system as rainwater percolates underground and reduce the H ions of the water (Omoboriowo *et al*., 2012). Also CO_2 picked up in the atmosphere during recharge by rain, breakdown organic matter derived from vegetation cover and humus buried in the sediment (Appelo and Postma, 1993) thereby increasing groundwater acidity. Acidic waters are favourable to the growth of iron bacteria which cause incrustation of pipes and severe corrosion of metal casing used for reticulation (Tebbutt, 1979; Olarewaju *et al*., 1996). According to Ofoma *et al*., (2008), consumption of water with low pH over a long period of time may lead to derangement of the acid-base balance in the body system, which may cause metabolic acidiosis.

The Electrical conductivity (EC) was lowest at BH2 with a mean value of 44.29μscm^{-1} and highest it BH3 with a mean value of 144.50μscm^{-1}. Borehole 1 recorded a mean value of 60.57µs/cm (Table 1). There was a high significant difference ($P<0.01$) across the three locations which was caused by the high EC at BH3. Although EC values were generally higher in the dry season months, no significant difference ($P>0.05$) was observed in seasonal comparison (Table 2). Electrical conductivity concentrations of the water in all boreholes were within recommended limits of 50µs/cm (WHO, 2010) and 1000µs/cm (NSDQW, 2007), indicating that the water is good and also excellent for agricultural purpose. The occurrence of significantly higher EC value of BH3, the farthest from the Petroleum Tank Farm, may be due to its shallowness which permitted contact with inorganic constituent.

Table 1: Summary of physical and chemical parameters for Borehole water of Ifie community and environs from January to August, 2015

	BH 1			BH 2			BH 3					
Parameters	**$\bar{X}$±SD**	**Min**	**Max**	**$\bar{X}$±SD**	**Min**	**Max**	**$\bar{X}$±SD**	**Min**	**Max**	**P-Value**	**NSDWQ (2007)**	**WHO (2010)**
pH	5.64±0.89	4.62	6.87	5.14±0.36	4.85	5.81	5.25±0.40	4.86	5.93	p>0.05	6.5 -7.0	6.50-9.2
EC (µs/cm)	60.57^{b} ±13.69	42.00	76.00	44.29^{b} ±8.98	33.00	54.00	144.57^{a} ±50.73	97.00	206.00	p<0.01	1000	500
TDS (mg/l)	30.24^{b} ±6.51	23.00	38.70	21.86^{b} ±5.37	15.00	29.00	81.00^{a} ±25.36	51.00	115.0	p<0.01	500	500
DO (mg/l)	2.58^{c} ±0.40	2.13	3.10	3.60^{b} ±0.34	2.92	4.00	5.85^{a} ±0.83	4.81	7.10	p<0.01	7.5	6.2
BOD (mg/l)	1.08^{b} ±0.35	0.71	1.56	1.33^{a}±0.29	1.02	1.87	1.61^{a} ±0.45	1.10	2.28	p<0.05	0	0.05
Bi-carbonate (mg/l)	2.05^{b} ±1.23	2.42	3.67	3.72^{b} ±1.53	3.26	5.02	9.04^{a} ±2.02	9.34	15.11	p<0.01	500	600
Sulphate (mg/l)	3.72^{b} ±1.53	1.35	5.03	2.05^{b} ±1.23	0.67	4.01	9.04^{a} ±2.02	5.63	10.54	p<0.01	100	400
Nitrate (mg/l)	1.96^{b} ±0.58	0.88	2.71	0.62^{b} ±0.35	0.15	1.08	2.70^{a} ±1.12	1.02	4.71	p<0.01	50	10
Phosphate (mg/l)	0.40^{b} ±0.18	0.16	0.71	0.26^{b} ±0.16	0.04	0.46	0.65^{a} ±0.14	0.44	0.81	p<0.01	5	10
Chloride (mg/l)	16.37^{b} ±3.14	11.87	20.02	10.51^{c} ±1.59	8.03	12..71	31.93^{a} ±4.50	24.81	35.82	p<0.01	250	250
Calcium (mg/l)	3.10^{b} ±0.80	1.91	3.87	2.48^{b} ±0.64	1.29	3.32	8.30^{a} ±2.18	4.83	10.17	p<0.01	75	200
Magnesium (mg/l)	1.09^{b} ±0.48	0.39	1.63	0.72^{b} ±0.55	0.19	1.51	3.85^{a} ±1.171.81	4.82		p<0.01	150	150
Sodium (mg/l)	0.62^{b} ±0.23	0.39	0.88	0.40^{b} ±0.190.16	0.77		2.39^{a} ±0.64	0.97	2.81	p<0.01	200	150
copper (mg/l)	0.07^{b} ±0.01	0.05	0.09	0.05^{b} ±0.020.02	0.08		0.14^{a} ±0.05	0.07	0.20	p<0.01	1.0	1.5
Zinc (mg/l)	0.25^{b} ±0.06	0.16	0.32	0.18^{b} ±0.09	0.02	0.30	0.44^{a} ±0.16	0.22	0.61	p<0.01	3.0	1.5
Iron (mg/l)	0.11^{b} ±0.05	0.02	0.18	0.11^{b} ±0.0y3	0.07	0.14	0.23^{a} ±0.160.14	0.31		p<0.01	0.3	1.0
Lead (mg/l)	0.00±0.00	0.00	0.00	0.00±0.00	0.00	0.00	0.00±0.00	0.00	0.00	-	-	-

