

# **Human Health Risk Assessment of Crude Oil Polluted Soil, Surface & Groundwater Sources in Emohua, Rivers State, Nigeria**

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## **Authors' contributions**

*This work was carried out in collaboration among all authors. All authors read and approved the final manuscript.*

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## **ABSTRACT**

This study was carried out to assess the human health risk associated with a crude oil spill site in Emohua Local Government Area of Rivers State, Niger Delta. The Total Content and Fraction's approaches were adopted to assess the human health risk. Total Content approach was carried out by comparing the concentration of various contaminants in the environmental media studied with the Intervention Values prescribed while the Fractions approach was carried out using RBCA Toolkit for Chemical Releases version 2.6. The results indicate that concentration indices for Total Petroleum Hydrocarbon (TPH) and Polycyclic Aromatic Hydrocarbon (PAH) were greater than the acceptable limit of 1.0 for both the maximum and mean concentrations in soil and groundwater, indicating unacceptable risk at this site. The result from the Fraction's approach showed that carcinogenic risks are identified for the site through the soil and groundwater exposure pathways as the Total Risk Values for soil ( $1.7 \times 10^{-3}$ ) and groundwater ( $5.6 \times 10^{-1}$ ) are higher than the target risk of  $1.0 \times 10^{-5}$  while toxic effects risks are identified for all pathways in the site with Total Health Risk Index for all four pathways greater than the applicable limit of 1.0. Ingestion of groundwater for carcinogenic risk with risk value  $5.6 \times 10^{-1}$  and inhalation of indoor air for non-carcinogenic risk Health Risk Index of  $1.0 \times 10^4$  are identified as the major contributing exposure pathways at this study site. It was therefore concluded that the study site poses unacceptable risk to human health and needs immediate intervention.

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**Keywords:** Human Health, Risk Assessment, Total Petroleum Hydrocarbon (TPH), Concentration Index, Intervention Value, Niger Delta.

## 1. INTRODUCTION

The increasing dependence on petroleum products for fuels and industrial stock since the industrial revolution [1] has led to extensive crude oil exploration and production activities [2]. This is further accentuated in Nigeria as crude oil is the main export product and revenue earner for the Nigerian government. [3] reported that oil spill is a major detrimental effect of the world's dependence on oil-based technology and further identified pipeline ruptures, tank overflows, well blowouts, activities of vandals, equipment failures as sources of crude oil pollution. The continuous use of petroleum hydrocarbons has led to widespread soil and groundwater contamination all over the world with the main sources of these contamination arising from oil exploration activities, pipeline ruptures, underground tank leakages, waste pits in oil production facilities and refinery waste [4]. In Nigeria the increasing oil exploration and production activities has led to increased incidence of oil spills in the Niger Delta [5].

In the Niger Delta region where oil is found in Nigeria oil spills are caused by pipeline corrosion, poor maintenance of infrastructure, spills and leaks at the well head, human error, theft of oil and intentional vandalism; and access roads, gas flaring, dredged spoils and flow stations are near homes, schools, farms and within communities [6], hence hundreds of thousands of people in the Niger Delta are exposed to oil contamination.

[1] reported that crude oil spills are tragic environmental disasters that can cause severe health problems, disturb the ecosystem and pollute the environment and further noted that oil spills affect human health through chemical exposure and by the psychological and socio-economic impact on the affected individuals and their communities.

[1] identified four categories of potential health risks of crude oil spills as follows;

- i. Safety of workers,
- ii. Toxic effects in workers, who work at the oil extraction platforms/facilities and those participating in cleanup activities of spills, visitors, and community members,
- iii. Mental health effects from social and economic disruptions and

- iv. Ecosystem effects that have consequences on human health.

