

Monitoring of soil and groundwater contamination following a pipeline explosion and petroleum product spillage in Ijegan, Lagos Nigeria

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Abstract In May 2008, an accidental damage of a Nigerian National Petroleum Corporation (NNPC) pipeline occurred in Ijegan area of Lagos, Nigeria, resulting in oil spillage and consequent contamination of the environment. The residual concentration of the total hydrocarbon (THC) and benzene, toluene, ethylbenzene, and xylene (BTEX) in the groundwater and soil was therefore investigated between March 2009 and July 2010. Results showed elevated THC mean levels in groundwater which were above the World Health Organization maximum admissible value of 0.1 mg/l. THC values as high as 757.97 mg/l in groundwater and 402.52 mg/l in soil were observed in March 2009. Pronounced seasonal variation in the concentration of THC in groundwater and soil samples show that there was significant ($P < 0.05$) difference in the measured concentration of THC between each season (dry and wet), with the highest being in the dry season and between the years 2009 and 2010.

Significant hydrocarbon contamination, 500 m beyond the explosion site and 25 months after the incident, was observed revealing the extent of the spillage of petroleum products. The highest concentrations of 16.65 $\mu\text{g/l}$ (benzene), 2.08 $\mu\text{g/l}$ (toluene), and 4864.79 $\mu\text{g/l}$ (xylene) were found in stations within the 100 m buffer zone. Most of the samples of groundwater taken were above the target value of 0.2 $\mu\text{g/l}$ set for BTEX compounds by the Environmental Guidelines and Standards for Petroleum Industry in Nigeria. The level of hydrocarbon in the impacted area calls for concern and remediation of the area is urgently needed to reduce further negative impact on the ecosystem.

Keywords Pipeline · Groundwater · Soil · Contamination · Petroleum products

Introduction

In recent years, there has been increasing concern over the contamination of groundwater by petroleum products and other contaminants as a result of pipeline leakage. The petroleum products will pollute groundwater including well water used for domestic purposes. Nigeria has a wide pipeline network and depots for distributing refined petroleum products (Renner et al. 2008). The widespread distribution of petroleum products arising from the rapid growth of the petroleum industry in Nigeria has resulted in the pollution of the environment through oil spills involving leakage from

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tankers, pipelines, tank farms, and dumping of waste petroleum products (Adeniyi and Afolabi 2002).

In May 2008, a pipeline explosion occurred in Ijegun, a suburb in Lagos, when construction workers accidentally damaged Nigerian National Petroleum Corporation (NNPC) Mosimi–Atlas cove system 2B pipeline carrying petroleum products. The spill resulted in contamination of the groundwater including wells, by the dissolved gasoline components, such as benzene, toluene, ethylbenzene, and xylene and raised concern over exposure of residents using this water. The explosion also led to a fire disaster causing loss of lives and properties along the pipeline right of way (ROW).

Underground and aboveground pipelines transport large quantities of crude oil and refined fuels, particularly diesel, gasoline, and heavy fuel oil. Consequently, these pipelines are subject to inadvertent damage. There is usually major public concern expressed following pipeline accidents, in many parts of the world. This is due to the fact that pipelines run through a large number of local communities so that repercussions and public interest are not inherently restricted to the area where the accident happens (Papadakis et al. 1999). According to Olivera-Villaseñor and Rodriguez (2005), for the pipelines built between 1970 and 1995 in Europe, there were 500 incidents, with 3,000 people injured and 2,000 deaths in 97 countries. From these incidents, 53 % were reported in natural gas pipelines, 18 % with liquefied petroleum gas, 17 % with crude oil, and 7 % with gasoline. In the case of Nigeria, the situation is not much better. Nigeria recorded a total number of 2,097 oil spill incidents between 1997 and 2001. In 2005, 117 cases of fire outbreaks were recorded as a result of pipeline vandalization and rupture of NNPC pipelines (Renner et al. 2008). The rupture and explosion of the NNPC high-pressure pipeline carrying gasoline from the Warri Refinery in Southern Nigeria to Kaduna in Northern Nigeria on October 17, 1998, killed 1,078 people, induced \$54 million in property damages and devastated 12 km² of land (Sovacool 2008).

The most toxic component of petroleum is typically the aromatic fraction, benzene, toluene, ethylbenzene, and xylene (BTEX) which have higher water solubility. One of the most common sources of BTEX contamination in soil and groundwater is spills involving the release of petroleum products such as gasoline, diesel, lubricating, and heating oil from leaking oil tanks.

Groundwater is a reliable source of water supply because it is often unpolluted due to restricted movement of pollutants in the soil profile. However, shallow and permeable water table aquifers are most susceptible to contamination (Adejuwon and Mbuk 2011).

