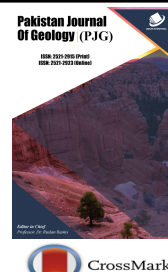## Pakistan Journal of Geology (PJG)

GEOLOGICAL AND HYDROGEOLOGICAL CHARACTERIZATION OF A HYDROCARBON IMPACTED SITE IN THE NIGER DELTA

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ARTICLE DETAILS

ABSTRACT

This study was conducted in K-Dere, Rivers State, Nigeria to determine the impact of oil spill contamination on soil and groundwater resources in the area. A total of twelve (12) wells were drilled at random to a depth of 10 m using an auger. The method of soil and groundwater analysis involved visual examination and laboratory analysis. Characterization of soils in the area revealed a predominance of fine and medium grained sand underlain by alternating layers of fine, silt and clayey formations. Soil samples from BH-04, BH-05, BH-06, BH-07, BH-07 and BH-11 have a weak to strong hydrocarbon smell and shows light to heavy sheen. Groundwater in all drilled holes was turbid and encountered at depths from 4.27 to 6.37m. BH-06 has a very strong smell and heavy sheen. Free phase hydrocarbon was also found in BH-06. The chemical concentration of Total Petroleum Hydrocarbons (TPH), Poly Aromatic Hydrocarbons (PAH) and BTEX (Benzene, Toluene, Ethylbenzene, Xylene) were determined from the groundwater samples. TPH ranged from <10μg/l to 222,000μg/l. BH-04, BH-06, BH-07 and BH-11 had TPH concentration above DPR intervention value of 600μg/l for water. Napthalene ranged from <0.3μg/L to 537μg/L. BH-04 and BH-06 had Napthalene concentration above the DPR intervention value of 70μg/L. Anthracene ranged from <0.045μg/L to 40.9μg/L. Only BH-06 exceeded DPR intervention value of 5μg/L. Phenanthrene ranged from <0.066μg/L to 135μg/L. Again, BH-06 exceeded the DPR intervention value of 5μg/L. Fluoranthracene ranged from <0.051μg/L to 14.4μg/L. Only BH-06 exceeded the DPR intervention value of 1μg/L. Benzo (a) anthrancene concentration in the groundwater samples ranged from <0.051μg/L to 3.52μg/L. Again, BH-06 exceeded the DPR intervention value of 1μg/L. Apart from benzene with a concentration of 2.5μg/L and Ethylbenzene with a concentration of 1.11μg/L in BH-06, all other BTEX compounds in groundwater in the area had concentrations <1μg/L and were within DPR intervention values. This result shows that the soils and groundwater in the area are heavily impacted by oil contamination. Groundwater is shallow (up to 0m bgl) and the direction of flow is towards the north-westerly and south-easterly directions. BH-06 which has a high hydraulic head also shows the highest level of soil and groundwater contamination in the area. It is therefore recommended that remediation be carried out in the area to prevent further damage to the soil and groundwater resources in the surrounding areas.

KEYWORDS

1. INTRODUCTION

Crude oil contaminated sites present a major challenge in many communities in the Niger Delta region of Nigeria [1,2]. Local soil contamination, mainly associated with operations and activities of the petroleum industry, is an actual and relevant environmental priority of the area [3]. These petroleum hydrocarbons adversely affect the germination and growth of plants in soils. Oil spills affect plants by creating conditions which make essential nutrients like nitrogen and oxygen needed for plant growth unavailable to them, retarding seed germination, stem density, photosynthesis rate. In crude oil contaminated areas vegetation is destroyed and recovery takes quite a long time.

Groundwater quality comprises of the physical, chemical, and biological qualities of the ground water. Temperature, turbidity, colour, taste, and odour make up the list of physical water quality parameters. Since most ground water is colourless, odourless, and without specific taste, we are typically most concerned with its chemical and biological qualities. Naturally, ground water contains mineral ions. These ions slowly dissolve from soil particles, sediments, and rocks as the water travels along mineral surfaces in the pores or fractures of the unsaturated zone and the aquifer. They are referred to as dissolved solids. Some dissolved solids may have originated in the precipitation water or river water that recharges the aquifer.