Human health risk assessment is the process of characterizing the magnitude and nature of health risks to humans from chemicals and other stressors that may be present in the environment [7] and majorly attempt to answer four questions viz the adverse health effects of human exposure to a chemical; maximum permissible chemical concentration level; duration of exposure and the relationship between concentrations of a chemical in environmental media and the incidence/severity of potential adverse human health effects [8]. The fundamental concept of Human Health Risk Assessment of contaminated sites is based on three essential components namely contaminants (source), exposure pathways and receptors. Human health risk assessment can be completed by several methods including the use of models and there are available commercial models.

Despite the huge number of oil spill incidents in the Niger Delta of Nigeria which according to NOSDRA oil spill monitor website about 7581 oil spill incidents were reported from 2008 to 2018, there is a scanty literature on empirical studies in terms of their potential effects on human health. This view is support by [6] as they reported that human studies in relation to crude oil pollution in the Niger Delta are more or less focused on the caustic relationship between pollution and poverty and the social tension between host communities and operators rather than on potential health issues. They further asserted that despite the citation of health problems to supported community agitations, there are a few non-systematic health studies to back up these claims.

This research therefore is necessitated by the need to carryout empirical estimation of potential health risks (carcinogenic and non-carcinogenic) associated with human exposure to crude oil in Emohua Local Government Area of Rivers State in the Niger Delta of Nigeria.

## 2. MATERIALS AND METHODS

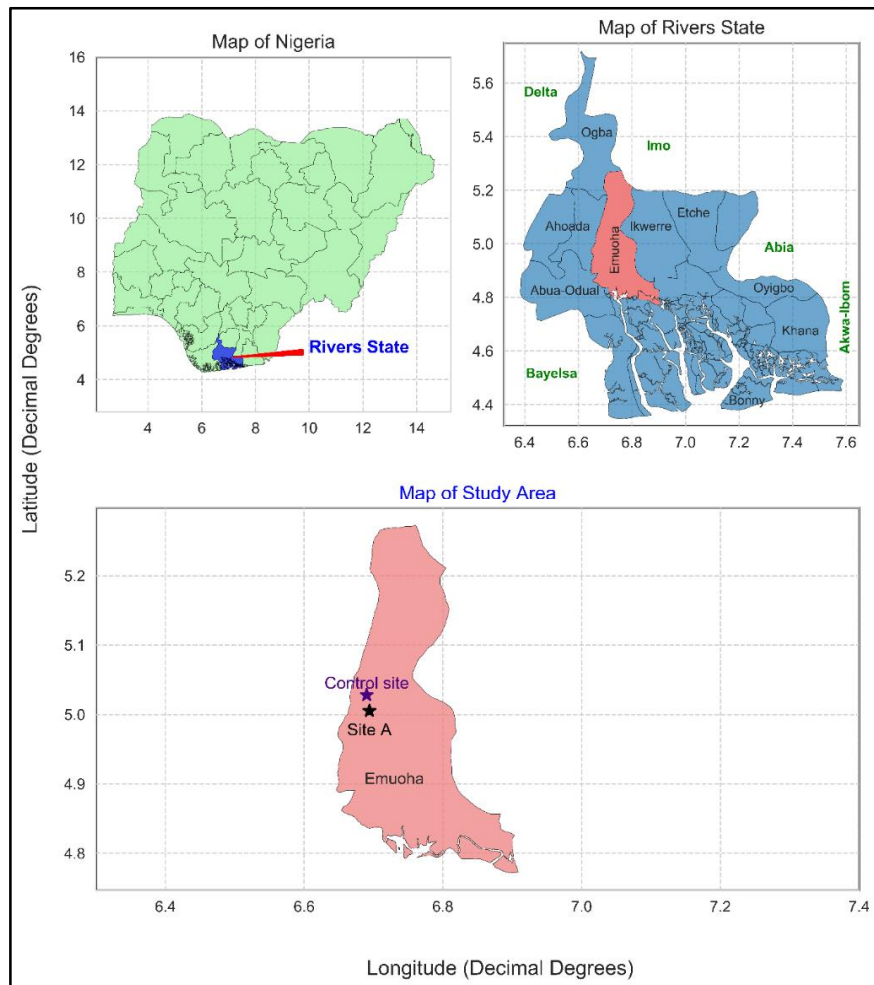
### 2.1 Study Site and Area

The study site is a crude oil spill location on geographical coordinates of longitude 6° 41' 42"E and latitude 5° 00' 19"E which is in