The Ijegun's aquifer is a crucial resource upon which the community depends for potable and domestic supplies. However, the sustainability of this resource is under threat due to the significant soil and groundwater contamination from petroleum product spillage. There is need to conduct an environmental monitoring of the impacted area of Ijegun contaminated by petroleum products. As there is no detailed study available regarding the assessment of the groundwater quality and spatial distribution of hydrocarbon of the study area after the explosion, the objective of this study was therefore to investigate and assess the residual contamination of total hydrocarbon content (THC) and BTEX compounds in the groundwater and soil after the pipeline explosion in Ijegun, Lagos. This will assist the regulatory agencies in determining the level of remediation the impacted area may require over time.

Materials and methods

Description of study site

Ijegun is located in the suburb area of Alimosho LGA, Lagos Nigeria with a population of close to a million people. It is bordered by Ijagemo and Ijedodo in the south, Isheri-Osun, Oke-rube in the west, and Abaranje in the east of Alimosho local government. It lies between longitude 3° 4.0' east and latitude 6° 28.8' and 6° 8.0' north (Fig. 2). The climate is characterized by two distinct seasons (wet and dry). Temperatures range from 28–33 °C.

Hydrogeology of the study area

Lagos State is basically a sedimentary area located within the western part of Nigeria, a zone of coastal creek and lagoon (Elueze and Nton 2004). The area is also developed by barrier beaches associated with sand deposits. The subsurface geology reveals two basic lithologies: clay and sand deposits. These deposits may be interbedded in places with sandy clay or clayed sand and occasionally with vegetable remains and peat.

The water-bearing strata of Lagos State consist of sand, gravel, or admixtures from fine through medium to coarse sand gravel (Adeleye 1975). Basically, there are four major aquiferous units that are being tapped for the purpose of water supply in the Lagos metropolis. The first aquifer extends from the ground level to roughly 12 m below the ground layers of clay and sand. This aquifer is prone to contamination because of its limited depth. The second aquifer is encountered between 20 and 100 m below sea level. The third aquifer is encountered in the central part of Lagos at a depth ranging from 130 to 160 m below the sea level. The fourth aquifer is located at an elevation of approximately 450 m below the sea level. Only few boreholes tap water from this aquifer (Jones and Hockey 1964). The hydrogeology of the study area falls within the first and second aquifer described above.

Sampling design

The impacted area around the pipeline ROW was divided into nine buffer zones (20 sampling stations) ranging from 50 m to beyond 500 m distance (buffer zones) away from the pipeline point of explosion in an attempt to establish a pollution gradient as shown in Table 1 and Fig. 1. The sampling station at Ijagemo served as the reference station. Timing of sampling was dictated by the two hydrological seasons (wet and dry)

Table 1 Sampling stations divided into buffer zones (distances away from the explosion point)

Buffer zones (distance away from explosion point)	Sampling stations
50 m buffer zone	S4, S8
100 m buffer zone	S3, W2, W3, W5
150 m buffer zone	S5, S9, S1, W18
200 m buffer zone	S12, S16, S10, S13, W9, W6, W4
250 m buffer zone	S6, W7, W13
300 m buffer zone	S7, S11, W8, W10
400 m buffer zone	W14, W12, W16, W17
500 m buffer zone	S17, W11, W15
Beyond 500 m buffer zone	S2, S14, S15, S18, W1, W19
Control	S19, W20

W groundwater, S soil

prevalent in the tropics which also bring about significant differences in the physicochemical conditions of the groundwater. Samples of contaminated groundwater and soil were taken over a 2-year period (two wet and two dry seasons) and investigated for total hydrocarbon content and BTEX compounds following the schedule: dry season sampling, 1–6 March 2009; wet season sampling, 15–20 July 2009; dry season sampling, 1–6 March 2010; wet season sampling, 15–20 July 2010. The global positioning system was used to measure the longitude, latitude, and the surface elevations of the sampling locations (Tables 2 and 3).

Sampling procedures

Collection of soil

Nineteen soil samples were collected around the impacted area of Ijegun and Ijagemo reference station (S19; 1.5 km from Ijegun) in replicates using a soil auger. The auger was plunged into the ground and the handle turned to collect soil at 0–15 cm. The latter step was repeated to collect soil from 15 to 30 cm. Both depths were composited into one sample. The soil samples collected were packed, labeled, and preserved for onward transmission to the laboratory in the University of Lagos for subsequent analysis within 24 h.

Collection of ground water

Twenty groundwater samples were collected in replicates from 20 sampling locations around the impacted area of Ijegun and Ijagemo reference station (W20; 1.5 km from Ijegun) using random sampling technique. The depth of the wells was determined using graduated steel tape method. Existing water wells and boreholes were sampled, kept, and preserved for analysis in the laboratory. The same wells and boreholes were sampled continuously over a period of 2 years covering two dry and two wet seasons. Samples were collected in 1.5-l plastic bottles for heavy metals and amber bottles for THC and glass vial with Teflon-lined septum for BTEX, after rinsing with the water being sampled and were properly sealed. The samples were collected after the extraction of water either from a hand pump or a tube well.