When gasoline is in contact with water, benzene, toluene, ethylbenzene and the xylene isomers (BTEX), account for as much as 90% of the gasoline components that are found in the water-soluble fraction [4]. Consequently, these chemicals are some of the most common contaminants found in drinking water. BTEX are toxic to humans and their removal from polluted environments is of special interest. Aquifers in Ogoni land are a crucial resource upon which the region's entire population depends for drinking water. The protection of these aquifers is therefore vital. The aquifers in this region are very shallow, with the top-most groundwater levels occurring anywhere between close to the surface and a depth of 10m. Hence, this study presents an assessment on the impact of oil pollution on soil and groundwater quality at Kdere, Ogoni in Gokana Local Government Area of Rivers State.

This study presents the geological and hydrogeological assessment of the extent of crude impact into the aquifer in the area. Aquifers in Ogoniland are a crucial resource upon which the region's entire population depends for drinking water. The protection of these aquifers is therefore vital. The aquifers in the area are very shallow, with the top-most groundwater levels occurring anywhere between close to the surface and a depth of 10m.

The basic objectives of the study include the following:

(i) Provide groundwater contamination information such as identification of groundwater contaminants and measure contamination levels. Also, to provide information of aquifer water quality, potential effects on public health and ecosystem.

(ii) Identify existing or potential changes in flow due to groundwater withdrawal.

2. THE STUDY AREA

The study area is situated approximately between longitude 7°12′ 59.446E and latitudes 4° 36′ 145.309N (Figure 1) in the Gokana Local Government Area of River State. The area which is plane in terms of its physical characteristics lies within the mangrove transmission zone of the Niger Delta and has just one main River and nexus of creeks and creek-lets which are tributaries into Imo river system. K-Dere is an integral part of the general geology of Niger Delta which has been described by some researchers. Niger Delta is located in the continental shelve of West Africa on the Gulf of Guinea and it comprised of three major litho-stratigraphic units namely; Akata, Agbada and Benin formations.

Akata Formation is the lowermost and oldest sedimentary of the Niger Delta. It is composed mainly of the marine shales and approximately 4,000m thick. It is the source rock of petroleum in the Niger Delta Complex. It contains lenses of over-pressured siltstones and fine-grained sandstones. This formation is believed to have been deposited in front of the advancing delta and ranges from the Paleocene to recent.

Agbada Formation is made up of alternations of sands, sandstones and minor intercalations of shale. The sandstones are often poorly sorted, and the grain size varies from fine to coarse. The shales are fairly hard, silty and locally glauconitic. Thickness of the Agbada Formation ranges from 10,000m to 12,000m. The major characteristic of the sands is that they are highly porous and with the presence of the clay horizon has made this formation very prominent as petroleum reservoir. The age ranges from Eocene to Recent. The Benin Formation extends from the West to the whole of Niger Delta and Southward beyond the present Coastline. It is overlain by the Quaternary deposits and consists of coastal plain sands. The formation is massive porous freshwater (fluviatile) sand with shale intercalations. Overall thickness ranges from 0m to 30m. This formation has been described as the prolific aquifer in the Niger Delta [5,6].

A group researcher described the aquifers in this area as a set of multiple aquifer systems stacked on each other with the unconfined upper aquifers occurring at the top [7]. Recharge to aquifers is direct from infiltration of rainfall, the annual total of which varies between 5000mm at the coast to about 2540mm landwards. Groundwater in the area occurs in shallow aquifers of predominantly continental deposits encountered at depths of between 45m and 60m. The lithology comprises a mixture of sand in a fining up sequence, gravel and clay. Well yield is excellent, with production rates of 20,000 liters /hour common and borehole success rate is usually high [8]. Across the area, measures transmissivity varies from 59 to 6050m^2/d, Hydraulic conductivity from 0.04 to 60m/d and storage coefficient from 10^{-6} to 0.15 [9]. Surface water occurrence includes numerous networks of streams, creeks and rivers.

