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RESEARCH PAPER

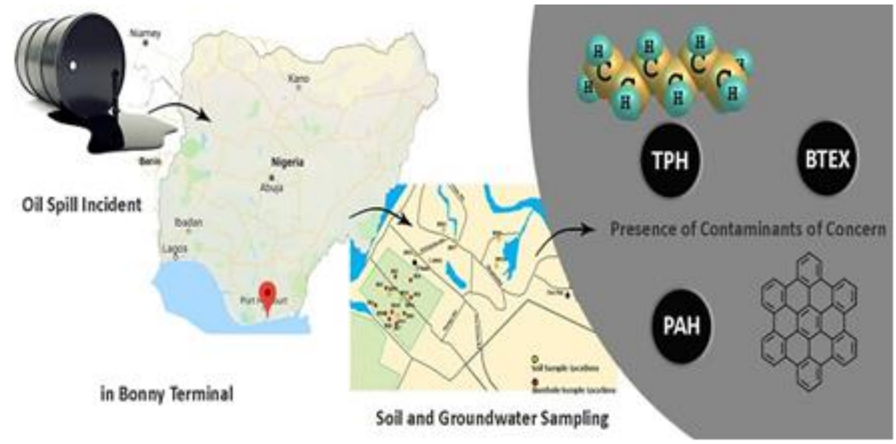
Investigation of hydrocarbon contaminant levels and groundwater quality assessment in parts of Bonny Island, Rivers State of Nigeria

Hycienth Ogunka Nwankwoala *, Erhinyoja Omofuophu
Department of Geology, Faculty of Science, University of Port Harcourt, Nigeria

Highlights

- The Niger Delta region has been rated as the most oil-impacted and polluted environment globally.
- Pollution caused by petroleum hydrocarbons is one of the most common environmental issues in the study area.
- The aim of the research is to assess groundwater quality around an oil spill site in Bonny, Rivers State.
- Government and relevant stakeholders should urgently take proactive steps to protect groundwater resources.

Graphical Abstract



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Abstract

This study investigates the environmental impact of a recent oil spill incident in Bonny terminal using groundwater media. The objective was to establish the presence of Contaminants of Concern (COC), determine, quantify and model spilled volume IEEE Transactions on Components, Packaging and Manufacturing Technology and ascertain potential health risk associated with the spill incident. The COC included Total Petroleum Hydrocarbons (TPH), Polyaromatic Hydrocarbons (PAH) and BTEX compounds. Groundwater was sampled in the vicinity of the spill incidents and further away into the surrounding communities. Groundwater assessment showed that TPH ranges from 9.04 to 20.60 µg/L with a mean value of 2526.90 ± 6392.40 µg/L. Apart from four boreholes, all others had TPH values exceeding DPR target value of 50µg/L. PAH was recorded only at three boreholes, with values: 0.13, 1.07, and 0.25µg/L, respectively. Meanwhile, BTEX compounds had concentration (5910 µg/L) that exceeded Directorate of Petroleum Resources (DPR) target value of 0.8 µg/L over 7000 times. The BW-3 is most deteriorated in water quality. These contaminated borehole-sampling locations are positioned at the vicinity of tank farm, at higher hydraulic heads and hence, might not pose much health risk to the surrounding communities. Groundwater movement in the area is towards the Bonny River at the southwestern part of the area. This study, therefore recommends remedial actions be taken immediately to prevent health risk in the tank farm area.

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* Corresponding author: h.o.nwankwoala@gmail.com (H.O. Nwankwoala)

1. Introduction

The Niger Delta region has been rated by environmental experts from the U.K., the USA, and Nigeria as the most oil-impacted environment and polluted area globally (Elum et al., 2016). Soil and groundwater are tainting, most of the time with overwhelming metals and oil based goods, a broad issue in Rivers State. This way, contamination brought about by oil hydrocarbons is one of the most widely recognized natural issues (Adebiyi et al., 2015; Hassan et al., 2018). The evaluation of well-being dangers created by oil investigation, abuse, and creation is a significant natural issue to guarantee individuals' prosperity. Recently, many environmental professionals have begun concentrating efforts on risk-based approaches to remediate the petroleum-contaminated site.