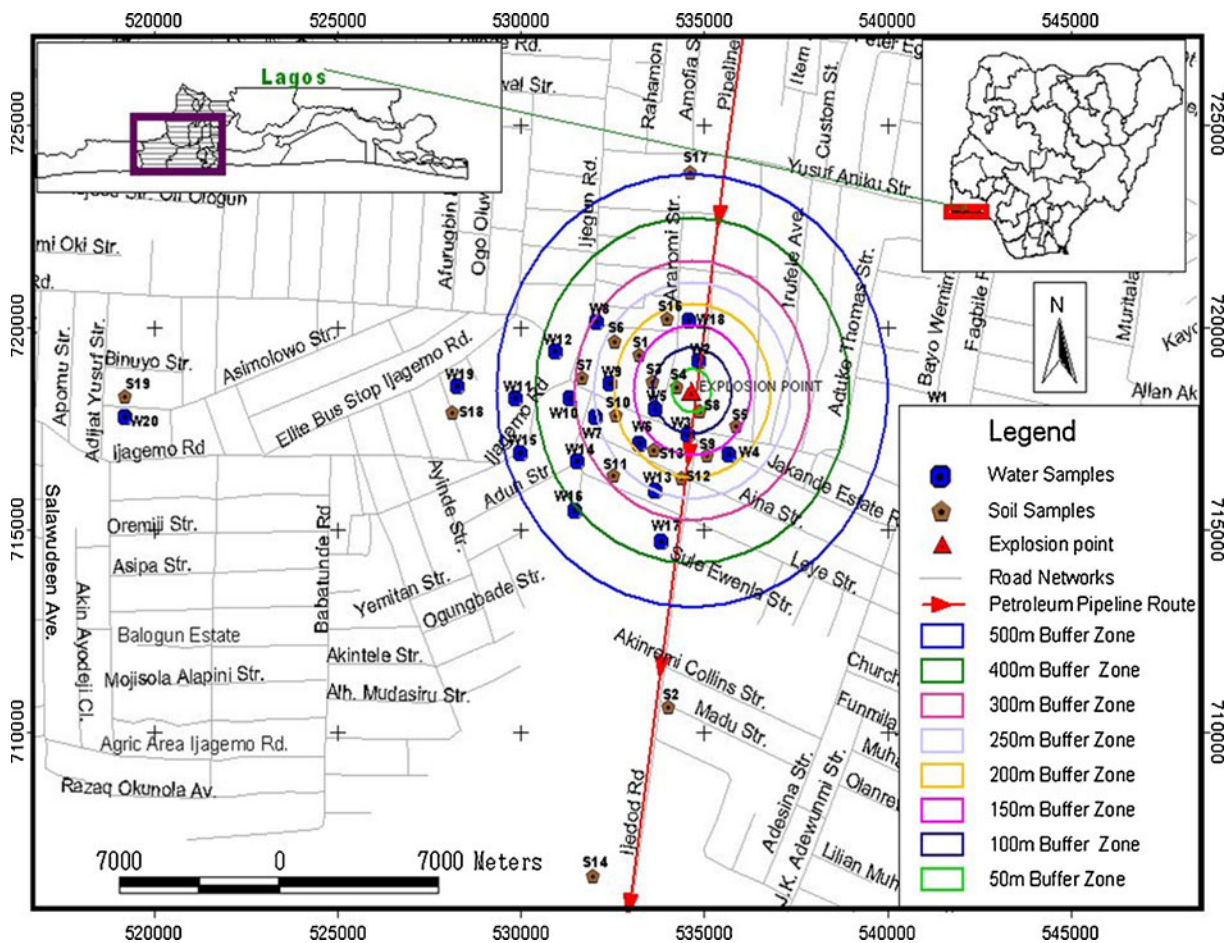


Fig. 1 Map of oil explosion impacted area of Ijegan, Lagos STATE, showing the sampled stations

Samples were properly labeled and stored in insulated coolers containing ice cubes at 2–6 °C and were transferred to the laboratory, University of Lagos for analysis within 24 h. Sampling, preservation, and transportation of water samples were carried out under standard method (APHA 1998).

Sample analysis

All the samples were analyzed for relevant physico-chemical parameters according to internationally accepted procedures and standard methods (APHA 1998). The parameters analyzed in the groundwater samples include pH, conductivity, total dissolved solids (TDS), zinc, nickel, and lead. The concentrations of heavy metals were determined using an atomic absorption spectrophotometer. pH was determined on site using a pH meter (Kahl Scientific Instrument

model II 4 W13) calibrated with freshly prepared buffer solutions (pH4, 7, and 9).

Determination of THC and BTEX compounds

Analysis was carried out for THC and BTEX using the ASTM D 2887-93 and US EPA 1664 methods (ASTM 1997). Samples were analyzed on Agilent 4890D gas chromatograph/ flame ionization detector already calibrated.

