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Assessing the total petroleum hydrocarbon content in groundwater in parts of Eleme, Southern Nigeria

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ABSTRACT

The total petroleum hydrocarbon content of groundwater In Eleme, Rivers State Nigeria, was assessed to determine the concentration of polycyclic aromatic hydrocarbon and aliphatic components in the groundwater. Ten (10) distinct boreholes water samples were obtained across the study area and were subjected to laboratory analysis using Gas Chromatography-flame ionization detection (GC-FID). The result reveals that the aliphatic hydrocarbon content ranges from 0.06-0.595mg/l and the polycyclic aromatic hydrocarbon content ranges from 0.068 to 0.239 (mg/L). These imply that the Total Petroleum Hydrocarbon concentrations are comparatively low and within the acceptable range when compared to standard limits from United State Environmental Protection Agency 2015. As a result, the contamination from total petroleum hydrocarbon in the research area does not constitute a serious environmental danger. However, continued oil spills should be avoided as they might result in harmful hydrocarbon buildups, therefore routine inspections will help to safeguard the groundwater supplies in the research areas.

***Keywords*:** Petroleum, Borehole, Aromatic, Concentration, Eleme, Nigeria

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1. INTRODUCTION

Over 70% of the earth's surface is covered by water, and about 97.3% of the earth's water is contained in the ocean as salty water while fresh water constitutes the remaining 2.7%. Out of the 2.7% of fresh water, about 2.03% is contained as polar ice and glaciers while about 0.61% is contained as groundwater. Lake, rivers, atmospheric vapor, soil moisture, and biological water consist about 0.06% of the total earth's water (Garg, 2009). Since salt water cannot be readily consumed by humans or freely used for various industrial and domestic purposes, humans and other living organisms depend on and compete for the limited freshwater sources available to them (Dami et al., 2013). The availability of quantitative and qualitative freshwater supplies for humans over the years has influenced settlement patterns in different geographical regions around the world (Farrar, 1977). However, for water to be adequately utilized, it has to be reasonably free from contaminants. Otherwise, such waters could pose serious health and environmental risks to living organisms that depend on them (Odesa et al., 2021).

Since the discovery of crude oil in 1956 in Nigeria, it has accounted for over 70% of the Nigerian government's annual revenue and 90% of the country's export earnings (Elwerfelli, and Benhin, 2018). Unfortunately, the commencement of oil exploration and exploitation was followed almost immediately by the two major causes of hydrocarbon pollution namely, the impact of gas flaring and oil spills which has unavoidably leads to the degradation of the environment having many effects on water resources (Ibezue et al., 2018). The groundwater resources in zones of crude oil exploration and production in most places are frequently contaminated with hydrocarbon due to Gas flaring and oil spillage.

This has made hydrocarbon pollution of such ecosystems a widespread environmental issue, especially in developing nations. Hydrocarbon is made up of Aromatic and Aliphatic. Groundwater pollution caused by aromatic and aliphatic hydrocarbons is a significant environmental concern with far-reaching consequences. Aromatic hydrocarbons, such as benzene, toluene, and xylene, are commonly found in petroleum-based fuels and solvents, while aliphatic hydrocarbons include compounds like gasoline and diesel. These substances can contaminate groundwater through upon release into the environment with processes such as spillage. Hydrocarbon spills are a common occurrence in Nigeria, and they are caused by a variety of factors, including corrosion of pipelines and tankers (which accounts for 50% of all spills), sabotage (36%), and oil production operations (6.5%), with inadequate or non-functional production equipment accounting for 1% of all spills (Adelana et al., 2011).

When released into the environment, aromatic and aliphatic hydrocarbons can infiltrate the soil and reach the groundwater, posing serious risks to human health and ecosystems. These compounds are toxic and carcinogenic, and prolonged exposure to groundwater contaminated by these compounds can lead to severe health issues, including damage to the nervous system, liver, and kidneys (Ambade, et al., 2021; Eyankware, et al., 2016).