P>0.05-Not Significant, P<0.05-Significant, P<0.01-Highly Significant
Similar superscript – No significant difference.

Table 2: Seasonal comparison of physical and chemical parameters for Boreholewater of Ifie community and environs

	Dry Season (Jan-April 2015)			Wet Season (May-Aug 2015)			
Parameters	$\bar{X}$±SD	Min	Max	$\bar{X}$±SD	Min	Max	p-value
Ph	5.08±0.38	4.62	5.91	5.69±0.70	4.86	6.87	P<0.05
Conductivity (µs/cm)	99.58±62.06	48.00	206.00	61.22±30.96	33.00	106.00	P>0.05
TDS (mg/l)	53.39±35.32	22.00	115.00	32.33±18.10	15.00	62.00	P>0.05
DO (mg/l)	4.03±1.48	2.37	7.10	3.99±1.62	2.13	6.50	P>0.05
BOD (mg/l)	1.53±0.40	1.00	2.28	1.09±0.30	0.71	1.61	P<0.05
Bi-carbonate (mg/l)	7.40±4.99	2.53	15.11	5.75±3.67	2.42	11.31	P>0.05
Sulphate (mg/l)	6.03±3.37	2.36	10.54	3.48±3.07	0.67	9.07	P>0.05
Nitrate (mg/l)	1.87±0.91	0.57	3.11	1.61±1.43	0.15	4.71	P>0.05
Phosphate (mg/l)	0.48±0.19	0.21	0.79	0.38±0.27	0.04	0.81	P>0.05
Chloride (mg/l)	21.58±10.62	10.02	35.82	16.97±8.37	8.03	31.07	P>0.05
Calcium (mg/l)	5.39±3.33	2.59	10.17	3.61±2.22	1.29	7.98	P>0.05
Magnesium (mg/l)	2.16±1.82	0.19	4.82	1.52±1.32	0.35	4.35	P>0.05
Sodium (mg/l)	1.30±1.01	0.29	2.81	0.92±0.98	0.16	2.81	P>0.05
copper (mg/l)	0.10±0.05	0.02	0.20	0.06±0.04	0.02	0.16	P>0.05
Zinc (mg/l)	0.36±0.15	0.18	0.61	0.20±0.11	0.02	0.41	P<0.05
Iron (mg/l)	0.18±0.07	0.11	0.31	0.12±0.06	0.02	0.21	P>0.05
Lead (mg/l)	0.00±0.00	0.00	0.00	0.00±0.00	0.00	0.00	-