Groundwater recharge system in the study area is sourced from direct precipitation with an annual intensity of as high as 2000 – 2400mm. Water permeates the Benin formation sands to recharge the aquifers. The multi-layer aquifer system has shallow unconfined aquifers at the upper limit of the geologic units providing most of the domestic water needs of the communities' inhabitants [7]. The water table in the area is between 0.7m to 3.5m depth and fluctuates with the prevailing land profile and season [10]. These aquifers are therefore vulnerable to pollution from a range of contaminants ranging from, hydrocarbon contaminant plumes, solid wastes and leachates.
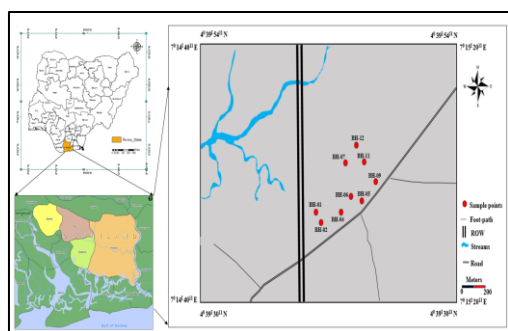

Figure 1: Map of the study area showing sample location

3. METHOD OF STUDY

Twelve number boreholes were excavated for sub-soil profiling. However, nine boreholes were sampled for characterization within the study area [11]. The litho-logs of the boreholes are presented in the Appendix. Water levels were determined in each borehole using an interface water depth indicator, while topographic elevation was measured at each sample point with GPS. With the information, groundwater level contour map of the area was constructed [12]. At each sampled borehole, the well was pumped significantly to ensure obtaining fresh water samples. For chemical analysis, replicate water samples were collected into clean plastic cans.

3.1 Soil sampling

The boreholes were drilled by percussion method with drill cuttings from the top to the terminal depths at -10.0m. From the open holes, the area is underlain predominantly by fine and medium grained sand overlain by near-surface alternating layers of fine, silt and clayey formations with crude-mix. Soil sampling was done using a random sampling technique [13]. The sample points selected for drill holes were farmlands and plantations. A hand drilling auger was used to drill 10 meters deep holes in each sample location. A total of twelve (12) boreholes were drilled and sampled in the study area. The drill cuttings were carefully examined as they came out of hole. They were examined for lithologic changes, colour, texture, grain size, hydrocarbon smell and presence or absence of oil sheen. Each sample described in the field was carefully logged and a kilogram was obtained for further laboratory analysis [14]. Each sample bag was carefully labelled using code names, and GPS reading were also obtained for each site.

3.2 Groundwater sampling

Groundwater was also sampled at each of the drill holes where soil samples were collected. During sampling, all air bubbles were eliminated from the clean plastic bottles. The water turbidity, presence or absence of oil sheen and hydrocarbon smell was determined by visual examination [15,16]. Water levels were determined in each drill hole using an interface water depth indicator, while topographic elevation was measured at each sample point with GPS. With this information, a groundwater level contour map of the area was constructed. Also, groundwater samples from the drilled holes were collected in clean plastic bottles for laboratory analysis.

3.3 Laboratory analysis

In the laboratory, the clean plastic bottles are rotated to allow for diffusion of internal standards and surrogates throughout the matrix. The bottles are placed in the auto-sampler carousel of the headspace analyzer and maintained at room temperature. Approximately 1 hour prior to analysis, the individual bottles are moved to a heated zone and mechanically agitated while the elevated temperature is maintained, allowing the volatile organic compounds (VOCs) to equilibrate between the headspace, liquid and any solid phases in the bottle.

The auto-sampler then pressurizes the vial with helium and forces a portion of the headspace gas mixture into the Gas chromatograph (GC) through a heated transfer line, either passing through the GC inlet or directly connected to the analytical column via an inert, low dead volume connector [17]. Determinative analysis is performed using the appropriate gas chromatograph/mass spectrometry determination (GC/MS) method. Any chemical preservative and matrix modifier added to the field samples should also be added to the calibration standards and other QC samples. The polycyclic aromatic hydrocarbon (PAH) was determined by Gas chromatography with mass spectrometric detection (GC/MS), volatile aromatic hydrocarbons (BTEX) by gas chromatography with photoionization detector (GC/PID).

4. RESULTS AND DISCUSSION

4.1 Soil stratigraphy

4.1.1 BW11-BH-1

The topsoil is characterized to -0.50m by brown clayey sand which is immediately underlain to -4.0m by light brown silty sand. Layer of light yellow fine sand extends from -4.0m to -8.0m. The end of the hole is characterized by light yellow fine to medium grained sand. Groundwater stood at -0.28m after boring.

