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Modeling and assessment of human health risks from exposure to hydrocarbon contaminated soils in parts of bonny, Rivers State, Nigeria

Nwankwoala HO[1*], Omofuophu E[2]
[1-2] Department of Geology, University of Port Harcourt, Nigeria

Abstract
The objective of this study was to establish the presence of contaminants of concern (CoC), determine, quantify and model spilled volume and ascertain potential health risk associated with the spill incident. The CoC include Total Petroleum Hydrocarbons (TPH), Polyaromatic Hydrocarbons (PAH) and BTEX compounds. The 3-D grid populated with the various modeled CoC, cross-sections and depth slices extracted from the model revealed that the CoC concentrations generally decreases with depth, with the highest concentrations centered towards the south-eastern part of the study area (Shell Tank Farm). The PAH model revealed that 563,000m^3 of the total volume of the modeled area (47% of the area) exceeded DPR target value of 1.0mg/kg. The TPH concentration in all locations exceeded DPR target value of 50mg/kg while 222,500m^3 of the modeled area (19% of the area) exceeded the intervention value of 5000 mg/kg. For BTEX, only 3% of the area exceeded the target value of 0.4mg/kg. Carcinogenic risk assessment for children and adults using both ingestion and dermal contact pathways showed that BS-1, BS-6, BS-7, BS-8 and BS-9 are carcinogenic to children while BS-7, BS-8 and BS-9 are carcinogenic to adults with the main contribution from Benzo (a) anthracene. PAH was recorded only at BW-1, (0.13µg/L), BW-3 (1.07µg/L) and BW-4 (0.25µg/L). Meanwhile BTEX compounds had concentration (5910µg/L) that exceeded DPR target value of 0.8µg/L over 7000 times. BS-10 is most deteriorated in soil quality. Soil sampling locations were cited within the tank farm vicinity, hence, might not pose much health risk to the surrounding communities because they are all positioned at higher hydraulic heads. This research therefore recommends that remedial actions be taken immediately to prevent health risk to workers in the tank farm area

Keywords: modeling, contaminants, potential health risk, soil quality, exposure, hazards, risk assessment

Introduction

The assessment of health hazards produced by oil exploration, exploitation and production is an important environmental issue in order to ensure the wellbeing of people. Recently, a lot of environmental professionals globally have begun concentrating efforts on risk-based approaches to remediate petroleum contaminated sites.

Human health risk assessment evaluates the probability and frequency of hazard, and the magnitude of the consequence (Nathanail, 2013) [9]. The procedure examines the presence of and concentration of chemical substances to determine if risk is acceptable or not. For the assessment of environmental risks associated with soil and groundwater contamination with petroleum hydrocarbons, it is important to evaluate the sources (spatial distribution and pathways) of TPH in soil and groundwater. Risk assessment includes detailed site characterization, human and ecological risk quantification, and selection of remedial aims (Sharma and Reddy, 2004) [14]. If contaminants levels after the risk assessment are unacceptable, remedial action must be selected and implemented to achieve the remedial aims in an efficient and cost effective manner. Soil being a "universal sink" bears the greatest burden of environmental pollution. Risk assessment procedures are generally based on the source-pathway-receptor model (ASTM, 1995; CONCAWE, 2003) [1, 5] and encompass the examination of the site characteristics, the environmental behavior and toxicity of the contaminants, the potential route of entry of the contaminants into the receptors (humans), the exposure of the receptors to the contaminants and their response to the dose. Thus, site characterization is the basis for risk assessment. Although much scientific literature is developing on risk assessment issues (Ferguson, 1996) [7], comparatively little attention is paid to the characterization (Carlon, 2001) [3].

Risk assessment is a systematic evaluation of the potential risk posed by contamination to the environment components and the ecosystems under present and future conditions. The development of human health and ecological risk-based standards is a key step in the site risk assessment process. Risk-based standards are used to: (i) Determine whether a remedial response action is necessary; (ii) Identify target cleanup levels in the event that a remedial action is required, and (iii) Document that a level of contamination to protect the human health and the environment been achieved at a site.