Quality assurance

Appropriate quality assurance procedures and precautions were taken to ensure the reliability of the results. Samples were carefully handled to avoid contamination. Appropriate sample preservation/labeling were ensured. All glassware was properly cleaned and reagents were

Table 2 Coordinates of soil sampling locations in Ijegun, Lagos

Code	Latitude	Longitude	Northing	Easting
S1	6.516717	3.259633	720,331.5	528,705.3
S2	6.509850	3.259850	719,572.4	528,729.7
S3	6.516333	3.259567	720,289.1	528,698.0
S4	6.516100	3.259733	720,263.3	528,716.4
S5	6.516067	3.260700	720,259.7	528,823.3
S6	6.516850	3.258650	720,346.2	528,596.6
S7	6.516733	3.257867	720,333.2	528,510.1
S8	6.516000	3.259667	720,252.3	528,709.1
S9	6.515100	3.260733	720,152.8	528,827.0
S10	6.515950	3.258633	720,246.7	528,594.8
S11	6.515017	3.258833	720,143.5	528,617.0
S12	6.514983	3.258967	720,139.8	528,631.8
S13	6.515250	3.259183	720,169.3	528,655.6
S14	6.506333	3.258100	719,183.5	528,536.4
S15	6.501100	3.257367	718,605.0	528,455.7
S16	6.517950	3.259833	720,467.8	528,727.4
S17	6.521000	3.260350	720,805.0	528,784.3
S18	6.516000	3.254883	720,252.0	528,180.2
S19	6.516100	3.247233	720,262.6	527,334.4

Table 3 Coordinates of groundwater sampling locations in Ijegun, Lagos

Code	Latitude	Longitude	Northing	Easting	Elevation
W1	6.515967	3.265967	720,249.0	529,405.7	59
W2	6.516750	3.258833	720,335.1	528,616.9	52
W3	6.515133	3.259850	720,156.4	528,729.4	48
W4	6.515167	3.260633	720,160.2	528,816.0	55
W5	6.515667	3.259233	720,215.4	528,661.2	47
W6	6.515333	3.259167	720,178.5	528,653.9	44
W7	6.515883	3.258167	720,239.2	528,543.3	38
W8	6.516100	3.257950	720,263.2	528,519.3	37
W9	6.516067	3.257833	720,259.6	528,506.3	35
W10	6.516283	3.257583	720,283.4	528,478.7	38
W11	6.516450	3.257167	720,301.9	528,432.7	44
W12	6.516583	3.257283	720,316.6	528,445.5	45
W13	6.515367	3.258250	720,182.2	528,552.5	33
W14	6.515567	3.258017	720,204.3	528,526.7	33
W15	6.515567	3.257967	720,204.3	528,521.2	32
W16	6.514533	3.258450	720,090.0	528,574.6	23
W17	6.514200	3.259117	720,053.3	528,648.4	32
W18	6.517900	3.260333	720,462.3	528,782.6	132
W19	6.515917	3.255233	720,242.8	528,218.9	60
W20	6.515900	3.247317	720,240.5	527,343.7	41

Table 4 Physicochemical parameters measured in the groundwater samples in Ijegun in year2009

Parameters	Buffer Zones								WHO	
	100 m	150 m	200 m	250 m	300 m	400 m	500 m	B500m		Control
pH	6.99±0.49	7.31±0.34	7.46±0.27	7.14±0.34	6.62±0.29	6.72±0.69	6.32±0.37	6.73±0.92	7.38±0.95	6.5–8.5
Conductivity (µS/cm)	202.00±154.50	224.50±21.29	433.67±34.65	384.00±110.31	330.00±62.23	360.00±66.53	336.00±52.33	721.00±59.4	421.00±20.44	500.00
TDS (mg/l)	110.30±84.91	123.50±10.61	226.00±27.5	211.00±60.81	161.50±28.99	196.3±36.85	184.50±28.90	396.50±33.23	420.00±34.27	500.0
Nickel (mg/l)	0.15±0.06	0.19±0.12	0.12±0.02	0.09±0.02	0.07±0.09	0.06±0.06	0.01±0.00	0.15±0.01	ND	0.07
Lead (mg/l)	0.09±0.07	0.14±0.09	0.11±0.13	0.42±0.42	0.18±0.13	0.12±0.11	0.22±0.29	0.01±0.00	ND	0.01
Zinc (mg/l)	0.07±0.05	0.06±0.08	0.04±0.004	0.01±0.02	0.04±0.004	0.04±0.004	0.01±0.02	0.02±0.01	0.01±0.00	5.00

ND not detected

Table 5 Physicochemical parameters measured in the groundwater samples in Ijegun in 2010