Emuoha Local Government Area (EMOLGA). EMOLGA is in Rivers State with a land area of about 831Km<sup>2</sup> and a population of approximately two hundred and two thousand persons (201,901) by the 2006 census figures. Fig. 1 shows map of the study area and site.

The site is in the Niger Delta of Nigeria with the land elevation generally below 20m above sea level. The area is gentle sloping and transversed by a seasonal swamp running from northeast to southwest joining the Sombriero River. The Niger Delta is a tropical rain forest with swamps and seasonally waterlogged low-lying areas, so is our study site with distinct natural vegetation. [5] reported the Niger Delta rain forest as structurally complex and floristically diverse. The sites have vegetation made up of grasses and shrubs with few scattered trees indicative of a secondary jungle forest. The major land use of the site is for

subsistence agriculture involving the cultivation of local crops mainly cassava, yam, cocoyam, maize and native vegetables. The agricultural practice is bush fallowing, which involves cultivating a piece of land in one farming season and allowing same uncultivated for a period (5 to 6 years) so that the fertility of the land will be restored before returning to cultivate the same piece of land. Bush burning is common practice in the area [9]. The site lies in a humid sub-equatorial climate characterized by wet and dry seasons. The wet season is longer and extends from March/April to October while the dry season extends from November to February. The mean annual temperature of the area is 27 (±3) degrees Celsius and the annual average rainfall is about 3000mm with average evapotranspiration of about 1000mm/year, leaving an effective rainfall of 2000mm/year [10].



**Fig. 1. Map of the Study Area**

## 2.2 SAMPLE COLLECTION

Samples of top/surface soil, sub-surface soil, surface water and ground water were collected from the site. Twenty (20) surface soil samples were collected at two horizons (1-15cm and 15-30cm) using hand auger and composited, three (3) surface water samples were collected from the site comprising of two community local fish ponds and one sample from the River Sombriero while five (5) groundwater and sub-surface sediment samples each were collected from 5 boreholes drilled and completed at the study site. All samples collected were preserved and transported appropriately to laboratory for analysis.

## 2.3 Laboratory Analysis

All samples collected (soil including profile soils, sediment, surface water and groundwater) were properly labelled, packaged, stored and transported to accredited laboratory for physico-chemical analyses. Laboratory analytical methods adopted are standard and internationally acceptable methods including USEPA 8015 for TPH, USEPA 8270 for PAH, USEPA 5030-B and ASTM procedures for metals.

## 2.4 Data Analysis

The results obtained from the laboratory analysis were subjected to both descriptive and inferential statistical analyses. Microsoft XLSTAT 2016 was used in performing all statistical analyses. The human health risk assessment was carried out using two approaches. A modified Total Petroleum Hydrocarbon Content Approach, which considers other contaminants like PAH, BTEX and heavy metals, and the Fractions approach. The modified Total Petroleum Hydrocarbon content approach was carried out by measuring TPH, PAH, BTEX and comparing the measured values to the intervention values in EGASPIN (2018). Human health risk was assessed using the concentration index for the contaminants as defined in Equations (1) and (2);

$$I_{TPH} = \frac{C_{TPH}}{IV_{TPH}} \quad (1)$$

$$I_{PAH} = \frac{C_{PAH}}{IV_{PAH}} \quad (2)$$

Where:  $I_{TPH}$  = Concentration index of TPH,  $C_{TPH}$  = Concentration of TPH in Substrate,  $IV_{TPH}$  = TPH

Regulatory Intervention value,  $I_{PAH}$  = Concentration index of PAH,  $C_{PAH}$  = Concentration of PAH in Substrate and  $IV_{PAH}$  = PAH Regulatory Intervention value

A concentration index greater than 1 (>1) indicates unacceptable human health risk.