The impacts of hydrocarbon contaminants on groundwater depend on some crucial factors which include but are not limited to (i) porosity and permeability of the underlying soil (ii) presence of hydrocarbon decomposing organisms (iii) rate of decomposition (iv) adsorption and absorption (v) residence time (vi) dispersion mechanism (vii) groundwater flow velocity (viii) solubility of the organic compound etc. When crude oil is released into the subsurface, it migrates downward due to the action of gravity and capillarity within the soil (Sethi and Di Molfetta, 2019). When crude it reaches the capillary fringe, its downward migration becomes difficult because of the increase in the water content, and this limits the amount of vertical migration and therefore spread laterally on top of the water table. Lichtenthaler, (1998) observed that the insoluble fraction of TPH can form a film with a thickness of about 0.01 to 3.0 mm layer, this made them readily available for adsorption and absorption by the aquifer within the groundwater flow system. The residual TPH exists in the groundwater as a solution. However, a sufficient concentration of TPH within the flow system can produce non-aqueous phase liquids (NAPLs) (Delille and Bassères, 1998). The lateral migration of the TPH follows the groundwater flow gradient via advection and dispersion (Essaid et al., 2015).

However, the repeated occurrence of hydrocarbon spillage in Eleme, Rivers State has become a frequent and long-lasting problem since the discovery of crude oil in the region. Just recently 11th of June 2023 an occurrence of another spillage within the area that affected six communities was aired(this day newspaper,2023). This and many other cases of oil spillages and their effect on the ecosystem have been widely reported across the Niger Delta region of Nigeria.

Abii, and Nwosu, (2009) reported and evaluated the impact of oil spillages on soil in Eleme, River State Nigeria, and observed that oil spillage within the area has negatively affected the fertility and nutrient of the soil. This aligned with the findings from Igwe, et al., (2017) who evaluated the impact of oil spillage on nearby farmland in River State Nigeria, and observed that the runoff from oil-impacted locations hurt the health and quality of the edible vegetables. However, the impact of oil spillage on groundwater was later evaluated by Nwachukwu and Osuagwu., (2014) and discovered a significant difference in Total Hydrocarbon Content (THC) in groundwater around oil-polluted sites higher than the control values used for the study. While, Eseimokumoh and Woyintonye, (2022) reported a similar case of polluted groundwater from hydrocarbon in the Imiringi Community of Ogbia LGA of Bayelsa State.

Other cases of groundwater pollution from Hydrocarbon spillages have also been recorded around the world. In the year 2000, Guanabara Bay oil spillage near Rio de Janeiro in Brazil an oil spillage released approximately 1.3 million liters of oil which contaminated the groundwater and surrounding marine ecosystems (Silva 2007). Elsewhere in Mayflower, Arkansas, United States in 2013, An ExxonMobil pipeline carrying Canadian crude oil ruptured, spilling thousands of barrels of oil. The spilled oil reached nearby wetlands and a subdivision, contaminating the soil and potentially infiltrating the groundwater (Belvederesi, 2018). Also in 2011, an oil refinery in Gela, Italy experienced a leak, leading to the contamination of nearby soil and groundwater with hydrocarbons (Garcia, et al., 2013).

One thing is certain, these long-standing challenges and their consequential effect on the environment, the repeated spillage occurring within the study area pose a threat to the availability of clean groundwater water, which may invariably serve as a threat to the health of the inhabitants. Hence there is a need for consistent monitoring of the groundwater which serves as the major source of drinking water within the study area.

Thus, this paper seeks to determine the concentrations of hydrocarbon contaminants in groundwater and assess if the groundwater consistently meets the United State Environmental Protection Agency (USEPA, 2015) guidelines for drinking water.

1. 1. Location, Physiography, and climate

The study area is located in the Alode community in Eleme LGA of Rivers State, Nigeria within latitudes 04°49’30’’N and 04°45’0’’N and longitudes 07°4’30’’E and 07°9’E. The major sources of livelihood of the people include farming, fishing, trading, and transportation business having an estimated population of 190,884 according to (NPC, 2006). The research area is located in a tropical climate with two distinct seasons: the rainy season and the dry season.

