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Groundwater Contamination Assessment in a Petroleum Impacted Sites in Parts of the Niger Delta, Nigeria

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Abstract

The assessment of the contaminant status of groundwater in an oil impacted site in Eneka community in Obio-Akpor local Government Area of Rivers State, located in the Niger Delta area has been carried out in this work through groundwater sampling from 20 water wells made by percussion drilling to depths of 15m and the chemical quantification of petroleum-related contaminant species (Mineral oil/EPH, PAH`s, VOC`s) by gas chromatography-mass spectrometry (GC-MS) testing. Free phase oil was found in the subsurface on top of the water table at depths range of 3.84 – 6.76m (av. = 5.59m) in sixteen wells. Four wells in the perimeter area of the site (BH- 8, - 13, - 16 and -18) were free of free phase oil. Groundwater level for the twenty (20) boreholes ranged from 4.56 – 8.81m (av. = 6.26m). Results of chemical quantitation of contaminants from four randomly selected boreholes, showed ranges of values of EPH (5710 – 325,000), total PAH (68.3 – 676), naphthalene (62.2 -58), fluoranthrene (0.0588 – 1.95), anthracene (<0.03 - <0.15), phenanthrene (0.918 – 41.1) and Benzo(a)anthracene (<0.034 – 0.922). For the VOC`s, ranges of 1180 – 141,000, 8.99 – 13,600, 80.6 – 1310, were recorded for benzene, toluene and ethylbenzene respectively, while a range of 378 – 7570 were recorded for the xylenes (p-xylene, m-xylene and o-xylene). Contaminant concentration compared against the EGASPIN intervention values revealed various exceedences. Four exceedences was recorded each for EPH, benzene and the xylenes, while three and two exceedences each was recorded for ethylbenzene and toluene. Total PAH recorded three exceedences. One exceedence each was recorded for naphthalene, fluoranthrene and benzo(a)anthracene, while phenanthrene had two exceedences.

Keywords: Sediment attenuation, Eneka, groundwater, free phase oil, oil impacted site.

1. Introduction

Uncontaminated natural groundwater in geological formations is pristine and suitable for use in both domestic and industrial purposes without a need for purification, a narrative that has unfortunately been changed by the industrial age as exemplified by oil exploration in many climes. The advent of hydrocarbon businesses in the Niger Delta area has heralded devastating environmental consequences through the release of petroleum-related environmental pollutants. Pollution and contamination of environmental media in the Niger Delta as a result of oil spills, due mainly to operational failures, a situation that has caused sporadic contamination of soil, bottom sediments, surface and groundwater and large scale habitat loss has become a common site.

The ease of contamination of groundwater is a function of the existence of suitable pathways in the form of permeable geologic formations with high hydraulic conductivity through which contaminants migrates into the subsurface. The Benin Formation of the Niger Delta area, characterized by fluvial facies which consists of sands and pebbles as dominant facies and minor clay facies (Short and Stauble, 1967), host groundwater resource upon which domestic and industrial water supply have depended for millennia. The dominant sandy facies, notable for high permeability, constitutes shallow unconfined aquifers in the region and the dependence on groundwater reservoired in these unconfined aquifers, is due to virtual non-existence of modern municipal water works that has the technological capability to tap groundwater from deeper confined aquifer that could be devoid of surface-derived contaminants.

Although the movement of free phase oil and its associated contaminants can be attenuated by appropriate lithologies (Guo, et al., 2010; Olu-Owalabi et al., 2015; Osokpor and Omo-Irabor, 2020), the occurrence of such lithologies with attenuating capacity is limited in areal and vertical extent in the surface and near-surface, being commonly restricted to ancient and extant flood plains in the Niger Delta area.