Polycyclic aromatic hydrocarbons are important widespread environmental pollutants, which are formed and released into environment through natural and anthropogenic sources. They are toxic; some of them carcinogenic, persistent and bioaccumulative compounds. The effects on human health will depend mainly on the length and route of exposure, the amount or concentration of PAHs one is exposed to, and of course the innate toxicity of the PAHs. A variety of other factors can also affect health impacts including subjective factors such as pre-existing health status and age. The ability of PAHs to induce short-term health effects in humans is not clear (Unwin *et al*., 2006) [16]. Occupational exposures to high levels of pollutant mixtures containing PAHs have resulted in symptoms such as eye irritation, nausea, vomiting, diarrhoea and confusion. Since the end of the 18th century, many PAHs were recognized as carcinogens and mutagens. It has been proven that some of them induce skin cancer and there are suspicions that some PAHs may induce lung cancer. However, carcinogenic activity is observed only after exposure to high concentrations for a long time.

Like many other environmental chemicals that are associated with breast cancer risk, PAHs are lipophilic and are stored in the fat tissue of the breast. PAHs have been shown to increase risk for breast cancer through a variety of mechanisms. The most common PAHs are weakly estrogenic (estrogen mimicking), due to interactions with the cellular estrogen receptor (Pliskova *et al*., 2005). PAHs can also be directly genotoxic, meaning that the chemicals themselves or their breakdown products can directly interact with genes and cause damage to the de-oxy ribonucleic acid (DNA) (Teaf, 2008) [15]. Several epidemiological studies have implicated PAH exposure in increased risk for breast cancer. One of the studies from the Long Island breast cancer study project found that women with the highest level of PAH-DNA adducts had a 50 percent increased risk of breast cancer. PAH-DNA adducts are indicators of problems in DNA repair in cells, one of the early hallmarks of tumour development (Xu *et al*., 2012) [24]. The Centre for Children's environmental health reports that exposure to PAH pollution during pregnancy is related to adverse birth outcomes including low birth weight, premature delivery, and heart malformations. Detrimental long-term, high-level exposure may lead to consequences including cataracts, kidney and liver damage, jaundice, and skin irritation and redness, specifically for naphthalene contact. The immune system also is vulnerable and benzo [*a*] pyrene (B (a) P) in large doses suppresses the system and damages erythrocytes. Laboratory research on female rats, as summarized by the Cornell university program on breast cancer and environmental risk factors (BCERF, 2001) [2], indicated that breast tissue injection and consistent high dose ingestion of B (a) P and dibenzo (a,l) pyrene caused a significant increase in the development of breast cancer (BCERF, 2001) [2]. However, these results have not been proven with any consistency in human studies. Sebastian *et al*. (2001) [13] observed that excessive cancer and leukaemia in workers and children living near petrochemical industries could be linked to contaminants from oil production.

Oil spills are common environmental issues prevalent in the Niger Delta region. These spills could occur in a number of ways, including; drilling operations, production operations, transportation of crude oil and also from storage facilities. A major cause of oil spill in the Delta arises from pipeline vandalisation and illegal bunkering activities. Oil spills on the environment eventually leads to soil and groundwater contamination, with a huge deleterious effect on plants, human health and wildlife. In Bonny area, there was a spill incident that occurred from shell's facility during the first quarter of 2017. Hence, this risk assessment study was conducted to determine the health implication on the residents as well as evaluate results to assess the human health risk in the area.

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 (Figure 1). The North and Western part of the study area is bounded by Bonny River, to the South of the area 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 area is assessable through Bonny River and other tarred roads in the area.

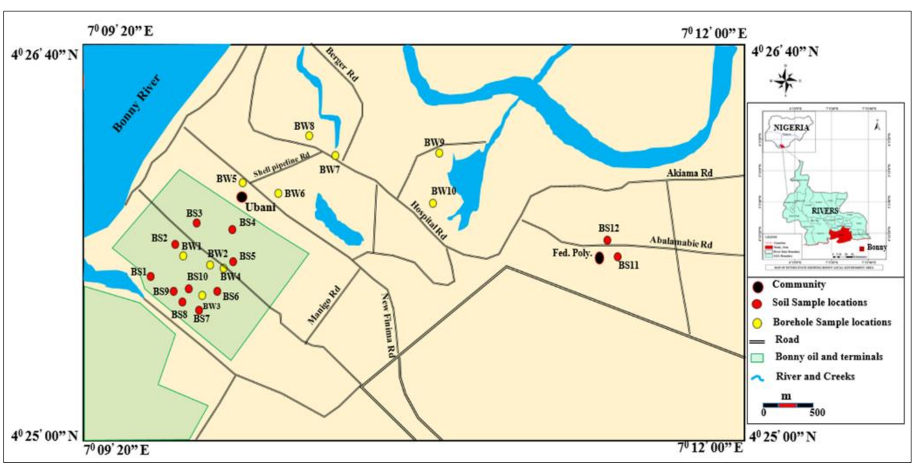

Fig 1: Map of the study area showing soil and groundwater sampling locations in Bonny