According to Nwankwor et al. (2016) and Eyankware et al. (2021), the research area experiences 1000 to 2000 mm of rainfall on average each year. They also noted that the rainy season lasts from mid-April to early November and that July and October are the months with the heaviest rainfall. The research area's temperature ranges from 26 to 28 °C, and the vegetation is typical of mangrove swamp forests, despite the fact that it has frequently been replaced by grassland due to substantial human activity such as farming, forestry, and exploration. In addition, it is distinguished by hazy, dry, and dusty winds from Arabia-Eurasia known as the North-East Trade Winds and a high-pressure belt (Nwankwor et al. 2016). According to Edokpa and Nwagbara (2017), the coastal region of the Niger Delta has an average monthly wind speed pattern that spans from 0 to 3 m/s, with periods of lower and higher trends visible during the night and evening hours. The research area has a mild topography with an average elevation of around 18 m above sea level and a notable lack of prominent hills that rise above the general landscape. The area's fop and low-relief characteristics sometimes increase flooding following rain. Numerous creeks with dendritic drainage patterns and some tributaries that discharge into the Atlantic Ocean cross the study region.

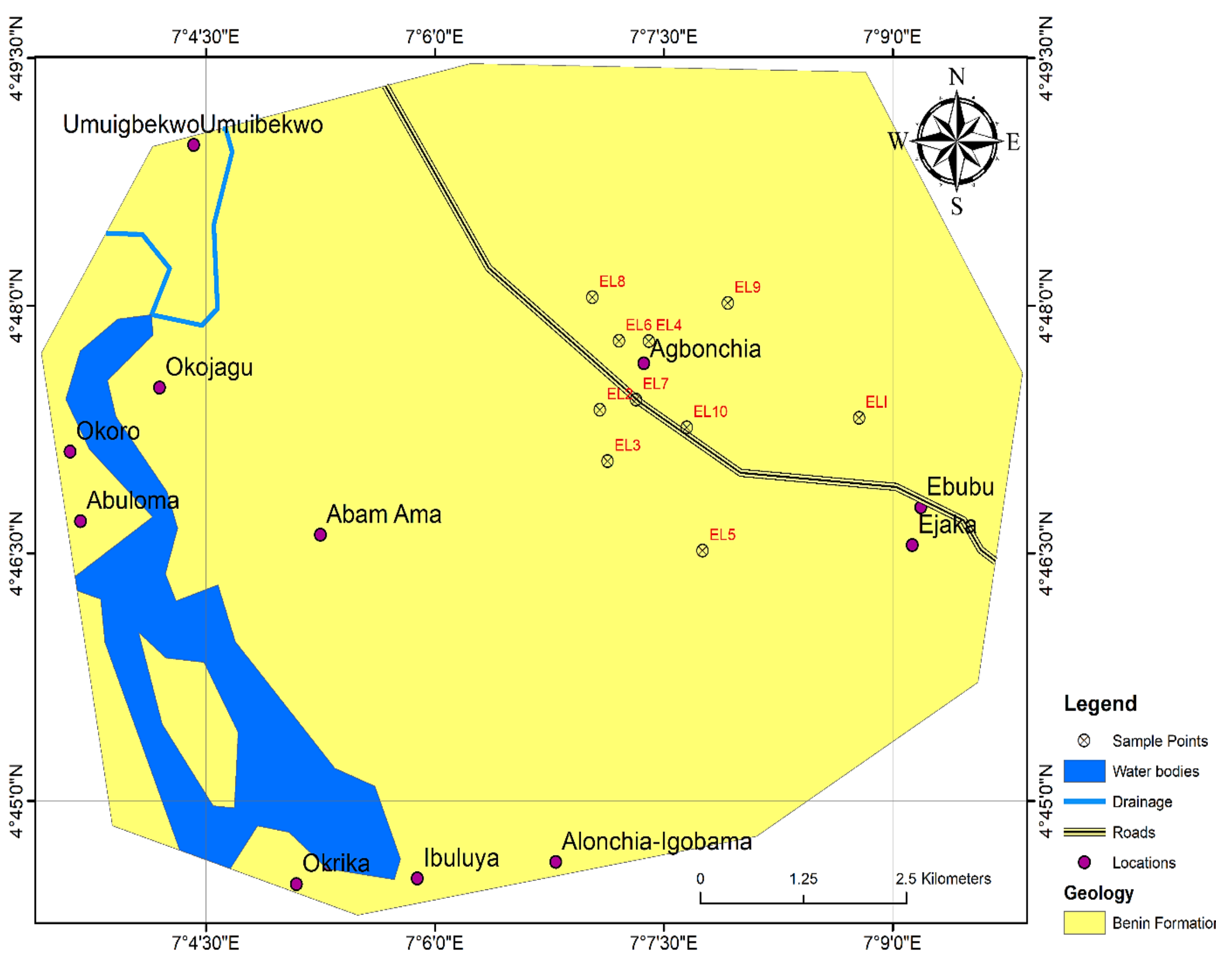

Fig. 1. Accessibility Map of the study area

The area of study is situated in the coastal zone, which experienced a tropical climate characterized by two distinct seasons – the rainy season and the dry season with a temperature range between 28.80c and 30.50c (Ofoma et al., 2005). The study area is well-drained by the Imu Ngololo River.

1. 2. Geology and Hydrogeology

The study area is located within the Niger Delta Sedimentary Basin whose origin is associated with the evolution of a triple junction rift-ridge system that initiated the separation of the South American plate and African plate in the Jurassic (Whiteman, 1982). This was followed by the deposition of sedimentary succession which include the Akata (oldest), Agbada(middle), and the Benin (youngest) Formation (Short and Stauble, 1967). The Benin Formation is distinguished by the occurrence of the intercalation of clay, silt, sand, conglomerate, and peat/lignite of various thicknesses (Short and Stauble, 1967). The Benin Formation is the aquiferous unit bearing the groundwater within the study region, it has a hydraulic transmissivity within the range of 1324 m^2/day - 5815 m^2/day (Ngah, and Eze, 2017). However, data from vertical electronic sounding obtained within the Alode community reveals that the groundwater occurs in confined and unconfined aquifers having an average depth of 62.7m (Amadi, 2019).