Despite surface water contamination, Groundwater contamination is a more complicated problem due to its late detection and higher skills required for its prediction (Nwankwoala, 2017), an investigation of the extent of the impact. Powerful tidy up and remediation of these sullied locales in the Niger Delta must be accomplished with adequate information. Of the site explicit variables required to be distinguished are topography, nature of the contaminant, pathway receptors linkages, poisonousness levels and organization of proper defilement the executives strategies and enactment (Logeshwaran et al., 2018).

Oil spills are common environmental issues prevalent in the Niger Delta region. These spills could occur in many ways, including; drilling operations, production operations, transportation of crude oil, and storage facilities. A major cause of oil spill in the Delta arises from pipeline vandalization and illegal bunkering activities. Oil spills on the environment eventually lead to soil and groundwater contamination, with a hugely deleterious effect on plants, human health, and wildlife. There was a spill incident in the Bonny area that occurred from a company's facility during the first quarter of 2017. Hence, this risk assessment study was conducted to determine the aerial extent of the spill, the volume of the spill, and the health implication on the residents in the area.

The aim of the research, therefore, is to assess groundwater quality around an oil spill site in Bonny, Rivers State to determine the concentration of total petroleum hydrocarbon (TPH), Polyaromatic hydrocarbon (PAH), and volatile compounds (BTEX) in groundwater as well as evaluate the results obtained and compliance with regulatory guidelines.

1.1. Location and accessibility

The study area, Ubani and its environs, is located in Bonny Island within latitudes 4º25'00" N and 4º26'40" N and longitudes 7º09'20" E and 7º12'00" E (Fig. 1). The North and Western part of the study area is bounded by Bonny River, to the South of the site is Bonny oil and gas terminal owned and operated by SPDC, while to the East of the area is the Federal Polytechnic of oil and gas, Bonny. Several swamps and creeks are predominant within the study area. The site is assessable through Bonny River and other tarred roads in the area.

1.2. Relief and drainage

The relief is generally lowland, which has an average elevation of 0m to 20 m above sea level (Eludoyin et al., 2012). Due to the complicated network of rivers and their discharge patterns, many morphological units are formed. These units are Sombreiro-Warri Deltaic Plain; freshwater back swamps, Dry flat land, and plain; saltwater or mangrove swamp and active/abandoned coastal beaches. Bonny Island exists in the dynamic/deserted seaside seashores (Akpokodje, 1987). The dirt in the territory, usually in sandy or sandy soil, is underlain by a layer of the impenetrable skillet and is continuously drained because of the substantial precipitation experienced in the region. The zone is very much depleted with both new and saltwater (Eludoyin et al., 2012).

1.3. Climate and vegetation

The examination zone appreciates the tropical hot rainstorm atmosphere because of its latitudinal position described by overwhelming precipitation extending from 2000 mm to 2500 mm from April to October.

Temperature is high all the year and a moderately steady high mugginess (Eludoyin et al., 2012). The average yearly temperature is 26.7 °C in Bonny (Ohwoghere-Asuma and Essi, 2017). About 85% of the mean annual rainfall occurs in the wet season, thereby causing the widespread occurrence of floods. The territory's primary vegetation type is the mangrove backwoods, which involves a large portion of the Niger Delta (Levin, 2016). The other vegetation type is optional vegetation that possesses a little territory. The mangrove swamp timberland encircles the auxiliary vegetation. The predominant vegetation front of the investigation region incorporates thick mangrove woodland, raffia palms, and light downpour timberland.

1.4. Geology of the area

The study area falls within the Niger Delta sedimentary basin. The basin architecture, structural configuration, tectonic elements, transgressive and regressive phases, basin fill, and petroleum systems have been studied enormously by various workers (Chukwu et al., 2018; Edegbai et al., 2019; Espurt et al., 2018). The geology of the area contains Quaternary deposits, which overlies the Tertiary sands and clayey sediments. Stratigraphically, the basin consists of three formations (Akata Formation, Agbada Formation, and Benin Formation) (Chukwu et al., 2018). These formations are now referred to as 'Groups' and are called Akata Group, Agbada Group, and Benin Group. The geography of the Bonny region involves fundamentally of alluvial sedimentary bowl and cellar complex (Fig. 2).