The anthropogenic release of free phase oil into the environment is known to cause various scales of pollution. Commonly, water holes drilled into the Benin Formation to abstract groundwater for domestic use in the Niger Delta area, is on the average, 40 feet deep. At this depth, the unconfined aquifer, composed of highly permeable and conductive earth materials, is exposed to downward migrating contaminants solutes that ultimately reach groundwater at depths from which water is abstracted for domestic use especially. Oil exploration and production establishments in the area, advocate a generally limited penetration of crude oil into the soils in the Niger Delta, though specific pathways may exist that could results in deeper penetration of the contaminants. The claim seem to be based on an oversimplification of soil and sediment compositional characteristic in the surface levels of the Benin Formation.

Groundwater contamination assessment is a risk-based concept (“origin-pathway-target”) model which depends on three elements: (1) hazard posed by a potentially polluting activity (origin); (2) the intrinsic vulnerability of groundwater to contamination (pathway); and (3) the potential consequences of a contamination event upon the groundwater (target) (Nobre et al., 2007; Zwahlen, 2004, Wang et al., 2012).

Fig. 1. Geographic location map of the study site indication with a black cross. The local government area (Obio/Akpo), where the site is located is indicated by yellow

Several countries in Europe (Andreo et al., 2006; Zwahlen, 2004), the Americas (Foster and Hirata, 1988; Nobre et al., 2007), Asia (Awawdeh and Jaradat, 2009; Baalousha, 2011; Fadlelmawla et al., 2011; Nguyet and Goldscheider, 2006), Africa (Boughriba et al., 2010; Saidi et al., 2011) have carried out risk assessment working (Wang et al., 2012) using these parameters.

In this work, we intended to evaluate the impact of spilled petroleum product on groundwater quality in the vicinity of an oil spill site in Eneka community, located in Obio/Akpo local government area of Rivers State in the Niger Delta (Fig. 1), by quantitative assessment of petroleum-derived chemical contaminants in groundwater.

1.1 Environmental Setting

Site location, description and background information

The site of investigation is located in Eneka town in Obio/Akpor local government area of Rivers State, Nigeria. The location of the site is shown in figure 1. The oil spill in the objective area occurred in June, 2013 during which time the cause of the spill was ascertained to have been caused by sabotage/oil theft. As an emergency response on the part of the operator, containment of the spill was immediately carried out to prevent further spreading of free phase oil and potential environmental pollution. As at the time of spill, visible environmental media affected by free phase oil were soils in farm lands and vegetation. Visual observation indicated free phase oil and oil patches on surface and near-surface soil and oil stain on vegetation in the vicinity of the spill. Areal extent of the spill as at June, 2013 was about 2.3Ha. Average depth of penetration of free phase oil on soil was 1m, while the nearest human habitation was >70m away.

Vegetation type, local human activities and land use

The vegetation in the area is made up chiefly of secondary vegetation type characterized by up-land plant species found in tropical equatorial climatic regions. Generally, the vegetation is composed of a mix of short shrubs, short to tall trees in open areas, while dense vegetation and thickets made up of tall evergreen tropical tree species and tall grasses occur beyond the immediate area of the spill. Species of the remnant natural vegetation include oil palm (*Elaeis guineensis*) and bamboo that are commonly seen in the area. Subsistence agricultural activities is commonly practiced among the rural population. Annual crops cultivated by the local population include plantain, pineapple, cassava, yam and maize etc. Perennial agricultural activity is also practiced in the form of oil palm cultivation in an oil palm plantation adjacent to the spill site. Besides the vegetation type described above, whether primary or secondary, other components of the vegetation in the area include fruit trees and/or crops such as pawpaw, mango, coconut, orange and the African pear trees.

2. Study Methodology

2.1 Risk-Based Assessment

This study based on a risk assessment which is pivoted on the "origin-pathway-target" model as stated earlier. The first element for consideration is a generic conceptual site model (CSM) which is used to develop the assessment strategy to identify facilities that represent a risk to human health or the environment, and therefore require remediation. In this vane, the main contaminant of concern is *crude oil* discharged to the ground surface and where pipelines are buried to below ground. An initial general limited penetration of crude oils into the soils in the area is envisaged. However, specific pathways may exist that could results in deeper penetration of the contaminants. Migration will predominantly be along the ground surface from high to low topography, or through slow soil infiltration into near surface groundwater table. The main risk to human health examined in this study is from direct ingestion oil and related contaminants present in abstracted groundwater.