Groundwater TDS followed same trend as EC. In all months of sampling, BH2 recorded the lowest values (15.02-29.00mg/L), while the highest values (51.00-115-00mg/L) occured in BH3. Although, there was a high significant difference (P<0.01) across the locations, caused by the high values at BH3, TDS concentrations in water from the three boreholes fell within WHO (2010) and NSDWQ (2007) acceptable limits. The significantly high TDS values at BH3, is possibly due to the fact that the area is the most densely populated and consequently witnesses higher ground water abstraction. According to Amangabara and Ejenma (2012) EC, salinity and TDS almost go together. A high TDS means that there are more cations and anions in the water, which makes the water become saline and increases its electrical conductivity.

The observed mean DO for BH1 (2.58mg/L), BH_2 (3.60mg/L) and BH3 (5.85mg/L) (Table 1) revealed that the water in the boreholes were low in DO when compared with the recommended values of 7.5mg/L (NSDWQ, 2007) and 6.2mg/L (WHO, 2010). Spatial variation was highly significant (P<0.01) and BH3 was the cause of the difference. Fluctuation in DO values occurred in both dry and wet seasons and so seasonal variation was not significant (Table 2). The oxidation of organic substances and reduced inorganic substances might be the cause of the low oxygen content in groundwater in all the locations, especially BH1 which is close to the Petroleum Tank Farm. The farther the borehole, the higher the DO value, indicating the possible effect of the Tank Farm activities on groundwater DO.

Biological Oxygen Demand (BOD) values ranged from 0.71 to 1.56mg/L, at BH1, 1.02 to 1,87mg/L at BH2, and 1.10 to 2.28mg/L at BH3, (Table 1).The highest value (2.28mg/L) was recorded in March at BH3, while the lowest value (0.71mg/L) was recorded in July at BH1. The observed BOD values were all above the acceptable limits of 0.05mg/L (NSDWQ and WHO), indicating that the borehole water was contaminated. The high BOD, especially at BH3, may be attributed to high biological activities arising from the improper disposal of domestic waste by the residents. In this study, BOD was higher in the dry season (1.53mg/L) than in the wet season (1.09mg/L), a trend similar to that reported by Amangabara and Ejenma (2012) in Yenagoa, Bayelsa State.

Bi-carbonate values in this study which ranged from 2.42mg/L to 15.11mg/L were far below the stipulated value of 500mg/L (NSDWQ, 2007) and 600mg/L (WHO, 2010) for drinking water. A highly significant difference (P<0.01) across the locations, caused by BH3 was observed. BH1 which is closest to the Petroleum Tank Farm recorded the lowest mean HCO_3 value of 2.05mg/L. According to Egbai *et al*. (2013), most bicarbonate ions in ground water are derived from the carbondioxide in the atmosphere, carbondioxide in the soil and that produced by the biota of the soil or by the activity of sulphate reducers and other bacterial in deeper formations and solutions of carbonate rocks.

The observed sulphate (0.67 - 10.55mg/L), nitrate (0.15 - 4.71mg/L), phosphate (0.04/0.81mg/L) and chloride (8.03 – 35.82mg/L) in this study were all within the permissible limits recommended by NSDWQ (2007) and WHO (2010). In all months of sampling, BH3 recorded the highest values of these salts, accounting for the high significant differences (P<0.01) observed across all three locations (Table 1).

Sulphate is a naturally occurring anion. High concentrations of sulphate in drinking water may cause transistory diarrhea (US, E.PA, 1990). The low levels of sulphate especially at BH1 cannot be explained. Elevated concentrations would have been expected by the presence of high vehicular activities and the petroleum refining process in the study area. According to Olobaniyi and Owoyemi (2004) gaseous emanations from the vehicles and petroleum refining process contain significant amounts of sulphur-rich gases, which are scavenged out of the atmosphere as acid rain and recharge the aquifer. This however is in contrast to the findings in the present study where low concentrations of sulphate were recorded.