Table 1: Soil Sample locations in the study area

S/N	Code	Location	Longitude	Latitude	Type of sample
1	BS-1	Bonny oil and gas terminal	7° 9'32.42"E	4°25'40.11"N	Soil
2	BS-2	Bonny oil and gas terminal	7° 9'36.73"E	4°25'46.47"N	Soil
3	BS-3	Bonny oil and gas terminal	7° 9'44.00"E	4°25'54.33"N	Soil
4	BS-4	Bonny oil and gas terminal	7° 9'53.62"E	4°25'52.53"N	Soil
5	BS-5	Bonny oil and gas terminal	7° 9'55.14"E	4°25'44.30"N	Soil
6	BS-6	Bonny oil and gas terminal	7° 9'51.53"E	4°25'37.20"N	Soil

7	BS-7	Bonny oil and gas terminal	7° 9'46.68"E	4°25'32.85"N	Soil
8	BS-8	Bonny oil and gas terminal	7° 9'40.93"E	4°25'31.91"N	Soil
9	BS-9	Bonny oil and gas terminal	7° 9'39.26"E	4°25'36.40"N	Soil
10	BS-10	Bonny oil and gas terminal	7° 9'38.67"E	4°25'39.94"N	Soil
11	BS-11	Federal Polytechnic, Bonny	7°11'40.29"E	4°25'45.91"N	Soil (Control)
12	BS-12	Federal Polytechnic, Bonny	7°11'37.11"E	4°25'48.47"N	Soil (Control)

Table 2: Standard laboratory procedures and methods for analysis of petroleum compounds

Chemical compound	Unit	Laboratory standard	Method
TPH	mg/kg	USEPA 8015	Gas Chromatography with flame ionisation detector
PAH			Gas Chromatography-Mass spectrometer
Naphthalene	mg/kg	USEPA 8270	
Acenaphthylene	mg/kg	USEPA 8270	
Acenaphthene	mg/kg	USEPA 8270	
Fluorene	mg/kg	USEPA 8270	
Anthracene	mg/kg	USEPA 8270	
Phenanthrene	mg/kg	USEPA 8270	
Fluoranthene	mg/kg	USEPA 8270	
Pyrene	mg/kg	USEPA 8270	
Benzo (a) anthracene	mg/kg	USEPA 8270	
Chrysene	mg/kg	USEPA 8270	
Benzo (b) fluoranthene	mg/kg	USEPA 8270	
Benzo (k) fluoranthene	mg/kg	USEPA 8270	
Benzo (a) pyrene	mg/kg	USEPA 8270	
Dibenz(a,h)anthracene	mg/kg	USEPA 8270	
Indeno(1,2,3-cd)pyrene	mg/kg	USEPA 8270	
Benzo (g,h,i) perylene	mg/kg	USEPA 8270	
BTEX			Gas Chromatography with Photo ionisation detector
Benzene	mg/kg	USEPA 8260	
Toluene	mg/kg	USEPA 8260	
Ethylbenzene	mg/kg	USEPA 8260	
m. p-Xylene	mg/kg	USEPA 8260	
o-Xylene	mg/kg	USEPA 8260	

Carcinogenic Risk Assessment

In order to determine the risk of cancer, human exposure pathways, toxicity, frequency of exposure and duration should be known amongst other parameters. USEPA (1991) [22] established a parameter for every carcinogenic compound (the slope factor), and it defines the relationship between dose and response. According to USEPA (2016) [23], this represents an estimated value for toxicity. To determine cancer risk, the following were considered: oral slope factor, frequency and the duration of exposure, daily intake (calculated based on concentration of each chemical), and so on (OEHHA, 2015) [11]. The OEHHA (2004) [10] parameters were utilized in the USEPA equations. In this study, cancer risk, for both children and adults were assessed using the equations:

$$\text{Cancer Risk} = \text{I(dose)} \times \text{SF} \qquad (1)$$

Where:
I = chronic daily intake (dose) (mg/kg/day)
SF= slope factor $(\text{mg/kg/day})^{-1}$
Where the cancer risk is arising from different contaminants of concern, the total risk is calculated as the sum of all risks generated by each pollutant for each exposure pathway:

$$\text{Risk} = \sum \text{Risk}_i \qquad (2)$$

Where;
Risk_i = estimated risk for each substance
The pathways of human exposure analyzed in this study are soil ingestion and dermal contact, adopting the recreational exposure scenario. Estimated doses were calculated by the equations below:

1. Ingestion of chemicals in soils:

$$\text{Dose}_{si} = \left[\frac{\text{CS}\times\text{CF}\times\text{IR}\times\text{FI}}{\text{BW}}\right] \times \left(\frac{\text{EF}\times\text{ED}}{\text{AT}}\right) \qquad (3)$$

2. Exposure through dermal contact:

$$\text{Dose}_{dc} = \left[\frac{\text{CS}\times\text{CF}\times\text{SA}\times\text{AF}\times\text{ABS}\times\text{EF}\times\text{ED}}{\text{BW}\times\text{AT}}\right] \qquad (4)$$

For calculating exposure through soil ingestion (Dose_{si}) and dermal contact (Dose_{dc}) the following were utilized: chemical concentration in soil (CS in mg/kg), exposure frequency (EF in events/year), fraction ingested from the contaminated source (FI, unitless), conversion factor (CF = 10^{-6} kg/mg), ingestion rate (IR, mg soil/day), body weight (BW in kg), exposure duration (ED in years), skin surface area available for contact (SA in cm^2/event), average time (AT in days), soil to skin adherence factor (AF in mg/cm^2), and the absorption factor (ABS, unitless).
Table 3 illustrates the known absorption factors (ABS) and cancer slope factors (CSF) used in this study to investigate carcinogenic risk. Parameters used for calculating exposure through dermal contact and soil ingestion are presented in Table 4. In this study, 32 kg was used as the body weight for children while, for adults, 70 kg was used. The average time (AT) taken into account is 2560 days for children (7 years) and 25,600 days for adults (70 years) while the exposure duration was taken as five years for children and 21 years for adults. All these parameters were gotten from Connor *et al*., (2007) software manual.

Table 3: Cancer slope factors and Adsorption Factors (dermal contact and oral ingestion)

Substance	Cancer Slope Factor $(\text{mg/kg/day})^{-1}$	Absorption Factors	Reference
Benzene	3.50E-02	1.30E-01	USEPA (2000) [21]
Ethylbenzene	1.10E-02	1.30E-01	NJDEP (2009)

Anthracene	2.30E-01	1.30E-01	HC2 (2007)
Benz[a]anthracene	1.20E+02	1.30E-01	USEPA (2003) [24]
Benzo[a]pyrene	1.20E+01	1.30E-01	USEPA (2003) [22]
Benzo[b]fluoranthrene	1.20E+00	1.30E-01	USEPA (2003) [21]
Benzo[k]fluoranthrene	1.20E+00	1.30E-01	USEPA (2003) [22]
Crysene	1.20E-01	1.30E-01	USEPA (2003) [22]
Dibenzo [a,h] anthracene	4.10E+00	1.30E-01	USEPA (2003) [22]
Fluoranthene	2.30E-02	8.00E-02	HC2 (2007)
Phenanthrene	2.30E-03	2.00E-01	HC2 (2007)

Table 4: Parameters used for exposure assessment (Adopted from Cocarta *et al*., 2017)

	Dermal Contact		
	SA–Skin Surface Area (cm^2/Event)	ED–Exposure Duration (Days)	EF–Exposure Frequency (Days/Year)
Children	5.14×10^3	1.82×10^3	1.50×10^1
Adults	9.11×10^3	7.66×10^3	3.00×10^1
	Soil Ingestion		
	FI–Fraction Ingested from Contaminated Soil (-)	IRs–Soil Ingestion Rate (mg/Day)	EF–Exposure Frequency (Days/Year)
Children	1.00×10^{-1}	1.50×10^2	9.00×10^1
Adults	3.00×10^{-1}	1.00×10^2	1.20×10^2