The second element considered here is the *potential pathways* (the intrinsic vulnerability factor). In groundwater assessment, contamination sources can only pose a risk to receptors if a pathway is present. Pathways connect sources and receptors. Potential pathways of concern in this study at/within the site is the friable and highly conductive sands of the Benin Formation.

The third risk assessment factor is the *potential receptors* or *target* which examines the potential consequences of a contamination event upon the groundwater as an environmental media and ultimately Human Health.

The assessment in this study is in accordance with DPR in Part VIII-F, Management and Remediation of Contaminated Land (EGASPIN 2002).

Well Based Description of Geology and Hydrogeologic Conditions of Eneka Spill Site

In order to define the geology of the Eneka spill site, close observation of subsurface samples recovered from each well bore at 0.5m intervals during drilling phase were comprehensively described and presented in lithologic formats.

2.2 Groundwater Sampling

Twenty cable percussion boreholes were drilled across the sites to a maximum depth of 15m below ground level (bgl.). The borehole co-ordinates were determined using GPS instruments and based on Nigeria Transverse Mercator (NTM).

Trial holes were excavated to 1m below ground level (bgl.) at each borehole location using a hand auger tool prior to drilling. The auger holes were subsequently drilled using a pre-mobilized cable percussion tool to produce 150mm diameter boreholes. Depth to groundwater was recorded upon encounter where present. Visual and olfactory observations of contamination were also noted during drilling.

Each borehole was cased and fitted with groundwater monitoring riser pipes comprising high-density polyethylene (HDPE) tubes which extended to maximum depths of 11.5 – 13m.

At depth interval of 2 – 13m below ground level, the HDPE tubes were perforated to suit the observed subsurface settings and depth of groundwater strikes. Clean pea gravel were then used to gravel-packed the response zones following which bentonite was used to seal each installation. The benonite seal was then overlain by concrete to secure a galvanized protective cover which stood at 0.5m above ground level. Bentonite seal was used as a blind at the base of each standpipe in holes where the fitting did not extend to the base.

The installations were then purged three times using a dedicated disposable bailer. After purging, the water samples were collected using the bailer and placed in sterile bottles/vials. A new disposable bailer was used to purge and sample each borehole to prevent the risk of cross-contamination.

Free phase oil was found in the subsurface on top of the water table at depths ranging from 3.84 – 6.76m (Av. = 5.59m) in sixteen wells across the site. Four well in the perimeter areas of the site (BH- 8, - 13, - 16 and -18) were free of free phase oil. Field data show that groundwater level for the twenty (20) boreholes ranged from 4.56 – 8.81m with an average depth of 6.26m across the spill area. Depths to Groundwater and oil levels were contoured across the site.

In order to carry out ground water monitoring, the HDPE tubes were perforated from about 2m to 13m bgl., in order to account for changing groundwater level with the seasons. The choice of perforation length was a function of the ground conditions encountered. Groundwater samples were recovered from all of the boreholes between 17th and 27th of February, 2014 for laboratory analysis. The installations were then purged three times using a dedicated disposable bailer. After purging, the water samples were collected using the bailer and placed in sterile bottles/vials. A new disposable bailer was used to purge and sample each borehole to prevent the risk of cross-contamination.

2.3 Groundwater Contamination Analysis

The chemical analyses undertaken for groundwater samples obtained from the spill site are listed in Table 1.