The concentrations of cations in the borehole water samples include: Calcium (1.29 – 10.17mg/L), Magnesium (0.19 / 4.82mg/L) and Sodium (0.16-2.8mg/L). These values were all within the acceptable limits for drinking water as stipulated by NSDWQ and WHO. Spatial variation was highly significant ($P<0.01$) for all three cations, and BH3 was the cause of the difference.

Magnesium is usually found in lower concentration than calcium due to the greater hardness and like calcium form scales and deposits on heating. Calcium salts and calcium ions are among the most commonly occurring inorganic chemical in nature. Though the human body requires approximately 0.7 to 2.0g of calcium per day as food element, excessive amounts can lead to the formation of kidney or gall – bladder stones (Amangabara and Ejenma, 2012). Calcium toxicity is rare, but over consumption may lead to deposit of calcium phosphate in soft tissue of the body.

The heavy metals levels were found to be very low in all the locations. The concentrations of copper (0.02-0.20mg/L), Zinc (0.02-0.6mg/L) and Iron (0.02-0.3mg/L) were all within permissible limits of NSDWQ and WHO. The observed Iron concentrations in this study is in contrast with the findings of Frank-Briggs (2003), Edet (2009), Edet *et al*. (2011), and Ogbeibu *et al*. (2012), where high concentrations of Iron were reported for underground water.

According to Fashola *et al*. (2013), the occurrence of iron may be related to the geological history and source rocks of the deposits that constitute the aquifer material in the Niger-Delta. Though located in the Niger-Delta region, the low iron concentration of the borehole water in the study area could be as a result of proper filtration of the water in the terrain.

The application of water quality Index (WQI) in this study was useful in assessing the overall quality of water at the three locations. The WQI ranged from 75.40 to 114.10 (Table 3). Based on the standard classification (Table 4) BH1 and BH2 had very poor water quality, while the water in BH3 with the highest WQI of 114.10, above the benchmark of 100, is unsuitable for drinking purpose. The overall evaluation of the results suggests that the activities at the Petroleum Tank Farm resulted, in aquifer contamination. However, the high concentrations of most of the parameters at BH3, the farthest from the Petroleum Tank Farm can be attributed to additional anthropogenic factors.

Table 3: Water quality Index (WQI) values of sampled boreholes

Borehole	WQI	Quality
BH1	75.40	Very poor
BH2	86.50	Very poor
BH3`	114.10	Unsuitable for drinking purpose
Benchmark	100.00	

Table 4: Water Quality Rating as per Weight Arithmetic Water Quality Index Method

WQI Value	Rating of Water Quality	Grading
0-25	Excellent water quality	A
26-50	Good water quality	B
51-75	Poor water quality	C
76-100	Very Poor water quality	D
Above 100	Unsuitable for drinking purpose	E

Source: Shweta *et al*. (2013)

Conclusion

The study reveals that the concentrations of most of the parameters studied, except for pH, DO and BOD, were within permissible limits of NSDWQ and WHO standards. Water quality Index (WQI) assessment further revealed poor ground water quality in the study area, suggesting that the borehole water is unsuitable for drinking without adequate treatment. Furthermore, the activities at the Petroleum Tank Farm can be said to have had effects on its surrounding groundwater with increased levels of pH, DO and BOD. Heavy vehicular movements and gas flaring at the Petroleum Tank Farm and the presence of organic matter in the soil of the study area may be responsible for the acidity. The pH can be adjusted by the addition of lime and more effectively through the Base Exchange method with dolomite (Fashola *et al*., 2013).

In order to prevent and control pollution in the study area, it is recommended that PVC pipes and other non – corrosive materials be used for boreholes construction, since acidic waters are aggressive to metallic pipes. Improved energy efficiency performance of all utilities such as in means of transport etc. and behavioural changes to reduce green house gases (GHGs) through adoption of renewable energy should be encouraged and advocated. More importantly, regular groundwater quality control monitoring should be encouraged to guide against future degradation of the water and safeguard human health.

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