Parameters	Buffer zones								WHO	
	100 m	150 m	200 m	250 m	300 m	400 m	500 m	B500m		Control
pH	6.50±0.32	7.39±0.57	7.17±0.35	7.48±0.04	6.81±0.71	6.52±0.21	6.68±0.44	7.01±0.48	7.51±0.89	6.5–8.5
Conductivity (µS/cm)	354.00±65.55	332.50±161.93	282.00±64.21	274.00±96.17	125.50±14.85	137.50±132.23	131.00±123.04	243.67±180.38	206.01±18.43	500.00
TDS (mg/l)	184.00±26.0	173.00±84.0	86.00±75.00	142.00±49.00	64.00±7.10	72.00±69.0	68.00±64.0	127.00±115.00	107±15.96	500.0
Nickel (mg/l)	0.01±0	0.01±0	ND	ND	ND	ND	ND	ND	ND	0.07
Lead (mg/l)	0.01±0	0.01±0	ND	ND	ND	ND	ND	ND	ND	0.01
Zinc (mg/l)	0.09±0	ND	ND	ND	ND	ND	ND	ND	ND	5.00

ND not detected

of analytical grades. Acid digestion was carried out for heavy metal analysis. Deionized water was used throughout the study. Reagent blank determinations were used to correct the instrument readings and repeated calibration of analytical equipment was done.

Results and discussion

Physicochemical parameters of Ijegan groundwater

The results of the physicochemical analysis of the groundwater samples are presented in Tables 4 and 5 showing the maximum permissible limits for drinking water as recommended by the World Health Organization (WHO). In the years 2009 and 2010, the pH, conductivity, TDS, and the level of zinc in groundwater from contaminated and control stations were within the WHO limit for drinking water (Tables 4 and 5). In the control station, nickel and lead were not detected in the groundwater while zinc was within the WHO limit in 2009. The level of nickel in the contaminated groundwater within the 100, 150, 200, 250, and beyond 500 m buffer zones in 2009 was higher than the WHO limit of 0.07 mg/l. The highest value of nickel, 0.19 mg/l in groundwater was observed within 150 m buffer zone. Osuji and Onojake (2004) reported high concentration of nickel in spilled oils from Niger Delta in Nigeria. The level of lead in groundwater sampled in all the buffer zones was higher than the WHO limit of 0.01 mg/l in 2009 except samples collected beyond

500 m (Table 4). Studies have shown that lead emitted to the environment is mainly associated with lead-rich petrol (Nganje et al. 2007). The presence of lead in the contaminated groundwater can be attributed to the leaded petrol which is still in use in Nigeria. Two years after the spill, in 2010, nickel, lead, and zinc were not detected in most of the buffer zones (Table 5). This suggests that degradation, dilution, and dispersion may have occasioned the significant reduction in the concentration of heavy metals.

Level of hydrocarbon in Ijegan groundwater

The concentration of THC measured in groundwater samples collected from the impacted areas of Ijegan is presented in Table 6. The THC concentrations observed in this study were above the WHO maximum admissible value of 0.1 mg/l for drinking water. THC values for year 2009 were higher than values for year 2010 (Table 6). In 2010, the mean concentrations of THC in groundwater in the 100 m buffer zones were lower than for year 2009, which was 13.29 and 5.97 mg/l for dry and wet seasons, respectively (Table 6). Thus, this inferred that most of the natural attenuation occurring may be attributed to dilution due to rainfall and dispersion by the facilitated groundwater flow. Degradation of petroleum hydrocarbon may have also occasioned the significant reduction in the concentration of hydrocarbon in 2010. The level of hydrocarbon in the control station was significantly lower than hydrocarbon in the contaminated sites (different buffer

Table 6 Mean concentration of THC in groundwater (milligrams per liter) samples collected from locations in buffer zones away from the explosion point in Ijegan (wet and dry seasons 2009 and 2010)

Groundwater	2009D	2009 W	2010D	2010 W
100 m	76.06±77.38	171.12±293.41	13.29±2.98	5.97±1.79
150 m	35.08±91.25	91.25±35.08	15.35±13.49	13.49±15.35
200 m	222.17±321.43	170.97±293.16	15.15±8.77	6.57±1.14
250 m	337.35±456.83	3.58±1.82	9.53±5.98	5.10±1.26
300 m	689.12±28.03	2.29±0.01	15.11±3.85	8.27±2.84
400 m	221.17±368.23	4.13±1.79	12.24±4.78	5.62±2.16
500 m	287.19±378.38	2.00±0.54	8.15±2.88	7.39±2.44
B500m	15.31±14.61	7.93±10.41	6.56±7.52	7.35±1.82
Control	0.57±0.02	0.38±0.01	5.75±0.07	0.47±0.02