Table 1: Groundwater chemical analyses undertaken for the Eneka spill site

Test	Number of tests undertaken
Mineral Oil - Extractible Petroleum Hydrocarbons (EPH)	04
Polyaromatic Hydrocarbons (PAH) - Naphthalene, Acenaphthylene, Acenaphthene, Fluorene, Phenanthrene, Anthracene, Fluoranthene, pyrene, Benz(a)anthracene, Chrysene, Benzo(b)fluoranthene, Benzo(k)fluoranthene, Benzo(a)pyrene, Indeno(1,2,3-cd) Pyrene, Dibenzo(a,h)anthracene, Benzo(g,h,i)perylene, Total detected PAH	04
BTEX (Volatile Organic Compounds) Benzene, Ethylbenzene, Toluene, P-xylene, M-xylene, O-xylene	04

Four groundwater samples obtained from the spill site were chemically tested as outlined in Table 1. The results were then compared against the EGASPIN 'Tier 1 Intervention Levels'. A graphic plot of groundwater EPH, PAH and VOC concentrations above the EGASPIN intervention value were then made.

2.4 Surveying (Ground Elevation Determination)

Ground elevation was determined using traversing and spot height method on completion of drilling. The elevations of all the boreholes were determined relative to a Temporary Bench mark (TBM) established for the site using field surveying equipment. The spot height points and contoured elevation for the site were then used to produce a "Top Groundwater Level Contour Map" and a "Subsurface oil thickness Contour Map" as at the time of study. The elevation determined for each borehole location is included in the respective borehole logs.

3. Results and Discussion

3.1 Site Specific Geology and Hydrogeology: Field Observation and Strata encountered

During the field work phase, visible soil contamination of free phase oil was observed in the subsurface on top of the water table at depths ranging from 3.84 – 6.76m (Av. = 5.59m) in sixteen wells across the site. Four wells in the perimeter areas of the site (BH- 8, - 13, - 16 and -18) were free of free phase oil. Field data revealed a groundwater level of 4.56 – 8.81m (av. = 6.26m) for the twenty boreholes across the spill area. Depths to Groundwater and oil levels were contoured across the site (Fig. 3 and 4).

The general sequence of strata encountered in the project area on all twenty boreholes locations ranged from grey-brownish organic-rich clayey fine-grained top soils from surface to 2.0m in thickness. The surface stratum is underlain by relatively thick inter-layers of mottled sandy clay/clay with fine sand/silty sand/pebbly sand from a depth range of 4 – 8m bgl. The mottled clay horizon is underlain by coarser grained sediments composed of poorly sorted clayey very fine to pebbly sands, down to bottom depths of each boreholes (Fig. 2). The composition of the sediments present in the different strata across the site is characteristic of fluvial origin. A representative profile of the strata encountered at the site is shown in figure 2. The specific nature and variation of strata encountered at each borehole location is a function of the local facies present in the subsurface, although it is generally a representative of the fluvial facies which make up the upper sequence of the topset Benin Formation (Short and Stauble,1967).

This stratigraphic configuration provides a potential pathway for the easy infiltration of contaminants to the subsurface, hence poses a high intrinsic vulnerability of the groundwater body in the area of study.

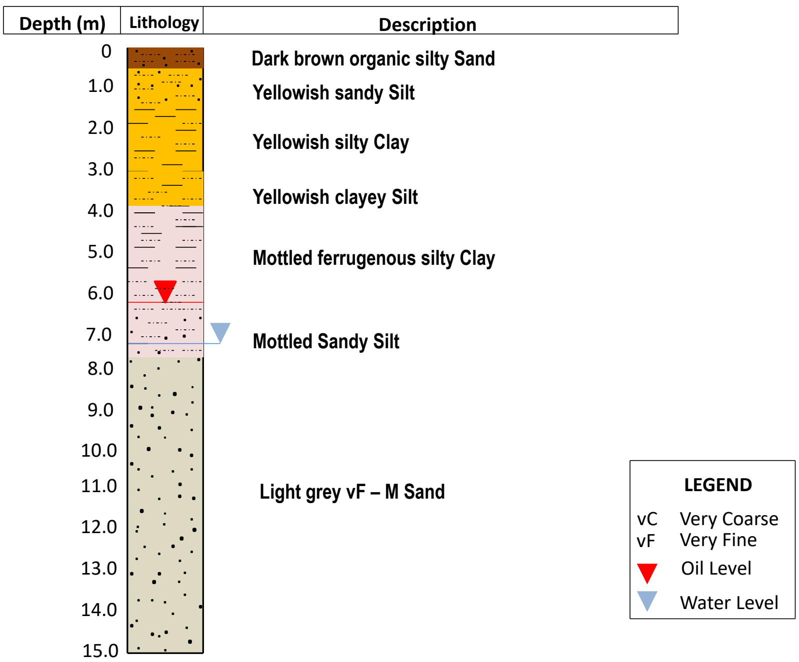

Fig. 2: Representative Soil/sediment profile for the study area.