1.5. Hydrogeology

Bonny Island falls within the Beach ridges on-shore geomorphic sub-environment of the Delta. In the area, the hydrogeology is influenced to ferruginous sandy formation due to the vicinity surface aquifers' oxidation condition and dominant saline water intrusion (Machiwal et al., 2019; Ohwoghere-Asuma and Essi, 2017). The sand and clay form the principal aquifer and aquitard in the area, respectively. Also, the water table varies during the seasons. So that water table decreases in the dry season. By and large, the water table in the zone is dynamic and ranges between 0.1–3 m relying upon the season (Ohwoghere-Asuma et al., 2017). A few networks in Bonny Island are confronting an intense deficiency of consumable water because of high iron-water, saltwater interruption, and tidal impact. Thus, numerous boreholes have been surrendered in the territory(Nwankwoala and Udom, 2010).

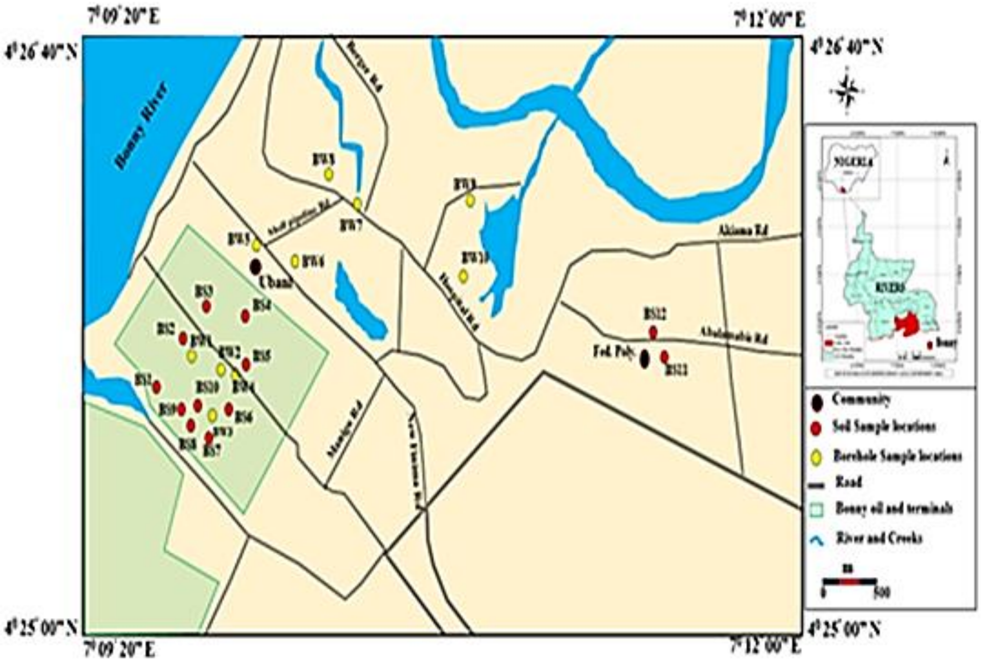

Fig. 1. Map of the study area showing soil and groundwater sampling locations in Bonny.

2. Materials and Methods

2.1. Groundwater sampling

Groundwater samples are obtained from six wells and four monitor boreholes in the study area (Table 1). Four samples were obtained from the spill site, while six samples were obtained from the surrounding communities away from the spill site. The groundwater samples were collected in pre-cleaned plastic bottles, Which were carefully labeled with marker pens. Before the sampling commencement, the water samples were used to wash the sample bottles before being filled to the brim with the sample water and corked tightly. At the spill site, the groundwater was sampled from drilled open holes. A sample container was tied to the end of a rope and lowered down into the hole to obtain laboratory analysis samples. At other sample locations, the pump was switched on for over 5 min, and the groundwater pumped out to allow any dissolved minerals to flow out of the well and pipes before samples for analysis was obtained. The groundwater was also described in terms of color, smell, and appearance. The samples were later transported to the laboratory for chemical analysis of TPH, PAH, and BTEX compounds. In many locations, groundwater could not be sampled because the wells were completely dry.