The TPH fractions approach was carried out using the RBCA Toolkit for Chemical Releases Version 2.6.

## 3. RESULTS AND DISCUSSION

### 3.1 Total Petroleum Hydrocarbon (TPH)

The Total Petroleum Hydrocarbon (TPH) for surface soil ranged from 5364 to 71283mg/kg with mean concentration of 16348.43mg/kg, the TPH for subsurface soil ranged from 25.9 to 6756mg/kg with mean concentration of 2168.58mg/kg, the TPH for surface water ranged from 0.017 to 0.033µ/l with mean concentration of 0.026µ/l and the TPH for ground water ranged from 0.010 to 11600µ/l with mean concentration of 2320.0µ/l. Fig. 2 shows the mean concentration of TPH in all four environmental media studied and the Nigerian regulatory intervention limits.

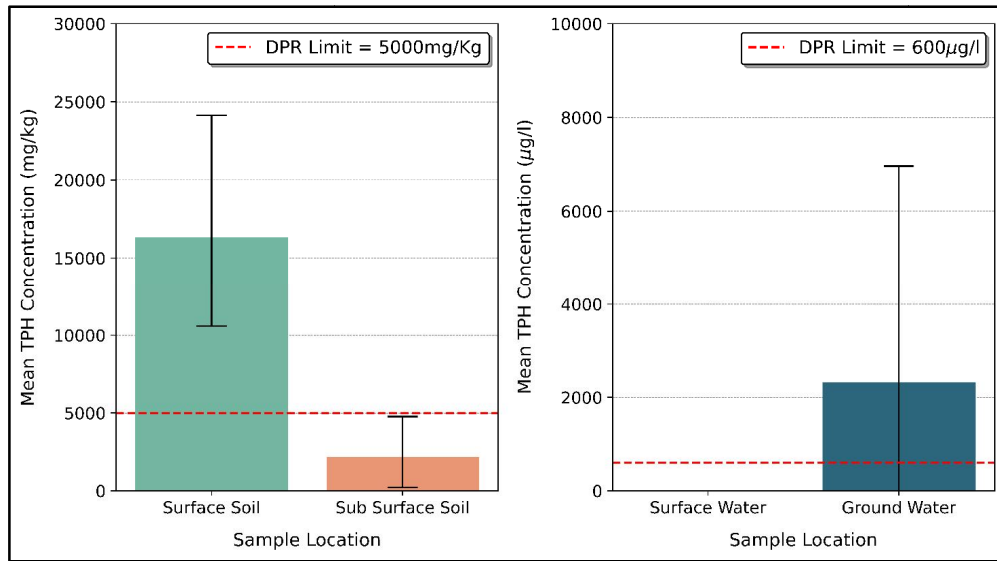
The TPH maximum and mean concentrations for surface soil; and the maximum concentration for sub-surface soil exceeded the DPR Intervention limit of 5000mg/kg while mean concentration for sub-surface soil was below the intervention limit.

The TPH maximum and mean concentrations for surface water were below the DPR intervention value of 600 µ/l while both the maximum and mean concentrations for groundwater exceeded the DPR Intervention value of 600 µ/l.