3.2 Groundwater chemical data

A summary groundwater contamination data is presented in Table 2. These were compared against the EGASPIN 'Tier 1 Intervention Levels' as shown in (Tables 2). A graphic plot of groundwater EPH, PAH and VOC concentrations above the EGASPIN intervention value are presented in figures 3-5.

3.3 Groundwater Extractible Petroleum Hydrocarbons (EPH)

A plot of EPH values obtained for the site is presented in figure 3. A comparison of the concentration of the groundwater Extractible petroleum hydrocarbon values with EGASPIN intervention values, showed four groundwater exceedences (Table 2, Fig. 3**)**.

3.4 Groundwater Polycyclic Aromatic Hydrocarbons (PAH)

A comparison of the groundwater PAH concentration with the EGASPIN intervention values, revealed three exceedences for total PAH in boreholes 13, 16 and 20, while one each was recorded for Naphthalene, Fluoranthrene, Phenanthrene and Benzo(a)anthracene, (Table 2, Fig. 4).

3.5 Groundwater Volatile Organic Compounds (VOCs)

Within the VOCs, four exceedences each were recorded for Benzene and the Xylenes. Two exceedences were recorded for Toluene, while Ethylbenzene recorded three exceedences (Table 12Fig. 5).

Table 2: Groundwater chemical data for the study site compared against EGASPIN intervention values

Determined	**Count**	**Min (µg/L)**	**Max (µg/L)**	**EGASPIN Intervention Value (µg/L)**	**No. of Exceedences Above Intervention Value**
			BTEX		
Benzene	04	1180	14100	30	04
Toluene	04	8.99	13,600	1000	02
Ethylbenzene	04	80.6	1310	150	03
P-xylene	04	378	7570		
M-xylene	04	378	7570	70	04
O-xylene	04	378	7570		
			EPH		
Mineral Oil (C_{10} – C_{40}), EPH	04	5710	325,000	600	04
			PAH		
Total PAH	04	68.3	676	70	03
Naphthalene	04	62.2	583	70	01
Fluoranthrene	04	0.0588	1.95	1	01
Anthracene	04	<0.03	<0.15	5	0
Phenanthrene	04	0.918	41.1	5	02
Benzo(a)anthracene	04	<0.034	0.922	0.5	01

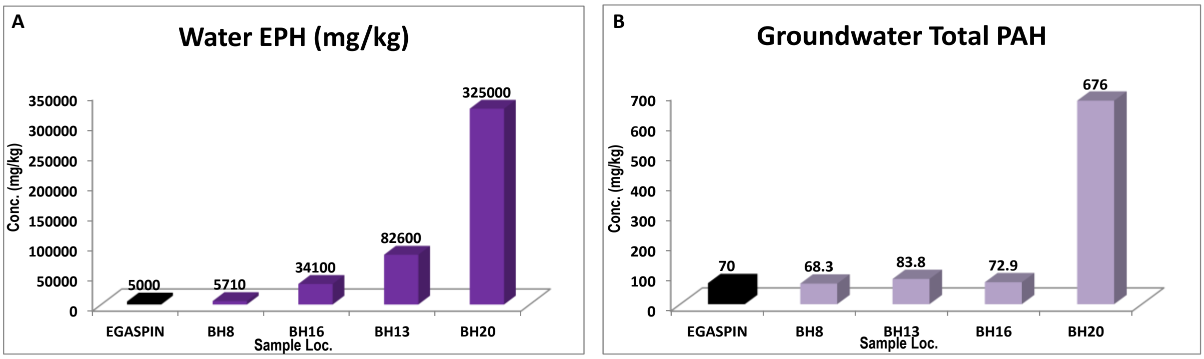

Fig. 3: Concentrations of groundwater EPH and PAH values above the EGASPIN intervention value at the Eneka spill site.