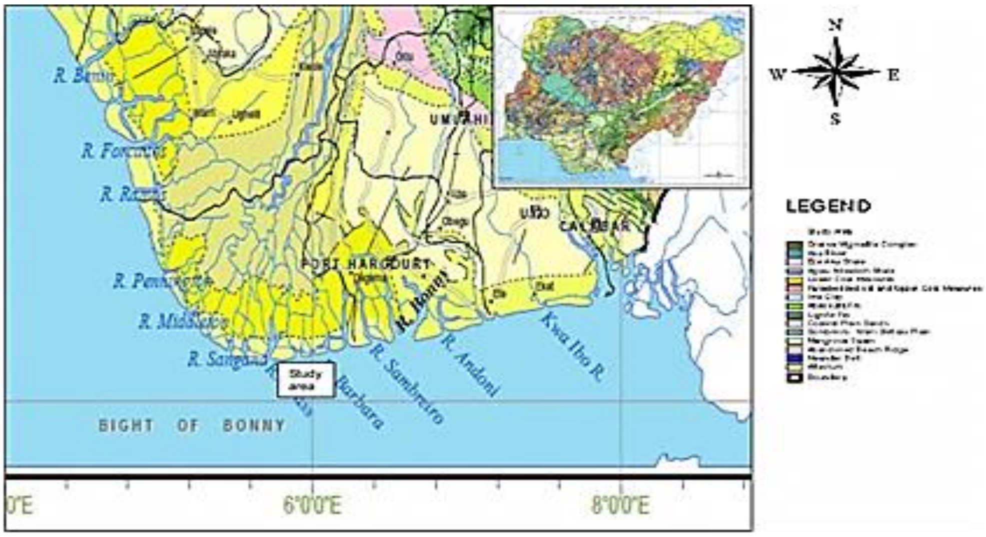

Fig. 2. Geologic map of the study area.

Table 1. Groundwater sample locations in the study area.

S/N	Code	Location	Longitude	Latitude	Type of sample
13	BW-1	Bonny oil and gas terminal	7° 9'36.74" E	4°25'44.48" N	Groundwater
14	BW-2	Bonny oil and gas terminal	7° 9'42.45" E	4°25'44.98" N	Groundwater
15	BW-3	Bonny oil and gas terminal	7° 9'42.42" E	4°25'37.04" N	Groundwater
16	BW-4	Bonny oil and gas terminal	7° 9'49.68" E	4°25'44.33" N	Groundwater
17	BW-5	Residential area, Ubani, Bonny	7° 9'55.38" E	4°26'04.68" N	Groundwater
18	BW-6	Residential area, Ubani, Bonny	7°10'06.18" E	4°26'02.57" N	Groundwater
19	BW-7	Bonny Govt. School	7°11'22.41" E	4°25'48.34" N	Groundwater
20	BW-8	Residential area, Ubani, Bonny	7°11'30.82" E	4°25'42.17" N	Groundwater
21	BW-9	Residential area, Bonny	7°11'13.13" E	4°25'48.76" N	Groundwater
22	BW-10	Residential area, Bonny	7°11'19.44" E	4°25'43.99" N	Groundwater

2.2. Determination of flow direction

The groundwater flow direction was determined with the aid of a water level meter. The water level meter was lowered into the open wells to be sampled, and as soon as the metal electrode makes contact with water, a sound is made, and the equivalent depth is recorded as the water table elevation. Similarly, a GPS is placed on the ground at the okay location in order to determine the ground surface elevation. The difference between the water table elevation and the ground surface elevation gives the static water level. Only five wells were utilized for the determination of flow direction. This is because the boreholes in other locations were cased, and it was not possible to be used for flow direction determination. The wells used for flow direction determination were located within the oil spill site.

3. Results and Discussion

The results of physical observation of groundwater samples (based on turbidity, odor, and appearance) were obtained from the spill site (Table 2). Results of geochemical analysis of groundwater samples on the basis of contaminants of concern (TPH, BTEX and PAH) according to Table 3. The results were compared with DPR (Prideaux and Prideaux, 2016) target and intervention recommended limits for safe drinking water. The TPH concentration in the area is presented graphically (Fig. 3). The map showing the spatial variations in TPH concentration across the entire spill area is presented in Fig.4. The result of groundwater flow direction determination is presented in Table 5, while Fig. 5 is a map showing the direction of groundwater movement.

3.1. Physical description of groundwater

The groundwater samples obtained from BW-1, BW-2, BW-3, and BW-4 are all turbid and have weak hydrocarbon smell (Table 2). BW-1 has a delicate sheen appearance; BW-2 and BW-4 have moderate sheen appearance while BW-3 shows a free hydrocarbon phase. This is strong evidence of groundwater contamination from the current spill incident that occurred in the area. The groundwater sample from BW-5 is slightly turbid and has no hydrocarbon smell or sheen.