4.1.2 BW11-BH-2

The sub-soil condition at this borehole is layer of brown fine sand from the top to -1.0m which in turn overlies another layer of light brown fine sand to -5.0m. Light yellow fine sand extends beneath the above layer from -5.0m to the end of the hole at -10.0m. The groundwater was at the surface.

4.1.3   BW11-BH-3

Topsoil is greyish brown fine sand to -0.50m. Brown fine sand underlies the topsoil to -5.0m where layer of light yellow fine sand was encountered. From -5.0m to -10.0m is light yellow and yellow fine to medium sands.

4.1.4   BW11-BH-4

Layer of light grey silty sandy clay of 7.0m thick underlie the topsoil from -0.50m. The clayey formation overlies yellow and light yellow fine sand to the end of the boring. Groundwater table was -3.59m.

4.1.5   BW11-BH-5

The topsoil is brown silty sand to -1.0m. From -1.0m to -2.0m is brown silty sand which overlies light brown silty sand to -3.0m. Deep yellow fine sand formation extends from -3.0m to -7.0m where layer of light yellow fine to medium grained sand extends to the terminal depth at -1.0m. The groundwater table stood at -1.63m after boring.

4.1.6   BW11-BH-6

Dark grey silty sand clay extends from the near-surface to -4.0m. Brown fine sand of 1.0m thick underlies the clayey formation. Light yellow fine sand extends beneath the brown fine sand to -10.0m. The groundwater was -3.0m.

4.1.7   BW11-BH-7

Alternating layers of brown fine sand and sandy clays characterize the borehole from the top to -3.0m. The fine sand is underlain from -1.0m by the sandy clay. From -3.0m to -1.0m is light yellow fine sand. Static groundwater table was -1.63m.

4.1.8   BW11-BH-8

Brown fine sand extends from the top to -2.0m. light brown silty sand underlain the topsoil to -4.0m where yellow fine sand of 2.0m thick was encountered. Underlying the yellow fine to -10.0m is light yellow fine to medium grained sand.

4.1.9   BW11-BH-9

Brown fine sand extends from the top to -1.0m underlying brown sandy clay which extends to-5.0m. From -5.0m to -8.0m is yellow fine sand and the lower end of the borehole is light red fine to medium grained sands with groundwater at -0.80m.

4.1.10   BW11-BH-10

At this borehole, brown sandy clay encountered from the top to -2.0m is underlain by light yellow fines and to-7.50m. Brown clayey sand underlies the fine sand to the terminal depth at -10.0m.

4.1.11   BW11-BH-11

The topsoil is characterized by dark grey clayey sand to -0.30m and thin layer of dark brown fine sand underlie the topsoil at -0.50m. Alternating layers of greyish brown and light grey silty sand and sandy clay underlies the fine sand to -3.0m. Yellow fine sand encountered beneath the clayey formation extended to -6.0m and also overlying brownish grey fine to medium grained sand to the terminal depth at -10.0m. The groundwater was 0.38m

4.1.12   BW11-BH-12

From the top to -0.50m is brown fine sand which is underlain to -3.0m by light brown fine sand. The fine sands are further underlain to the terminal depth by light yellow fine sand. Static groundwater table was -0.80m.

The results of soil stratigraphic analysis in the study area are presented in Table 1and Figure 2. Each of the boreholes was drilled to 10m depth and the drill cuttings were described by visual inspection. Soil descriptions from the open holes showed that the area is underlain predominantly by fine and medium grained sand overlain by near-surface alternating layers of fine, silt and clayey formations with crude mixtures (Figure 2). Figure 3
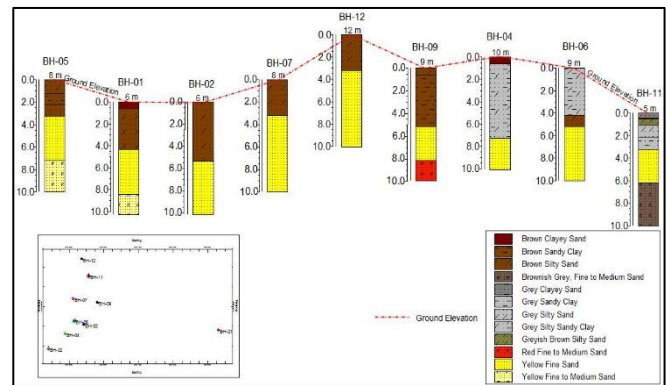
shows the soil stratigraphy correlation in the area.