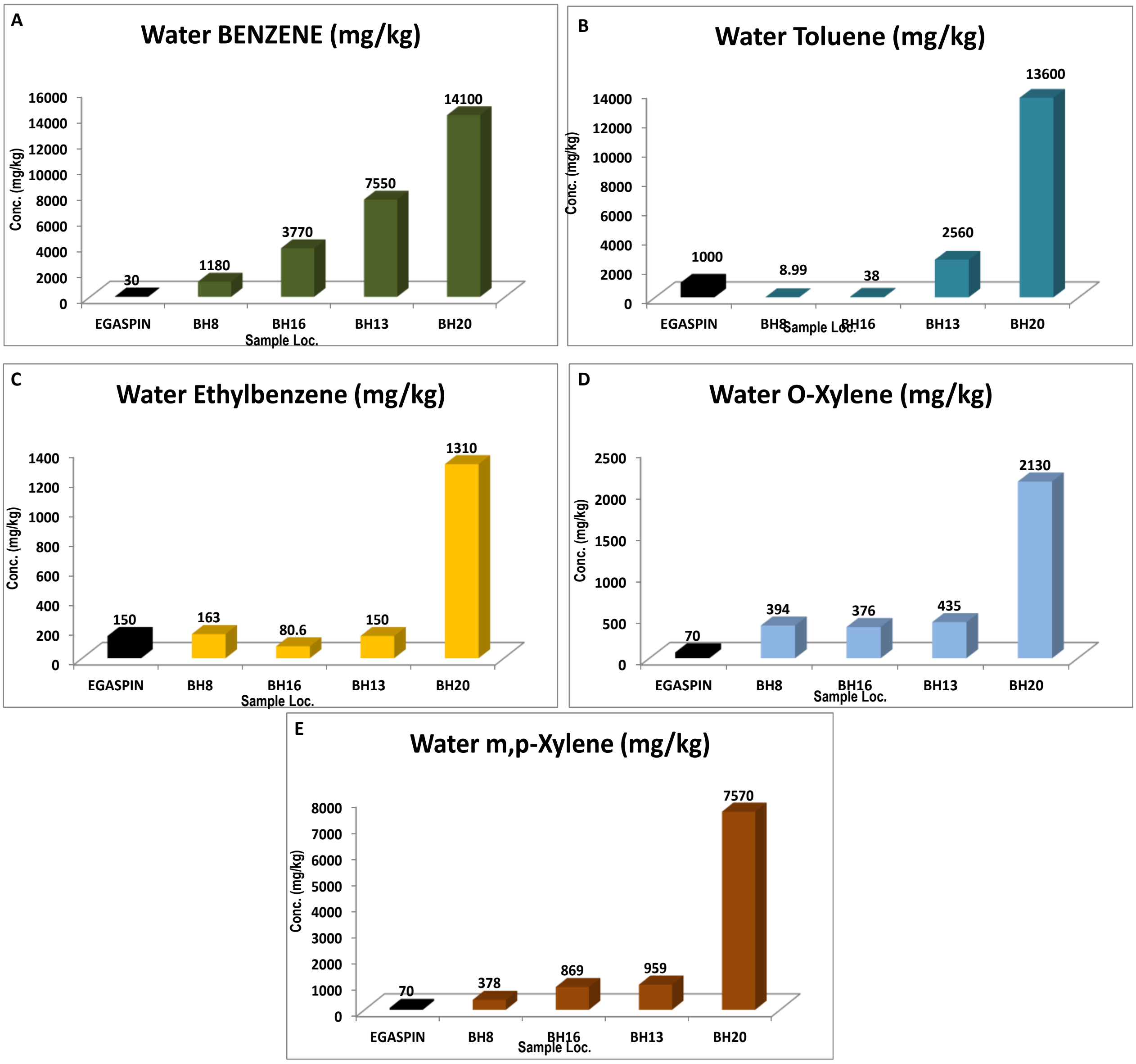

Fig. 5: Concentrations of groundwater VOC`s relative to EGASPIN intervention value at the Eneka spill site. A: Benzene. B: toluene. C: Ethylbenzene. D: O-Xylene. E: m/p-Xylene.