W wet season, D dry season

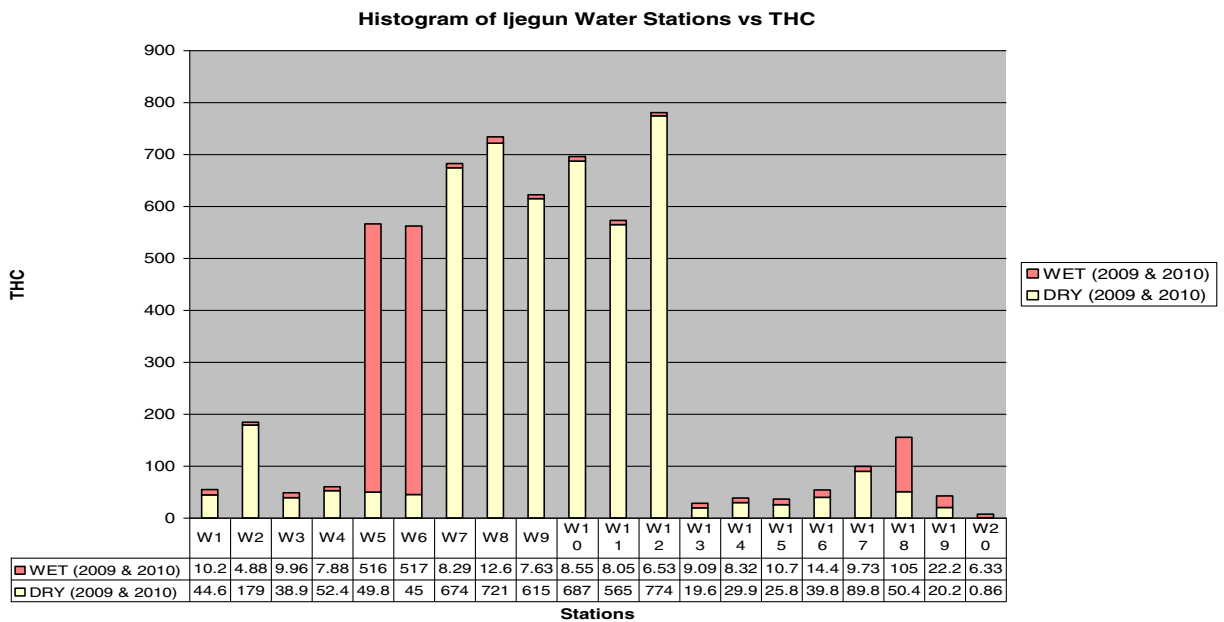


Fig. 2 Seasonal variation in the concentration of THC in groundwater samples collected from different locations around the pipeline oil explosion impacted area at Ijegan in 2009 and 2010

zones). Results show that all the wells sampled had significant levels of hydrocarbon. There was presence of hydrocarbons in the groundwater 500 m beyond the explosion site revealing the extent of the spill of petroleum products. Twenty-five months after the spill, the groundwater was still contaminated with petroleum hydrocarbon and above the WHO limit of 0.1 mg/l in drinking water. This suggests that natural attenuation has not successfully reduced the hydrocarbon level below WHO limit. Consequently, active remediation measures will be required.

There were varying degrees of THC contamination in all the groundwater sampled. There was no significant difference (statistically) in THC concentrations among the buffer zones. The trend of THC concentrations in the groundwater samples from locations in the buffer zones was 300>250>500>200>400>100 >150>B500m; 100>200>150>B500>400>250>300>500 m; 150>200>300>100>400>250>500>B500; 150 m>300 m>500 m>200 m>B500m>100 m>400 m>250 m, for 2009 wet, 2010 dry and 2010 wet seasons respectively (Table 6).

Fig. 3 Contour map of Ijegan contaminated site showing sampling stations and groundwater flow direction using Suffer 9 program

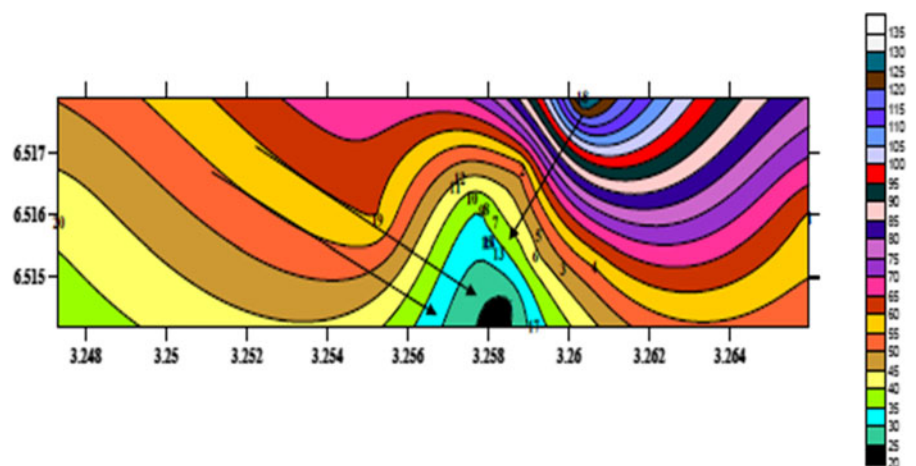


Table 7 Mean concentrations of BTEX compounds in groundwater samples collected from stations in different buffer zones away from the point of explosion in 2009

Buffer zones (m)	Benzene (µg/l)	Toluene (µg/l)	Ethylbenzene (µg/l)	Xylene (µg/l)	BTEX (total) (µg/l)
100	16.65	2.08	80.78	4,864.79	4,964.33
150	1.19	1.41	121.04	4,383.60	4,507.24
200	0.09	0.44	57.75	3,388.93	3,447.20
250	0.14	0.48	39.38	3,968.04	4,008.04
300	0.03	0.69	66.94	4,452.63	4,520.28