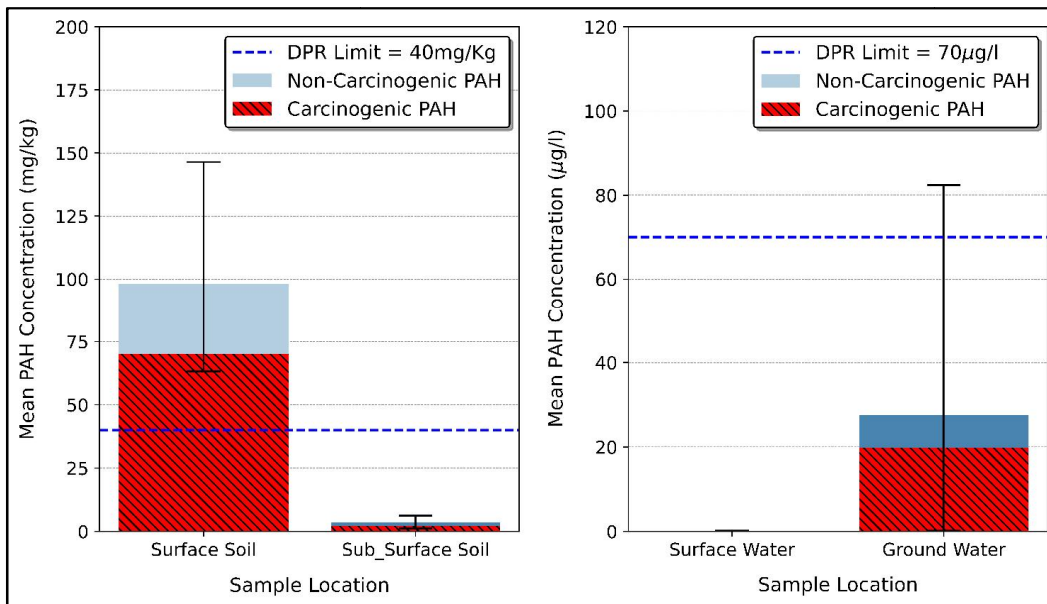
### 3.2 Polycyclic Aromatic Hydrocarbons (PAHs)

Sixteen priority pollutants identified by the United State Environmental Protection Agency (USEPA) were measured in surface soil, sub-surface soil, surface water and ground water. Fig. 3 shows the mean concentrations of PAHs, the ratio of carcinogenic to non-carcinogenic PAHs in the four environmental media and Nigerian regulatory intervention limits.

The PAH maximum and mean concentrations for surface soil exceeded the DPR Intervention limit of 40mg/kg while those for sub-surface soil were below the intervention limit.



**Fig. 2. Mean TPH concentrations for all Environmental Media**



**Fig. 3. Mean PAH concentrations for all Environmental Media**

PAH maximum and mean concentrations for surface water; and mean concentration for groundwater were below the DPR intervention limit of 70µg/l while the groundwater PAH maximum concentration exceeded the intervention limit.

### 3.3 Heavy Metals

The results of the EGASPIN (2018) recommended 10 heavy metals analyzed indicated that all mean concentrations of the

metals were below regulatory limits as shown in Fig. 4.

Only the maximum concentration value of Lead for surface soil was above the DPR intervention limit of 530mg/kg but the mean concentration was within limit.

### 3.4 Human Health Risk Assessment

As earlier mentioned, two approaches were adopted, the modified total content approach

using the concentration index and the Fractions approach using the RBCA Tool Kit for Chemical releases.

**3.4.1 Total content approach**

The modified total content approach advocates the assessment of TPH with other contaminants. For this study all parameters that were found to have either the mean or maximum concentration values to be above the DPR corresponding intervention limit are classified as contaminants of concern and therefore assessed. The contaminants of concern for this study are TPH in soil and groundwater, PAH in soil and Lead in soil. The concentration indices for all three contaminants are calculated for both the maximum and mean concentrations to identify the maximum and most likely risks associated with the contaminant as shown in Table 1.