3.6 Groundwater and Free Phase Oil Flow of Eneka Spill Site

A subsurface contour map of groundwater and free phase oil encountered at depth across the site indicate that two areas of groundwater high and low occur in the central aspect of the spill site (Fig. 6 and 7). The groundwater high exists west of the central area around well 14, while the low occur in the eastern aspects of the central area around wells 7 and 11. A southwest flowing trend exist in the southern part of the spill area, where the flow is observed to flow towards wells 15, 18, 19 and 20 (Fig. 7). Across the site, free phase oil was encountered on top of the water table in sixteen wells with thickness increasing toward the southern aspect of the spill area, probably indicating a dominant southward flow direction toward built-up area (Fig. 7).

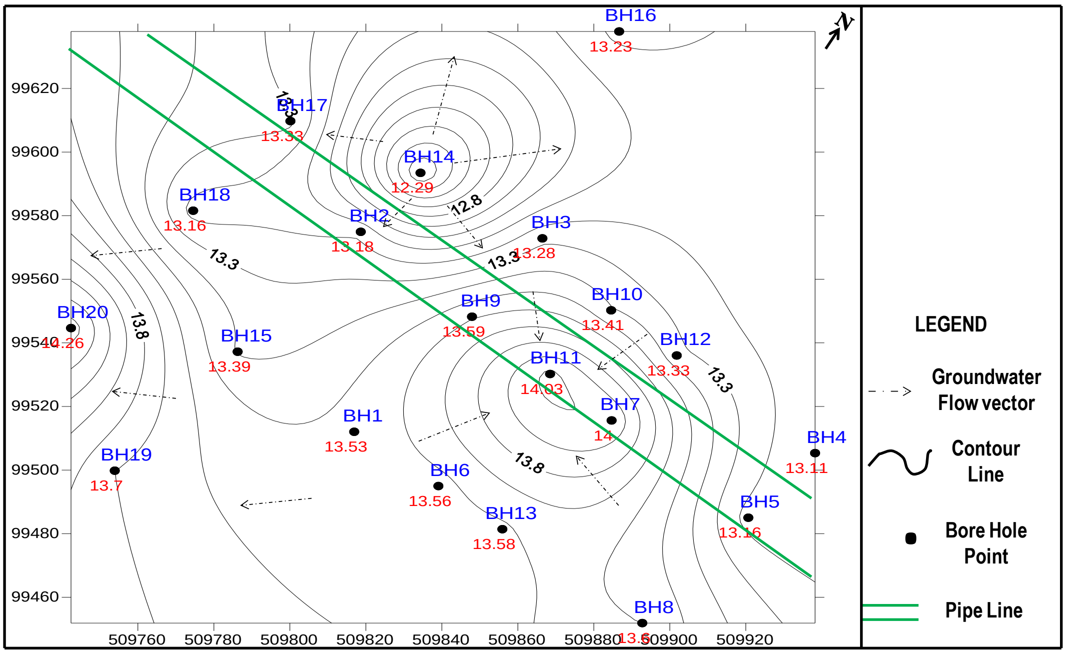

Fig. 6: Top Groundwater level contour map at the site

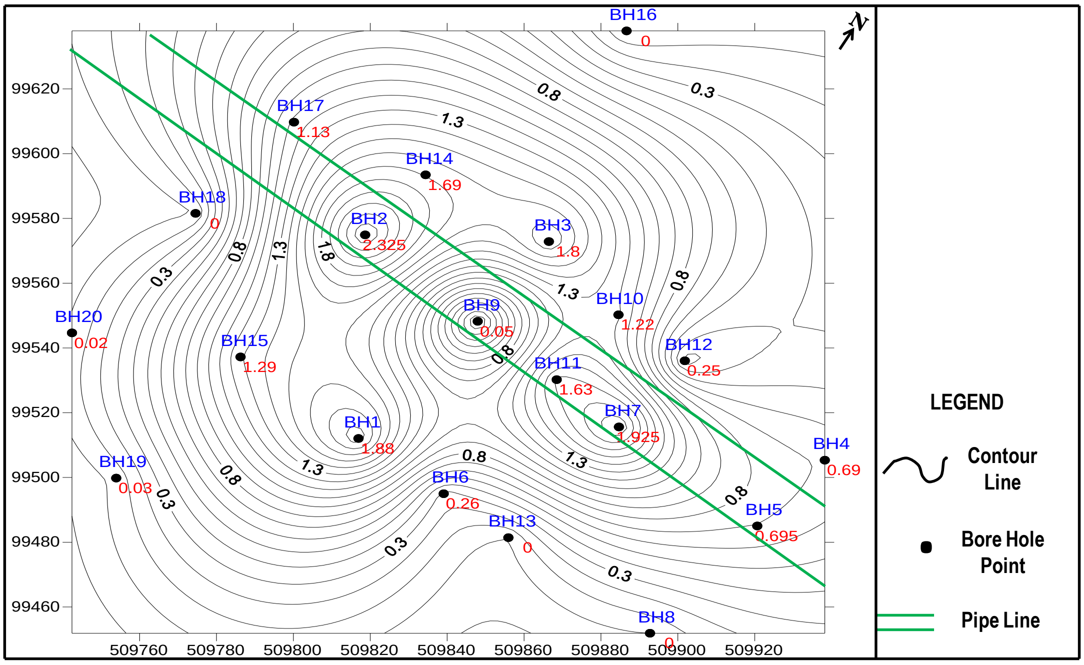

Fig. 7: Subsurface oil thickness contour map at the site.

The high contaminant concentration values obtained from the groundwater analysis reveal the vulnerability of the local geosystem to pollution associated with oil exploitation activities. Since the study location is a microcosm of the general sedimentologic and stratigraphic frame of the Niger Delta surface geology, exemplifies the environmental vulnerability of the Niger Delta region. Characteristically, oil is immiscible with water, hence will "float" on water (Chilton, 1992), as observed on the water table in the site. The aromatics present in oil also display this attribute, which due to their low density and high viscosity in the immiscible phase, tend