Table 2. Results of physical observation of groundwater samples in the area.

Sample ID	Color	Physical Observation
BW-1	Turbid	Weak hydrocarbon smell, Light sheen
BW-2	Turbid	Weak hydrocarbon smell, moderate sheen
BW-3	Turbid	Weak hydrocarbon smell, Free Phase
BW-4	Turbid	Weak hydrocarbon smell, moderate sheen
BW-5	Slightly turbid	No hydrocarbon smell, No sheen
BW-6	Clear	Weak hydrocarbon smell, No sheen
BW-7	Clear	No hydrocarbon smell, No sheen
BW-8	Clear	No hydrocarbon smell, No sheen
BW-9	Slightly turbid	No hydrocarbon smell, No sheen
BW-10	Clear	No hydrocarbon smell, No sheen

3.2. Contaminants of Concern in Groundwater

The concentration of TPH in groundwater from the spill area ranges from 9.04 to 20600 μg/L with a mean and SD of 2526.90 ± 6392.40 μg/L (Table 3). These values are all higher than the DPR target, and intervention recommended values of 50 and 600μg/L, for safe discharge from industries into the groundwater system. The average TPH concentration exceeded the DPR target value over 50 times, and the DPR intervention value by over four times. The result of this study is in agreement with the values obtained by some works (Logeshwaran et al., 2018; Nwankwoala, 2017). The highest TPH concentration was recorded from BW-3, which is at the Bonny oil terminal, while the lowest TPH was recorded from BW-9, which is at a residential area in Bonny. Fig. 3 shows all the boreholes that exceeded the DPR target and intervention values. The map of TPH distribution in the study area shows that boreholes situated at the south-western axis are the most deteriorated (BW1, BW-2, BW-3, BW-4), with BW-3 being the most corrupted. The maximum TPH concentration obtained from this study is lower than those obtained in a similar survey in Eleme (485,000 μg/L) (Fig. 4).

The total PAH concentration in groundwater from the study area ranges from 0.13 to 1.07 μg/L with a mean and SD of 0.37 ± 0.48 μg/L. PAH was recorded only for BW-1 (0.13 μg/L), BW-3 (1.07 μg/L), and BW-4 (0.25 μg/L). All other boreholes had PAH concentrations below the detectable instrument limit of < 0.01 μg/L. The

Water samples from BW-3 and BW-4 exceeded the DPR target value of 0.15 μg/L, but are within the intervention limits of 81.5 μg/L.

The BTEX group of compounds were recorded only at BW-3 as follows; Benzene (660 μg/L), Toluene (800 μg/L), Ethylbenzene (250 μg/L), m,p-xylene (160 μg/L), and o-xylene (4040 μg/L). These values all exceeded DPR target values of 0.2, 0.2, 0.05, 0.2, and 0.2 μg/L respectively. The following parameters also exceeded the DPR intervention limits; Benzene (DPR intervention value is 30 μg/L), Ethylbenzene (150 μg/L), m & P-xylene (70 μg/L), and o-xylene (70 μg/L). Only Toluene had a value that was within the DPR intervention limit of 1000 μg/L. At all other locations, BTEX compounds were below the detectable limit of the instrument (< 0.01 μg/L). This result, therefore, shows that BW-3 has the most deteriorated water quality. This is not surprising because BW-3 is situated at the spill site (Bonny oil terminal). Apart from BW-1, BW-2, BW-3, and BW-4, all other sampled boreholes all lie within the residential areas.