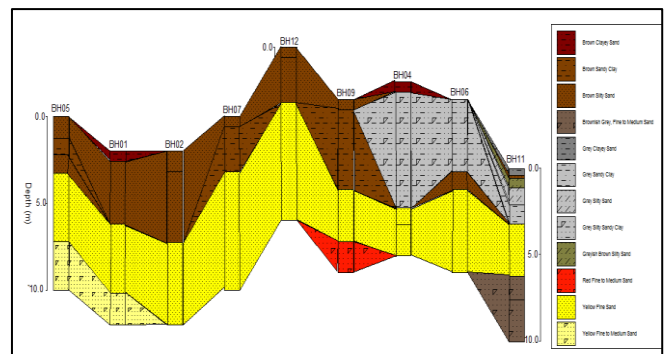**Figure 2:** A cross section showing the soil profile in the study area

Figure 3: A cross section showing the correlation of the soil stratigraphy across the area

4.2   Hydrocarbons in soil

Visual examination of the soil samples also revealed the presence of hydrocarbon contents based on oil sheen and smell. All the soil samples from BH-01, BH-02, BH-09 and BH-12has no hydrocarbon smell and no sheen. Meanwhile at BH-04, clayey sands at a depth of 0.5m has a weak hydrocarbon smell and light sheen, the underlying silty sandy clay has moderate hydrocarbon smell and moderate sheen down to a depth of 2.0m [18-20]. Also, the underlying silty sandy clay has weak hydrocarbon smell and has a light sheen down to 3.0m depth. The silty sands at a depth of 1.0m in BH-05 has strong hydrocarbon smell and moderate sheen, while the underlying sandy clay and silty sand to a depth of 3.0m has a weak hydrocarbon smell and shows light sheen. The silty sandy clay in BH-06 has weak to moderate hydrocarbon smell and shows light sheen from 1.0m to 4.0m depth. Underlying this layer is fine sand which has moderate hydrocarbon smell and moderate sheen [21-24]. The sands were also stained with oil don to a depth of 5.0m. From 6.0m to 7.5m depth, the fine sands have a weak hydrocarbon smell and shows moderate sheen. In BH-07, the fine sand at 0.3m depth has moderate hydrocarbon and has a light sheen, whereas the underlying 0.20m thick fine sands has strong hydrocarbon smell and moderate sheen. The sandy clay layers which underlie the fine sand to a depth of 3.0m had a weak hydrocarbon smell and a light sheen. Other parts of the soil have no hydrocarbon smell or sheen. In BH-11, the silty sand at a depth of 1.0m had strong hydrocarbon smell and heavy sheen while the underlying sandy clay and fine sand at 3.0m to 4.0m had weak hydrocarbon smell and a light sheen.
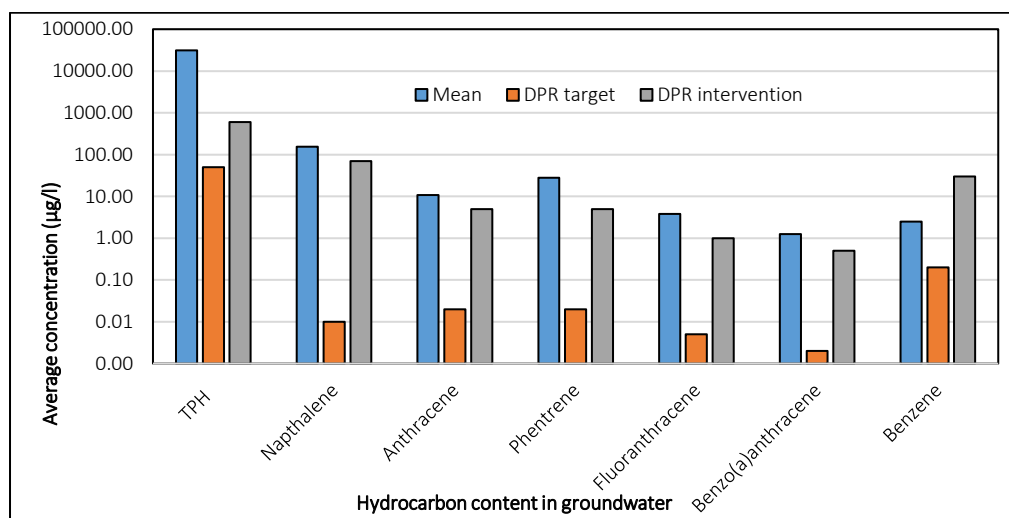
4.3   Hydrocarbons in groundwater