2. MATERIALS AND METHODS

Ten (10) water samples were collected from boreholes across the study area. Groundwater samples will be collected from boreholes with liter plastic bottles sterilized with 10% dilute nitric acid rinsed in distilled water and finally rinsed severally with water from the source before filling. The samples were taken to the laboratory the same day and were prepared and subjected to laboratory analysis using Gas Chromatography-flame ionization detection (GC-FID).

3. RESULTS

Table 1a. Polycyclic Aromatic Hydrocarbon Content (mg/L)

COMPONENT	EL1	EL2	EL3	EL4	EL5	EL6	EL7	EL8	EL9	EL10
Naphthalene	0.001	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
2-methylinaphthalene	0.000	0.001	0.000	0.000	0.000	0.000	0.000	0.000	0.002	0.000
Acenaphthalene	0.009	0.002	0.002	0.001	0.002	0.001	0.002	0.001	0.001	0.001
Acenaphthene	0.000	0.000	0.002	0.002	0.000	0.00	0.001	0.001	0.001	0.001
Fluorene	0.001	0.000	0.001	0.000	0.000	0.000	0.001	0.000	0.001	0.001
Phenanthrene	0.000	0.001	0.000	0.000	0.002	0.000	0.000	0.000	0.000	0.002

Anthracene	0.002	0.001	0.000	0.001	0.002	0.000	0.001	0.001	0.000	0.001
Fluoranthene	0.000	0.000	0.001	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Pyrene	0.000	0.000	0.000	0.000	0.001	0.000	0.000	0.000	0.000	0.000
Benzo[a]anthracene	0.001	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Chrysene	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Benzo[b]fluoranthene	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Benzo[a]pyrene	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Benzo[k]fluoranthene	0.000	0.000	0.000	0.000	0.000	0.000	0.001	0.001	0.000	0.000
Indeno[1,2,3-cd]pyrene	0.000	0.000	0.000	0.000	0.001	0.000	0.000	0.000	0.001	0.000
Dibenzo[a,h]anthracene 22	0.000	0.000	0.000	0.000	0.000	0.001	0.000	0.000	0.000	0.000
Benzo[g,h,I]perylene	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Max	0.009	0.002	0.002	0.002	0.002	0.001	0.002	0.002	0.002	0.002
Average	0.001	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Sum	0.024	0.007	0.008	0.006	0.008	0.003	0.008	0.006	0.008	0.008