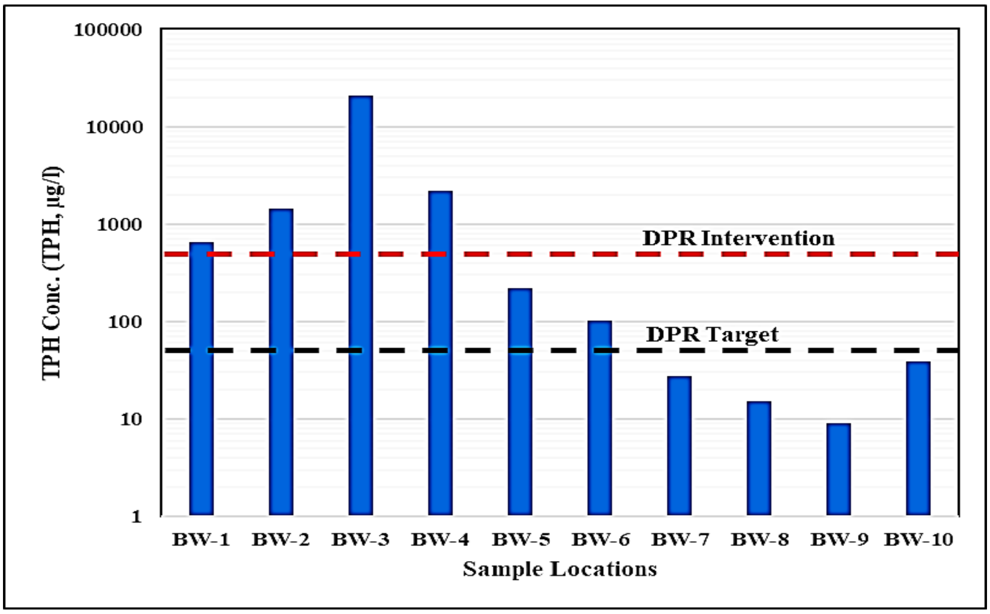

Fig. 3. TPH concentration in the study area compared with regulatory guidelines.

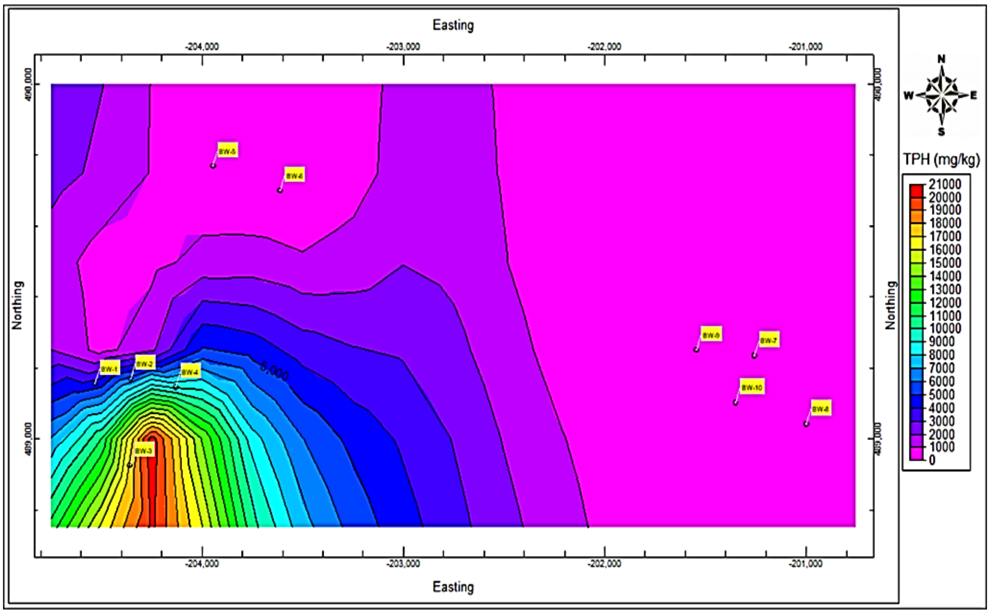

Fig. 4. Map showing the spatial variation of TPH across the study area.

Table 3. Results of groundwater quality analysis in the study area.