to "float" at the water table also. Lawrence and Foster (1987), noted that the transport of immiscible phase pollutants in groundwater is governed by completely different factors from those which determine groundwater flow, notably density and viscosity of the immiscible fluid. This implies that subsequent lateral subsurface transport of such pollutants will be governed by hydraulic gradient. This mechanism lead to invasion of offsite groundwater bodies. Also, in this situation, the contaminants can rise with rising water levels and during subsequent recession, the contaminants may be held by surface tension effects in the pore spaces of the unsaturated zone (Chilton, 1992), where continuous dissolution and transport to groundwater becomes the keynote and also made available to invading plant roots.

Conclusion

Following the chemical data characteristics of the groundwater with respect to EPH, PAHs and VOCs, it is can be concluded that:

1. The oil spill at the investigation site was a potential environmental contaminant.
2. A pathway exist in the site (permeable and conductive sediments) through which potential contaminants (spilled oil) infiltrated the groundwater in the spill vicinity.
3. Based on comparison of assessment chemical data and

regulated standards, the groundwater body in the spill vicinity is impacted by the oil spilled at the site hence, the site is due for clean-up and remediation of soil and groundwater.

4. The “origin-pathway-target” model approach applied in this study, has proven to be a veritable tool in assessing the groundwater contamination in the vicinity of an oil spill.

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