Table 1b. Total Aliphatic Hydrocarbon Contents (mg/L)

COMPONENT	EL1	EL2	EL3	EL4	EL5	EL6	EL7	EL8	EL9	EL10
C8	0.000	0.000	0.000	0.001	0.000	0.002	0.000	0.000	0.000	0.000
C9	0.000	0.000	0.000	0.000	0.000	0.000	0.001	0.000	0.002	0.001
C10	0.000	0.000	0.000	0.001	0.000	0.001	0.001	0.000	0.000	0.000
C11	0.000	0.000	0.005	0.000	0.000	0.000	0.010	0.001	0.00	0.003
C12	0.000	0.000	0.002	0.000	0.001	0.000	0.002	0.001	0.040	0.000
C13	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
C14	0.000	0.000	0.000	0.002	0.000	0.002	0.021	0.000	0.001	0.001
C15	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.001	0.000	0.011
C16	0.000	0.002	0.001	0.000	0.030	0.000	0.003	0.000	0.000	0.000
C17	0.001	0.000	0.000	0.000	0.000	0.021	0.001	0.000	0.001	0.001

Pristane	0.000	0.000	0.000	0.000	0.000	0.000	0.001	0.000	0.000	0.004
C18	0.000	0.001	0.001	0.002	0.002	0.000	0.003	0.000	0.000	0.000
Phytane	0.010	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.009	0.000
C19	0.030	0.010	0.000	0.000	0.000	0.000	0.000	0.060	0.000	0.023
C20	0.001	0.010	0.000	0.000	0.050	0.000	0.020	0.008	0.000	0.000
C21	0.00	0.000	0.020	0.001	0.000	0.040	0.000	0.000	0.003	0.001
C22	0.010	0.000	0.000	0.000	0.000	0.000	0.030	0.000	0.080	0.000
C23	0.000	0.019	0.000	0.000	0.012	0.000	0.000	0.200	0.000	0.000
C24	0.000	0.000	0.012	0.040	0.000	0.070	0.004	0.002	0.000	0.000
C25	0.004	0.005	0.003	0.000	0.010	0.000	0.000	0.000	0.000	0.000
C26	0.015	0.000	0.000	0.000	0.040	0.002	0.030	0.100	0.005	0.010
C27	0.000	0.023	0.006	0.020	0.000	0.010	0.000	0.000	0.000	0.000
C28	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.001	0.000
C29	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Max	0.03	0.023	0.02	0.04	0.05	0.07	0.031	0.2	0.08	0.023
Mean	0.004	0.004	0.002	0.005	0.008	0.008	0.006	0.022	0.009	0.003
Sum	0.105	0.109	0.060	0.122	0.203	0.226	0.164	0.595	0.231	0.081

Table 2. Some listed PAH compounds as priority pollutants by USEPA, (2015)

PAH Contaminant	Permissible Limit (mg/L)	Hazard Designation	Molecular Formula
Benzo[a]pyrene	0.0002	Carcinogen	$C_{20}H_{12}$
Naphthalene	0.008	Possible carcinogen	$C_{10}H_8$
Anthracene	0.008	Not classified	$C_{14}H_{10}$
Benzo[b]fluoranthene	0.0002	Possible carcinogen	$C_{20}H_{12}$
Benzo[k]fluoranthene	0.0002	Possible carcinogen	$C_{20}H_{12}$
Benzo[ghi]perylene	0.0002	Possible carcinogen	$C_{22}H_{12}$

Chrysene	0.0002	Not classified	$C_{18}H_{12}$
Dibenzo[a,h]anthracene	0.0002	Carcinogen	$C_{22}H_{14}$
Fluoranthene	0.02	Not classified	$C_{16}H_{10}$
Fluorene	0.02	Not classified	$C_{13}H_{10}$
Indeno[1,2,3-cd]pyrene	0.0002	Possible carcinogen	$C_{22}H_{12}$
Phenanthrene	0.01	Not classified	$C_{14}H_{10}$
Pyrene	0.01	Not classified	$C_{16}H_{10}$

Seventeen different aromatics and 23 different aliphatic hydrocarbons were tested for in 10 different samples across the study area. Table 3 reveals the concentration of the total petroleum hydrocarbon in groundwater across the study area.