Visual inspection of the groundwater samples obtained from the drill holes shows that the shallow groundwater in the area is turbid. The groundwater from BH-01, BH-02, BH-05 and BH-09 has no hydrocarbon smell and no sheen, while BH-04, BH-07, BH-11 and BH-12 have weak hydrocarbon smell and a light sheen. In BH-06, the groundwater sample has a strong hydrocarbon smell and heavy sheen [25]. Also, free phase hydrocarbon was encountered in the groundwater in BH-06. The presence of hydrocarbons in groundwater renders the water unsuitable for consumption. Figure 4 shows the average concentration of hydrocarbon constituents in groundwater compared with regulatory limits while Table 3 is the results of groundwater flow direction determination in the area [26-28]. Figure 5 shows the groundwater flow direction in the area.

Table 1: Results of chemical analysis of groundwater samples in the study area

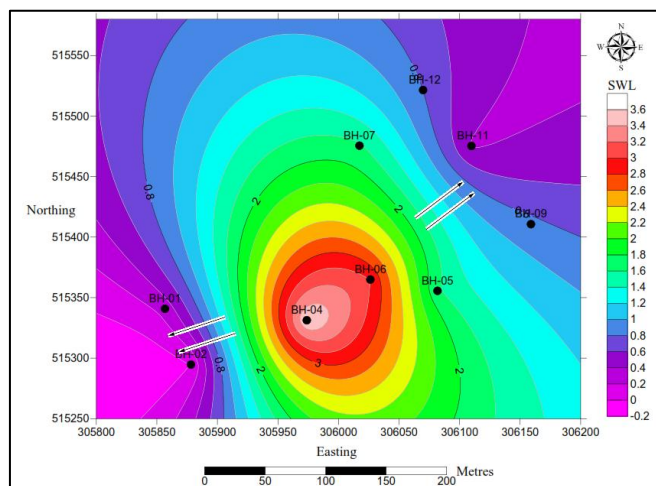| Elements	Unit	BH-01	BH-02	BH-04	BH-05	BH-06	BH-07	BH-09	BH-11	BH-12	DPR target	DPR intervention
TPH	µg/l	183	<10.00	4940	25	222,000	1,360	433	18,600	402.00	50.00	600.00
Napthalene	µg/l	<0.30	<0.30	77.4	<0.30	537.00	2.01	<0.30	0.941	<0.30	0.01	70.00
Anthracene	µg/l	<0.045	<0.045	0.804	<0.045	40.90	0.143	<0.045	1.07	<0.045	0.02	5.00
Phentrene	µg/l	0.14	<0.066	4.56	<0.066	135.00	0.558	<0.066	0.429	<0.066	0.02	5.00
Fluoranthracene	µg/l	<0.051	<0.051	0.361	<0.051	14.40	0.0573	<0.051	0.373	<0.051	0.005	1.00
Benzo(a)anthracene	µg/l	<0.051	<0.051	0.114	<0.051	3.52	<0.051	<0.051	0.144	<0.051	0.002	0.50
Benzene	µg/l	<1.00	<1.00	<1.00	<1.00	2.50	<1.00	<1.00	<1.00	<1.00	0.20	30.00
Toluene	µg/l	<1.00	<1.00	<1.00	<1.00	<1.01	<1.00	<1.00	<1.00	<1.00	0.20	1000.00
Ethylbenzene	µg/l	<1.00	<1.00	<1.00	<1.00	1.11	<1.00	<1.00	<1.00	<1.00	0.20	150.00
m,p- Xylene	µg/l	<1.00	<1.00	<1.00	<1.00	<1.00	<1.00	<1.00	<1.00	<1.00	0.20	70.00
o-Xylene	µg/l	<1.00	<1.00	<1.00	<1.00	<1.00	<1.00	<1.00	<1.00	<1.00	0.20	70.00