Sample ID	BW-1	BW-2	BW-3	BW-4	BW-5	BW-6	BW-7	BW-8	BW-9	BW-10	DPR Target Value (µg/l)	DPR Intervention Value (µg/l)
TPH (µg/l)	650.9	1430.21	20600	2174	221.32	102.39	27.32	15.33	9.04	38.45	50	600
PAH (µg/l)											0.15	81.5
Naphthalene	< 0.10	< 0.1	0.23	< 10	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1		
Acenaphthylene	< 0.10	< 0.10	0.02	0.10	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1		
Acenaphthene	< 0.10	< 0.10	< 0.10	< 0.10	< 0.10	< 0.10	< 0.10	< 0.10	< 0.10	< 0.10		
Fluorene	< 0.10	< 0.10	< 0.10	< 0.10	< 0.10	< 0.10	< 0.10	< 0.10	< 0.10	< 0.10		
Anthracene	0.03	< 0.10	0.27	< 10.00	< 0.10	< 0.10	< 0.10	< 0.10	< 0.10	< 0.10		
Phenanthrene	< 0.10	< 0.10	< 10.00	< 10.00	< 0.10	< 0.10	< 0.10	< 0.10	< 0.10	< 0.10		
Fluoranthene	< 0.10	< 0.10	< 10.00	< 10.00	< 0.10	< 0.10	< 0.10	< 0.10	< 0.10	< 0.10		
Pyrene	< 0.10	< 0.10	0.09	0.10	< 0.10	< 0.10	< 0.10	< 0.10	< 0.10	< 0.10		
Benzo[a]anthracene	< 0.10	< 0.10	< 0.10	< 0.10	< 0.10	< 0.10	< 0.10	< 0.10	< 0.10	< 0.10		
Chrysene	< 0.10	< 0.10	< 0.10	< 0.10	< 0.10	< 0.10	< 0.10	< 0.10	< 0.10	< 0.10		
benzo(b)fluoranthene	0.10	< 0.10	0.43	0.04	< 0.10	< 0.10	< 0.10	< 0.10	< 0.10	< 0.10		
Benzo(k) fluoranthene	< 0.10	< 0.10	< 0.10	< 0.10	< 0.10	< 0.10	< 0.10	< 0.10	< 0.10	< 0.10		
Benzo(a)pyrene	< 0.10	< 0.10	0.03	0.01	< 0.10	< 0.10	< 0.10	< 0.10	< 0.10	< 0.10		
Dibenz(a,h)anthracene	< 0.10	< 0.10	< 0.10	< 0.10	< 0.10	< 0.10	< 0.10	< 0.10	< 0.10	< 0.10		
Indeno[1,2,3-cd]pyrene	< 0.10	< 0.10	< 0.10	< 0.10	< 0.10	< 0.10	< 0.10	< 0.10	< 0.10	< 0.10		
Benzo(g,h,i)perylene	< 0.10	< 0.10	< 0.10	< 0.10	< 0.10	< 0.10	< 0.10	< 0.10	< 0.10	< 0.10		
Total	0.13	< 0.10	1.07	0.25	< 0.10	< 0.10	< 0.10	< 0.10	< 0.10	< 0.10		
BTEX (µg/l)											0.80	1250.00
Benzene	ND	ND	660	ND	ND	ND	ND	ND	ND	ND	0.20	30.00
Toluene	ND	ND	800	ND	ND	ND	ND	ND	ND	ND	0.20	1000.00
Ethylbenzene	ND	ND	250	ND	ND	ND	ND	ND	ND	ND	0.05	150.00
M & p-xylene	ND	ND	160	ND	ND	ND	ND	ND	ND	ND		
o-Xylene	ND	ND	4040	ND	ND	ND	ND	ND	ND	ND	0.20	70.00
Total	ND	ND	5910	ND	ND	ND	ND	ND	ND	ND		

3.3. Groundwater flow direction

The hydraulic head utilized for groundwater flow direction determination was calculated as the difference between the surface elevation and the static water level. The surface elevation ranged from 4.8m to 7.8m, while the static water level ranged from 4.16m to 4.74m. The shallow water levels are to be expected since the study area (Bonny Island) is located at the coastal boundary. The hydraulic head ranges from 0.55 to 3.16 m, with the highest head at BW-10 and the lowest hydraulic head at BW-1. Groundwater flows from higher head to lower head. Hence, the groundwater flow is from the eastern part of the study area to the southeastern part of the study area (Fig. 4). Therefore, the high concentration of contaminants found in BW-1, BW-2, BW-3, and BS-4 are not likely to be transported to BW-5, BW-6, BW-7, and BW-8, BW-9, and BW-10. This is because these boreholes are situated at a higher flow gradient. All contaminants in the groundwater from BW-1, BW-2, BW-3, and BW-4 will be transported into the Bonny River which is situated in the southeastern part of the study area.

Table 4. Statistical summary of groundwater quality analysis in the area.