The Fig. 2 revealed that the concentration levels for the different hydrocarbon groups present in water samples.

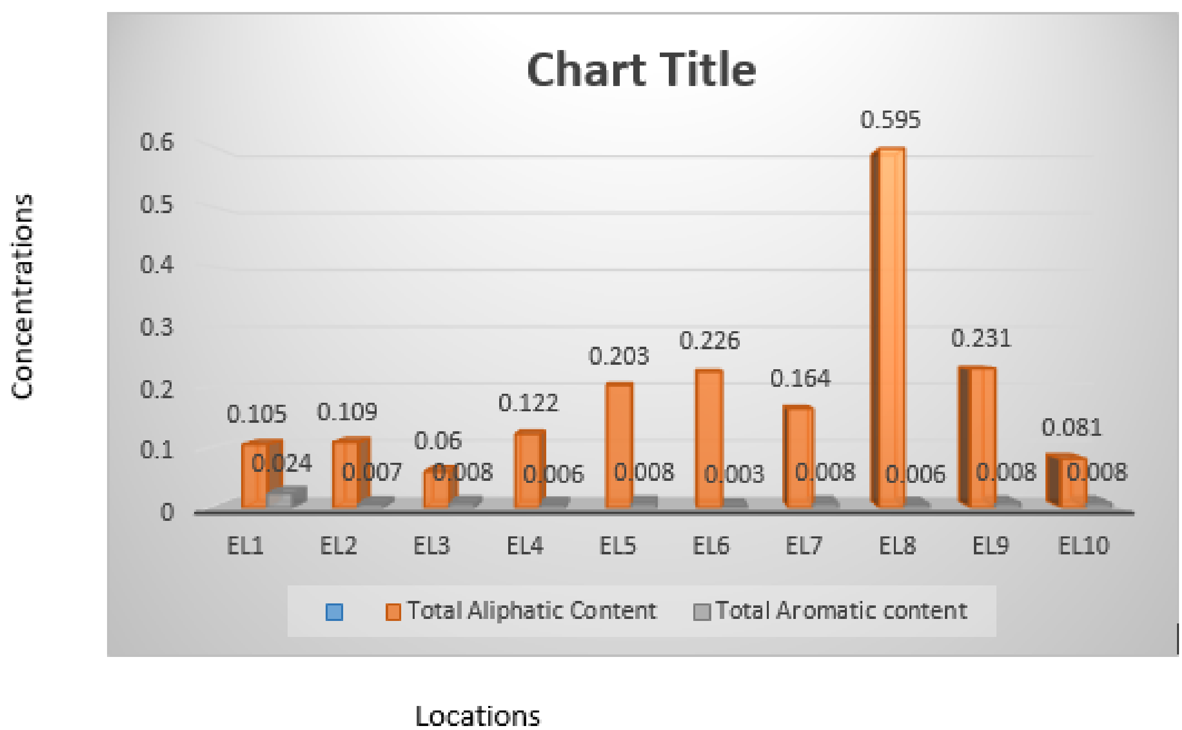

Fig. 2. Aromatic and Aliphatic concentration level represented in bar graph

Both the bar charts and the line graph above were consistent in showing that the aliphatic components were more in concentration than the aromatics.