Table 2: Statistical analysis of chemical compounds in groundwater

Elements	Unit	Min	Max	Mean	SD	DPR target	DPR intervention
TPH	µg/l	<10	222000	30992.88	77433.96	50	600
Napthalene	µg/l	<0.03	537	154.34	257.61	0.01	70
Anthracene	µg/l	<0.045	40.9	10.73	20.12	0.02	5
Phentrene	µg/l	<0.066	135	28.14	59.77	0.02	5
Fluoranthracene	µg/l	<0.051	14.4	3.80	7.07	0.005	1
Benzo(a)anthracene	µg/l	<0.051	3.52	1.26	1.96	0.002	0.5
Benzene	µg/l	<1.00	2.5	2.50	0	0.2	30
Toluene	µg/l	<1.00	<1.00	<1.00	0	0.2	1000
Ethylbenzene	µg/l	<1.00	1.11	<1.00	0	0.2	150
m,p- Xylene	µg/l	<1.00	<1.00	<1.00	0	0.2	70
O-Xylene	µg/l	<1.00	<1.00	<1.00	0	0.2	70

Figure 4: Average concentration of hydrocarbon constituents in groundwater compared with regulatory limits

Table 3: Results of groundwater flow direction determination

Borehole No.	Depth of borehole (m)	Surface Elevation (m)	Groundwater elevation above Datum (m)	Static groundwater Level (m)
GW_01	10.00	6.00	5.72	0.28
GW_02	10.00	6.00	6.00	0.00
GW_04	10.00	10.00	6.41	3.59
GW_05	10.00	8.00	6.37	1.63
GW_06	10.00	9.00	6.00	3.00
GW_07	10.00	8.00	6.37	1.63
GW_09	10.00	9.00	8.15	0.85
GW_11	10.00	5.00	4.27	0.38
GW_12	10.00	6.00	5.20	0.80

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Figure 5: Map showing the direction of groundwater flow in the area

5. CONCLUSION

Soil and groundwater quality assessment was carried out in K-dere, a community in Ogoniland to determine the impact of oil spill contamination on the area. The approach adopted was random sampling. Twelve boreholes were drilled with the aid of an auger to a depth of 10m. The methods of soil and groundwater analysis adopted were visual examination and laboratory analysis. The boreholes sampled included BH-01, BH-02, BH-04, BH-05, BH-06, BH-07, BH-09, BH-11 and BH-12.

The depth to groundwater in all drill holes were shallow, ranging from 4.27 to 6.37m. The water in the drill holes was all turbid. The water samples from BH-04, BH-07, BH-11 and BH-12 all have weak hydrocarbon smell and shows a light sheen. BH-06 has a very strong hydrocarbon smell and heavy sheen. Free phase hydrocarbon was also found in BH-06.

The TPH concentration in groundwater ranged from <10μg/l to 222,000μg/l. BH-04, BH-06, BH-07 and BH-11 had concentrations which exceeded the DPR intervention value. Naphthalene in BH-04 and BH-06 had concentrations above the DPR intervention value. Anthracene ranged from <0.045μg/L to 40.9μg/L. Phenanthrene, Fluor anthracene and Benzo (a) anthracene ranged from <0.066μg/L to 135μg/L, <0.051μg/L to 14.4μg/L and <0.051μg/L to 3.52μg/L. Only BH-06 exceeded the DPR intervention limits for these chemical compounds.

Apart from benzene with a concentration of 2.5μg/L and Ethylbenzene with a concentration of 1.11μg/L in BH-06, all other BTEX compounds had concentrations <1μg/L which are within DPR intervention limits. Groundwater flow is towards the north-westerly and south-easterly directions. BH-06 which has a high hydraulic head also shows the highest level of soil and groundwater contamination in the area.

This study shows that the soils and groundwater in the area are heavily impacted by oil contamination. BH-06 is the most impacted site and happens to have a higher hydraulic head. Hence, there is an urgent need for remediation to be carried out in the area to prevent further damage to the soil and groundwater resources in the surrounding areas.

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