Results and Discussion

Health Risk Assessment and Modeling

The total carcinogenic risk arising from the oil contaminated soils in the study area were analyzed for two major exposure pathways (ingestion and dermal contact) using children and adults as case studies. Among the 16 Polyaromatic hydrocarbons identified in soils from the area, 9 chemicals were considered as contaminants of concern (COC) for carcinogenic risk assessment (Tables 5 and 6). From the BTEX group of contaminants, benzene and ethylbenzene were the main COC. These COC were selected based on USEPA (1991; 2006) [20], which suggests that their toxicological profiles are recognized as carcinogenic for humans. The results for carcinogenic risk assessment for children and adults are presented in Table 6. Total carcinogenic risks along with WHO (2012) [23] regulatory limit are presented in Table 6 and Figure 8. Detailed step-wise procedures and constants used for carcinogenic risk assessment are presented in the Appendix. The Total Petroleum Hydrocarbons were not be used for risk assessment because the general measure of TPH provides insufficient information about the amounts of individual COC present.

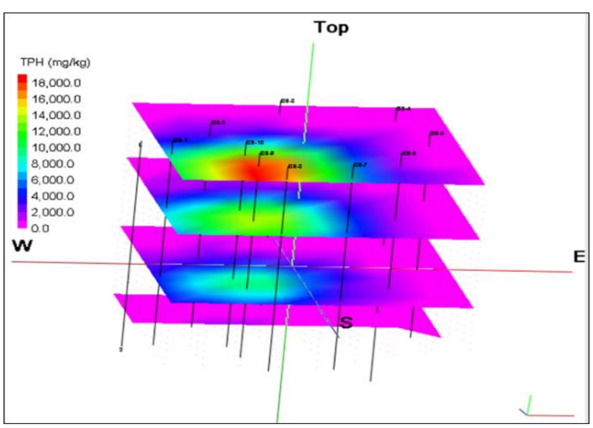

Fig 2: Depth slices extracted from the 3-D TPH grid model at 0.1m, 0.5m, 1.0m and 1.5m around the spill area

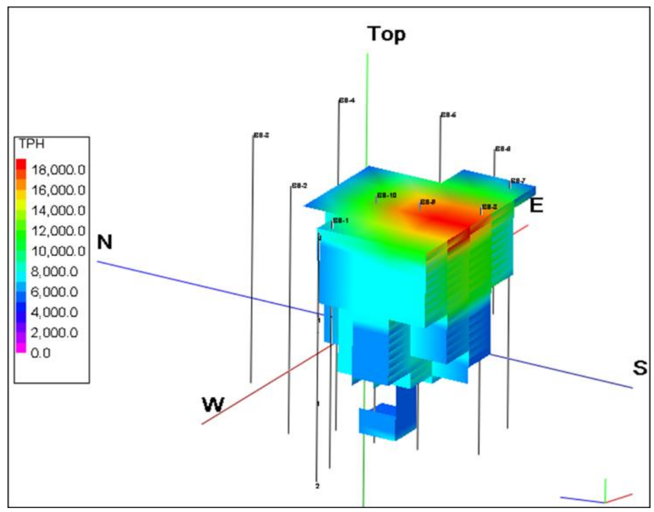

Fig 3: 3-D block model showing the horizontal and vertical variations in TPH concentration around the spill area after applying the DPR intervention value (5000 mg/kg) as a cutoff (Volume 222,500m^3)

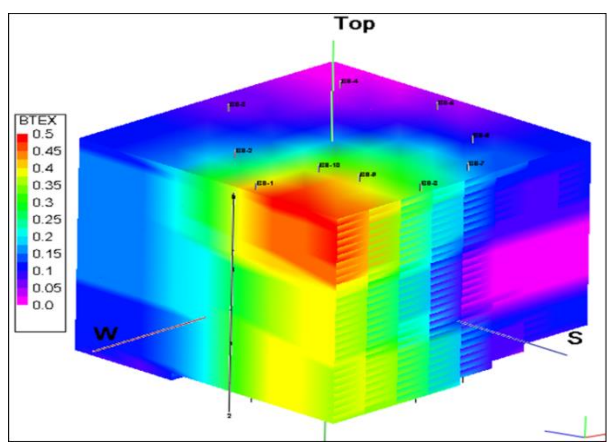

Fig 4: 3-D block model showing the horizontal and vertical variations in BTEX concentration around the spill area