Seasonal variation in the concentration of THC in groundwater samples collected from different locations around the pipeline oil explosion impacted area at Ijegun in 2009 and 2010 is presented in Fig. 2. Statistical comparison by analysis of variance (ANOVA) of THC concentrations in groundwater samples from the locations sampled showed that there was significant ($P < 0.05$) difference in the measured concentration of THC between each season (dry and wet) and between the years (2009 and 2010). In general, the THC values for dry seasons were significantly higher ($P < 0.05$) than the values for wet seasons. Based on these results, it can be inferred that dilution due to rainfall during the wet season contributed greatly to the decrease in the contaminant concentrations in this petroleum contaminated site, which is an example of natural attenuation (Choi and Lee 2011).

Groundwater contour map of Ijegun contaminated site

The contour map using colors to represent the elevation of water is shown in Fig. 3. Surfer 9 computer package was used. The water elevation contour map of Ijegun revealed that groundwater flow direction is towards the southern part of the region. The elevation is low (less than 50 m) at sampling locations where very high hydrocarbon concentrations were observed (Figs. 2 and 3). The highest concentration of 780.53 mg/l for the four seasons was recorded at station W12 (Fig. 2) with low elevation of 45 m. Station W1 with hydrocarbon concentration of 54.8 mg/l was at 59 m elevation. Thus pollutants are more likely to migrate faster to the groundwater system where the elevation is lower. Based on the flow pattern of the aquifer system in Ijegun, boreholes should be sited in the north and eastern regions where hydrocarbon contamination is unlikely.

Table 8 Mean concentration of THC in soil (milligrams per kilogram) samples collected from locations in buffer zones away from the explosion point in Ijegun (wet and dry seasons 2009 and 2010)

Soil				
	2009 W	2009D	2010 W	2010D
50 m	4.06±3.07	207.48±275.82	9.06±3.91	11.17±2.56
100 m	7.43±7.43	401.41±0.00	12.85±12.85	5.55±0.00
150 m	34.73±32.31	87.21±58.30	10.43±2.71	142.39±105.91
200 m	75.84±60.34	40.75±7.56	11.91±4.57	27.92±24.08
250 m	12.04±12.04	246.87±0.00	9.76±9.77	2.16±0.00
300 m	33.16±45.73	149.48±193.84	149.48±5.67	11.41±12.57
500 m	90.71±90.72	21.25±0.00	9.68±9.69	18.55±0.00
B500m	69.48±93.28	113.12±91.07	9.38±2.22	31.08±16.09
Control	44.61±12.23	22.71±3.24	28.43±4.33	7.03±1.29

W wet season, D dry season

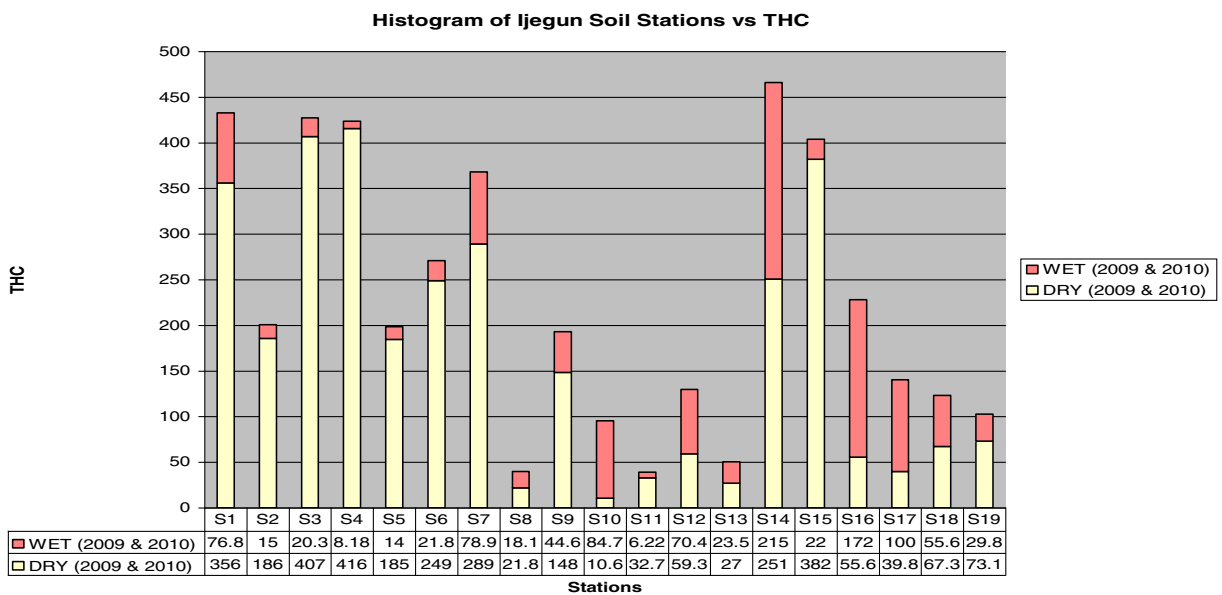


Fig. 4 Seasonal variation in the concentration of THC in soil samples collected from different locations around the pipeline oil explosion impacted area at Ijegun in 2009 and 2010