Table 4. Summary of TPH

Components	EL1	EL2	EL3	EL4	EL5	EL6	EL7	EL8	EL9	EL10
Total Aliphatic Content	0.105	0.109	0.060	0.122	0.203	0.226	0.164	0.595	0.231	0.081
Total Aromatic content	0.024	0.007	0.008	0.006	0.008	0.003	0.008	0.006	0.008	0.008
Total Petroleum Hydrocarbon	0.129	0.116	0.068	0.128	0.211	0.229	0.172	0.601	0.239	0.089

4. DISCUSSIONS

The total aliphatic concentration ranges from 0.06-0.595, while, the aromatic concentration ranges from 0.003 to 0.024 across the study area. Meanwhile the concentration of the aromatics compounds of great priority such as Benzo[a]pyrene, Benzo[b]fluoranthene, Benzo[k]fluoranthene, and Chrysene. According to USEPA, (2015), reveals non-detectable except for Benzo[k]fluoranthene flouratine which have 0.001 mg/l at location 7 and 8 which is within the USEPA, (2015) acceptable limit. However, the total petroleum hydrocarbon content across the study area ranges from 0.068 to 0.239 mg/l which is within the 1mg/l limit proposed by USEPA (2015).

4. 1. TPH Concentration

The low concentration of TPH in the groundwater within the study area can be attributed to the geochemical properties of the crude and the aquiferous properties. Rapid partitioning of the hydrocarbon between water, air, and sediment as explained by Knap,(1982) is believed to be a major factor that determines the low concentration of the hydrocarbon in the water. Evaporation plays a major role by removing the lighter fractions, this makes the remaining portions available for sorption and percolation (Knap, 1982). This study is also of the view that biodegradation process plays a major role in reducing the concentration of the hydrocarbon through degradation and decomposition. Wu et al., (2017) observed that the rate of biodegradation of TPH decreases with an increase in carbon content.

However, the result of the geophysical investigation carried out within the study area by Amadi (2019), using three VES showed that VES 1 and VES 3 reveals unconfined aquifer while VES 2 reveals confined aquifer. This infers that variation in concentration of the TPH is probably also controlled by the local geological attributes of the study area and this may also be responsible for the low concentration of the TPH in the groundwater.

4. 2. Variation in Aliphatic and Aromatic Hydrocarbon concentration

The study observed that the aliphatic component across the study area is more in concentration than the aromatic component. This observation could be due to the chemistry of the crude. in general, aromatic compounds tend to be less volatile than aliphatics (Wu et al., 2017). Aromatic with less than 4 rings are soluble in water while those with 5 rings and above are insoluble in water, they cling to sediments through sorption and tend to be more persistent in soil compared to aliphatic compounds due to their stable structures (Cerniglia, 1992, Shor and Kosson,2004; Zhu, and Pignatello, 2005). The stability of the aromatic compounds make them more resistant to biodegradation and thus, more persistent in soil when compared to aliphatic compound of the same carbon bands (Wu et al., 2017). Nevertheless, the less soluble nature of the aliphatic allows it to travel faster through the soil to groundwater than the aromatic and is less affected by sorption. This suggests the possible reasons why the aliphatic compounds are higher in concentration in the groundwater samples. This study is consistent with the findings of Ibezue et al., (2018) who evaluated the concentration of TPH in groundwater within Jesse and Environ in Ethiope West LGA, Delta State Nigeria.

5. CONCLUSIONS

The total aliphatic concentration ranges from 0.06-0.595, while, the aromatic concentration ranges from 0.003 to 0.024, meanwhile, TPH ranges from 0.068 to 0.239 mg/l. the comparison of the individual contaminants to the USEPA (2015) standard reveals that the groundwater is suitable for consumption based on the measured parameters. Conclusively, even though both the rate of biodegradation and volatility are greater in aliphatic compounds compared to aromatic compounds of the same carbon bands, the rate of absorption and adsorption tends to concentrate the aromatic in the sediments. The less viscous nature of the aliphatic tends to enhance its transportation rate, thus its high concentration in the groundwater sample. This makes them more persistent in sediment and less available in groundwater. Thus, this again explains the difference in concentration level between the aliphatic and aromatic in the study area.

5. 1. Recommendation

Following the recent spillages within the area and the observation of petroleum contaminants within the groundwater, the study recommends

1) Immediate clean-up and remediation of the spillage sites
2) Regular evaluation monitoring of groundwater within the study area
3) Biological and Heavy metals composition of the groundwater should be properly evaluated before the groundwater acceptability for domestic usage.

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