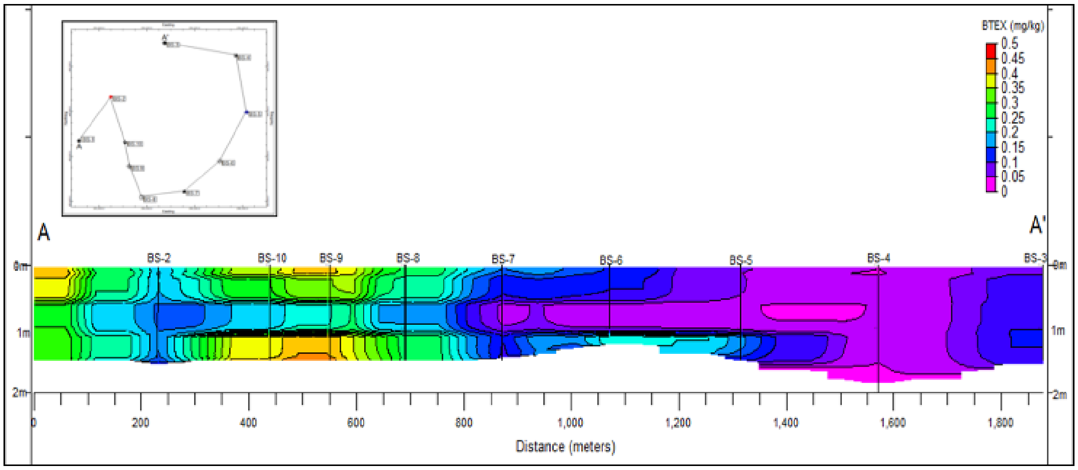

Fig 5: A cross-section across the entire wells showing BTEX variations with depth

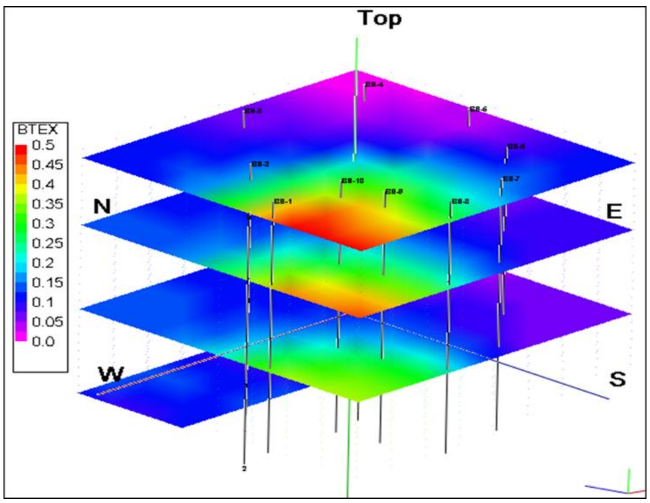

Fig 6: Depth slices extracted from the 3-D BTEX grid model at 0.1m, 0.5m, 1.0m and 1.5m around the spill area

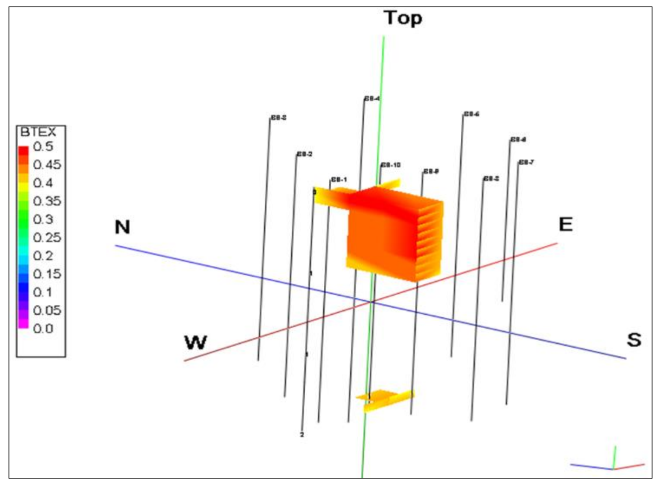

Fig 7: 3-D block model showing the horizontal and vertical variations in BTEX concentration around the spill area after applying the DPR target value (0.4 mg/kg) as a cutoff (Volume 40,000m^3)

Table 5: Results of carcinogenic risk assessment in Children from soils in the study area (Total from dermal contact and soil ingestion)