Distribution of BTEX in Ijegun groundwater

Mean concentrations of BTEX compounds in groundwater samples collected from stations in different buffer zones away from the point of explosion is presented in Table 7. The groundwater samples collected within the 100 and 150 m buffer zones away from the explosion point had very high values of BTEX compounds. The highest concentrations of 16.65 $\mu\text{g/l}$ (benzene), 2.08 $\mu\text{g/l}$ (toluene), and 4864.79 $\mu\text{g/l}$ (xylene) were found in stations within the 100 m buffer zone (Table 7). Concentrations of BTEX in the groundwater were higher than concentrations in the soil samples. Due to their polarity and very soluble characteristics, BTEX compounds are able to enter the groundwater systems and cause serious pollution problems (Brigmon et al. 2002). Consequently, these chemicals are some of the most common contaminants found in drinking water and

have been linked with a variety of health effects in humans (Yadav and Reddy 1993; Budavari 1996).

The high value of xylene recorded in this study can be due to the fact that xylenes are widely used as organic solvents and are present in numerous consumer products. Xylene also has the highest percentage weight compared to the other BTEX compounds in gasoline (benzene, 11 %; toluene, 26 %; ethylbenzene, 11 %; and xylene, 52 %; Jesper and Jason 1996). All the groundwater sampled within the 100 and 150 m buffer zones were above the safe value of 0.2 $\mu\text{g/l}$ set for BTEX compounds in the Environmental Guidelines and Standards for Petroleum Industry in Nigeria (EGASPIN).

Level of hydrocarbon in Ijegun soil

The level of hydrocarbon in the control station was 44.61 mg/l which was significantly higher than soil

Table 9 Mean concentrations of BTEX compounds in soil samples collected from stations in different buffer zones away from the point of explosion in 2009

Buffer zones (m)	Benzene ($\mu\text{g/kg}$)	Toluene ($\mu\text{g/kg}$)	Ethylbenzene ($\mu\text{g/kg}$)	Xylene ($\mu\text{g/kg}$)	BTEX (total)
100	0.03	0.46	2.57	1,020.12	1,023.17
150	0.04	0.77	7.49	1,167.84	1,176.12
200	0.02	0.51	0.15	783.69	784.38
250	0.15	0.39	0.12	408.41	409.07

samples collected from 50 and 100 m buffer zones in the wet season of 2009 (Table 8). The major contributor of THC in the control station is most likely vehicular emissions because the station is located along a busy road. In Detroit, the average total hydrocarbon concentration was found to be higher (20,900 µg/kg) for soils along busy streets when compared to 2,299 µg/kg for open-space soils (Wang et al. 2007).

The soil THC concentrations found around impacted area of Ijegun were lower than that reported in some studies on the distribution of soil hydrocarbons (Johnsen et al. 2006; Ye et al. 2006; Zuo et al. 2007). Seasonal variation in the concentration of THC in soil samples collected from different locations around the pipeline oil explosion impacted area at Ijegun in 2009 and 2010 is presented in Fig. 3. Statistical comparison by ANOVA of THC concentrations in soil samples from the locations sampled showed that there was significant ($P < 0.05$) difference in the measured concentration of THC between each season (dry and wet) and between the years 2009 and 2010. Generally, the THC values for dry seasons were significantly higher ($P < 0.05$) than the values for wet seasons, due to dilution in the wet season (Fig. 4).

Distribution of BTEX in Ijegun soil

Mean concentrations of BTEX compounds in soil samples collected from stations in different buffer zones away from the point of explosion is presented in Table 9. Soil samples collected within the 100 and 150 m buffer zones had significantly higher concentrations for all the monoaromatic compounds. The high value of BTEX compounds is due to its significant percentage in petroleum products. They make up about 18 % (w/w) in standard gasoline blend as the compounds are added to motor fuels to increase fuel performance (Budavari 1996). The values for xylene (408.41–1,167.84 µg/kg) were above the safety limits for soil pollution (50 µg/kg) as set out in the EGAS-PIN as target values for BTEX.

Conclusion

The results of the investigation show that the groundwater and soil of the impacted area of Ijegun were highly contaminated with total hydrocarbon content and the monoaromatic hydrocarbons BTEX. As a result

of the high concentration of hydrocarbon in the groundwater which is higher than the WHO limit of 0.1 mg/12 years after the explosion, the groundwater has lost its potability and the inhabitants of the area are prone to immediate health problems associated with BTEX compounds. Remediation program in the impacted area is therefore recommended to ameliorate the suffering of the inhabitants.

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