Chemical parameter	Unit	Min	Max	Mean	S.D.	DPR target value	DPR Intervention Value
TPH	μg/L	9.04	20600	2526.90	6392.40	50.00	600.00
PAH (μg/l)	μg/L	0.13	1.07	0.37	0.48	0.15	81.50
Benzene	μg/L	N.D.	660.00	-	-	0.20	30.00
Toluene	μg/L	N.D.	800.00	-	-	0.20	1000.00
Ethylbenzene	μg/L	N.D.	250.00	-	-	0.05	150.00
M & p-xylene	μg/L	N.D.	160.00	-	-	0.00	70.00
o-Xylene	μg/L	N.D.	4040.00	-	-	0.20	70.00

Table 5. Results of groundwater flow direction determination.

Sample ID	Surface Elevation (MASL)	Static Water Level (mbgl)	Hydraulic head (m)
BW-1	4.81	4.26	0.55
BW-2	4.85	4.19	0.66
BW-3	4.83	4.23	0.60
BW-4	4.83	4.16	0.67
BW-5	6.10	4.30	1.80
BW-6	5.56	3.87	1.69
BW-7	6.60	4.54	2.06
BW-8	7.84	4.74	3.10
BW-9	7.22	4.29	2.93
BW-10	7.32	4.16	3.16

4. Conclusions

The concentration of TPH in groundwater obtained from BW-1, BW-2, BW-3, BW-4, BW-5, and BW-6 all exceeded the DPR target value of 50 μg/L. Again, BW-1, BW-2, BW-3, and BW-4 all exceeded the DPR intervention value of 600 μg/L. Amongst all the boreholes, BW-3 has the highest TPH, which exceeded the DPR target value over 412 times. BW-1, BW-2, BW-3, and BW-4 are boreholes situated in the oil tank farm and are not utilized for drinking, but experimental work. The PAH concentration in BW-3 and BW-4 exceeded the DPR target value of 0.15 μg/L. Meanwhile, BTEX compounds were recorded only in BW-3 at very high concentrations. This is no serious alarm for the surrounding residents because the groundwater flow direction was towards the southeastern part of the study area, the Bonny River. Groundwater quality within the tank farm and Ubani area are contaminated with TPH and should not be consumed to avoid health implications. The communities situated at the North, Northeast, and eastern part of the site should not be concerned with Possible groundwater contamination from the spill incident because the groundwater movement is towards the southeastern part of the study area (i.e., towards Bonny River). Government agencies and other relevant stakeholders should urgently take proactive steps to review applicable legislation, enforcement, and pollution management processes to protect groundwater resources.

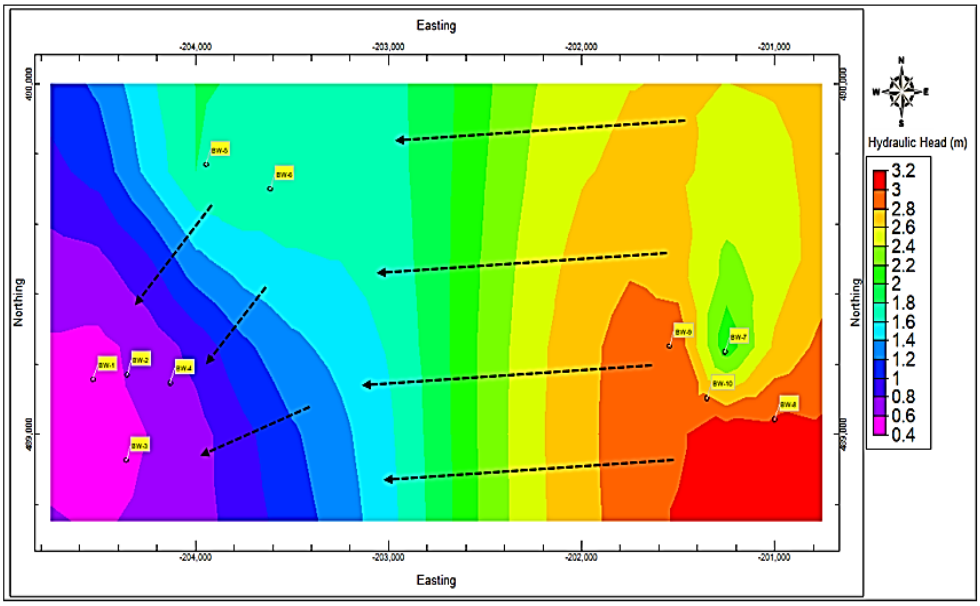

Fig. 5. Map showing the groundwater flow direction across the study area (Arrows indicative of flow direction).

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