Parameter	BS-1	BS-2	BS-3	BS-4	BS-5	BS-6	BS-7	BS-8	BS-9	BS-10
Anthracene	5.38E-09	8.64E-10	-	4.32E-10	2.88E-10	2.88E-09	4.97E-09	2.86E-08	1.66E-08	1.56E-08
Phenanthrene	2.59E-11	7.20E-12	-	2.88E-12	-	5.76E-12	2.30E-11	2.88E-10	3.28E-10	9.14E-11
Fluoranthene	2.50E-10	2.16E-10	-	4.32E-11	-	3.17E-10	1.46E-09	3.60E-10	2.49E-09	8.42E-10
Benzo (a) anthracene	1.25E-06	4.51E-07	-	3.01E-07	-	1.15E-06	5.11E-06	5.63E-06	1.00E-05	-
Chrysene	1.45E-09	7.51E-10	1.50E-10	6.01E-10	-	1.35E-09	4.32E-09	6.42E-09	5.07E-09	1.50E-09
Benzo (b) fluoranthene	3.51E-09	1.50E-09	-	-	-	1.55E-08	2.48E-08	1.43E-08	2.37E-08	6.76E-09
Benzo (k) fluoranthene	3.01E-09	7.51E-09	1.50E-09	-	-	1.45E-08	4.58E-08	3.76E-09	9.77E-09	1.88E-08
Benzo (a) pyrene	7.01E-08	7.51E-08	1.50E-08	-	1.50E-08	9.52E-08	2.55E-07	5.26E-08	7.51E-08	1.20E-07
Dibenz(a,h)anthracene	6.85E-09	6.85E-09	6.42E-09	5.13E-09	5.13E-09	2.91E-08	6.55E-08	1.28E-08	1.54E-08	2.05E-08
Benzene	7.61E-11	7.61E-11	7.61E-11	-	-	-	1.02E-10	-	3.33E-09	-
Ethylbenzene	1.85E-10	7.07E-11	-	-	-	-	6.52E-11	-	5.64E-09	1.03E-10

Table 6: Results of carcinogenic risk assessment in Adults from soils in the study area (Total from dermal contact and soil ingestion)

Parameter	BS-1	BS-2	BS-3	BS-4	BS-5	BS-6	BS-7	BS-8	BS-9	BS-10
Anthracene	3.06E-09	4.9E-10	-	2.5E-10	1.6E-10	1.64E-09	2.8E-09	1.63E-08	9.43E-09	8.9E-09
Phenanthrene	1.48E-11	4.1E-12	-	1.6E-12	-	3.28E-12	1.3E-11	1.64E-10	1.87E-10	5.2E-11
Fluoranthene	1.42E-10	1.2E-10	-	2.5E-11	-	1.8E-10	8.3E-10	2.05E-10	1.42E-09	4.8E-10
Benzo (a) anthracene	7.13E-07	2.6E-07	-	1.7E-07	-	6.56E-07	2.9E-06	3.21E-06	5.71E-06	-
Chrysene	8.27E-10	4.3E-10	8.6E-11	3.4E-10	-	7.7E-10	2.5E-09	3.66E-09	2.89E-09	8.6E-10
Benzo (b) fluoranthene	2E-09	8.6E-10	-	-	-	8.85E-09	1.4E-08	8.13E-09	1.35E-08	3.9E-09

Benzo (k) fluoranthene	1.71E-09	4.3E-09	8.6E-10	-	-	8.27E-09	2.6E-08	2.14E-09	5.56E-09	1.1E-08
Benzo (a) pyrene	3.99E-08	4.3E-08	8.6E-09	-	8.6E-09	5.42E-08	1.5E-07	3E-08	4.28E-08	6.8E-08
Dibenz(a,h)anthracene	3.9E-09	3.9E-09	3.7E-09	2.9E-09	2.9E-09	1.66E-08	3.7E-08	7.31E-09	8.77E-09	1.2E-08
Benzene	4.21E-11	4.2E-11	4.2E-11	-	-	-	5.6E-11	-	1.84E-09	-
Ethylbenzene	1.08E-10	4.1E-11	-	-	-	-	3.8E-11	-	3.31E-09	6.1E-11

Table 7: Total carcinogenic risk obtained from soil assessment in the study area

Location	Children (7 years)	Adult (70 years)		
	Total Cancer risk	Interpretation	Total Cancer risk	Interpretation
BS-1	1.34E-06	YES	7.65076E-07	NO
BS-2	5.44E-07	NO	3.09762E-07	NO
BS-3	2.32E-08	NO	1.31993E-08	NO
BS-4	3.07E-07	NO	1.74737E-07	NO
BS-5	2.04E-08	NO	1.16486E-08	NO
BS-6	1.31E-06	YES	7.46758E-07	NO
BS-7	5.51E-06	YES	3.13963E-06	YES
BS-8	5.75E-06	YES	3.27781E-06	YES
BS-9	1.02E-05	YES	5.80342E-06	YES
BS-10	1.84E-07	NO	1.05078E-07	NO
WHO	1.00E-06	1.00E-06		

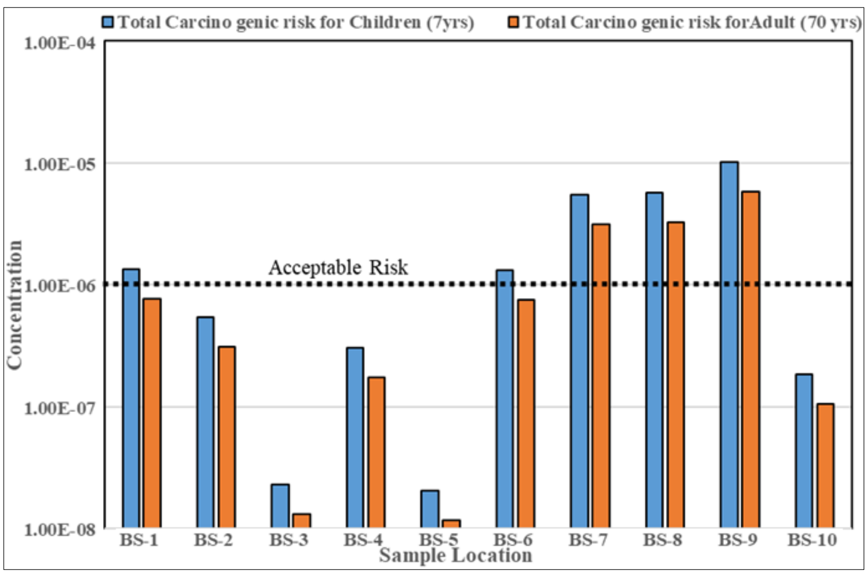

Fig 8: Total carcinogenic risk from crude oil contaminated soils in the investigation area

The acceptable carcinogenic risk as recommended by WHO (2012) for all COC is 1 x 10^{-6} (Table 7). The results of carcinogenic risk assessment in this study show that BS-1, BS-6, BS-7, BS-8 and BS-9 are carcinogenic to children while BS-7, BS-8 and BS-9 are carcinogenic to adults because they exceeded WHO regulatory guideline (Table 7 and Figure 8). The main contaminant contributing to the high carcinogenic risk in soils of the study area is Benzo (a) anthracene. Meanwhile, the soils in all other sample locations were within the WHO recommended guidelines.

Conclusion

The recent oil spill incident that occurred from one of Shell's tank in Bonny Island made it necessary to qualitatively determine the impact the spill has on the surrounding communities by analyzing two very important environmental media; Soil and groundwater. The study objectives included; determining the presence of contaminants of concern (TPH, PAH and BTEX) in the soils and groundwater in the area; determining the spill area and volume that exceeded regulatory guidelines; assessing the carcinogenic health risk associated with the area; determining areas that need urgent remediation action; and proffering some remedial actions to support management decision making.

The 3-D block models generated for TPH, PAH and BTEX, along with the cross-sections and extracted time slices all shows that the concentration of these COC generally decrease with depth, and the centre of the spill is located at the south-eastern part of the survey area. Based on these models, three spill zones were identified; Zone 1-highly contaminated areas (BS-8, BS-9, BS-10); Zone 2- moderately contaminated areas (BS-1, BS-2, BS-6, BS-7); and low contaminated areas (BS-3, BS-4, BS-5).

Assessment of carcinogenic risk for children and adults revealed that BS-1, BS-6, BS-7, BS-8 and BS-9 are carcinogenic to children while BS-7, BS-8 and BS-9 are carcinogenic to adults and the contaminant contributing to these high risks is Benzo (a) anthracene.

The entire soils in the area are contaminated with TPH, 47% of the area is contaminated with PAH and approximately 3% of the area is contaminated with BTEX compounds. Soils within the tank farm and Ubani (BS-1, BS-6, BS-7, BS-8) are carcinogenic to both children and adults, hence should not be used should not be used for agriculture to avoid health implications.

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