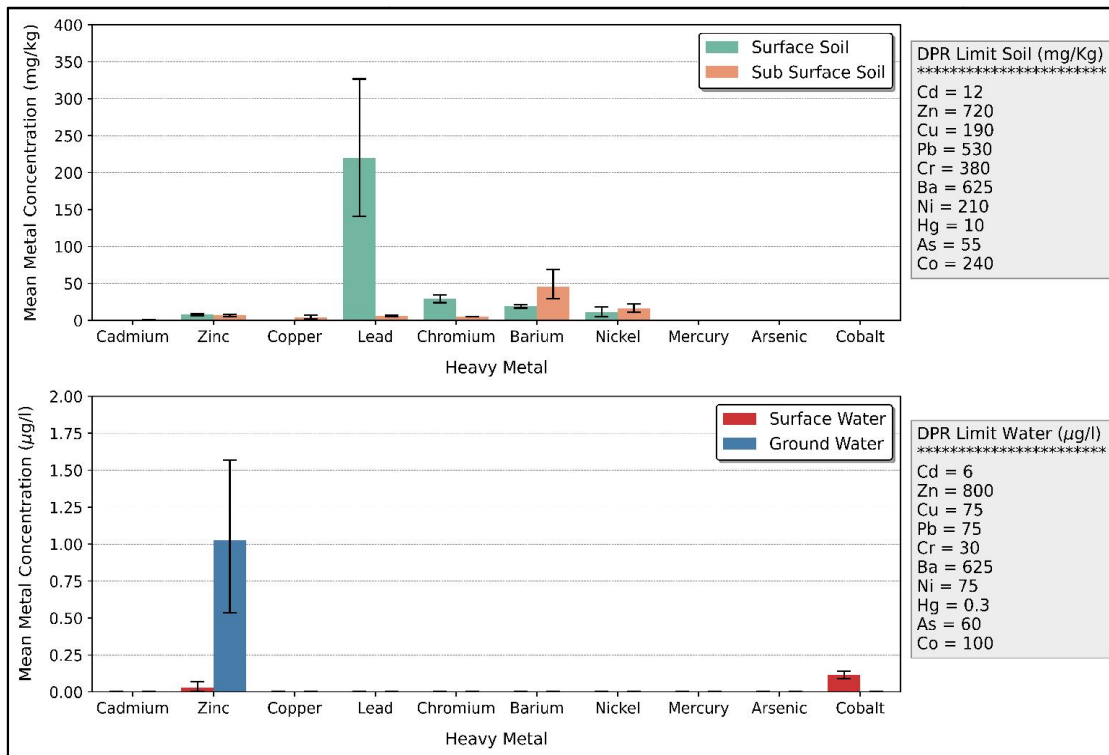
The Total Petroleum hydrocarbon risk in soil for the Study Site for both maximum and mean concentrations indicate significant human health risk at this site as the Concentration Indexes were both greater 1 (>1). The Total Petroleum Hydrocarbon risk in groundwater for the Study Site for both maximum and mean concentrations indicate significant human health risk at this site

as the Concentration Indexes were both greater than 1 (>1). The Poly Aromatic Hydrocarbon risk in soil for Site for both concentration levels indicate human health risk as the Concentration Indices are greater than 1 (>1). The Lead risk in soil for the study site indicates substantial risk with the maximum concentration (1.55>1.00) and acceptable risks with the mean concentration (0.415<1.00) implying that though there exists the risk of Lead but the most likely scenario will be an acceptable risk.

**3.4.2 Human health risk assessment using TPH fractions approach**

The risks from the modeling of the study site for both carcinogenic and toxic effects are summarized in Fig. 5 (snipped/screen shot from the results of the RBCA Tool Kit Version 2.6).

The evaluation identified soil exposure pathways (dermal and ingestion) and groundwater pathways (ingestion) as exceeding limits for carcinogenic risk and all four evaluated exposure pathways (outdoor air, indoor air, soil and groundwater) as having both hazard quotient and hazard index greater than 1.0E+0, therefore exceeding applicable toxicity limits.



**Fig. 4. Mean heavy metal concentrations for all environmental media**

**Table 1. Total Content Approach Concentration Index Calculations**

Contaminants	Risk Index	Site A
Total Petroleum Hydrocarbon (soil)	Maximum Concentration	$\frac{71283}{5000} = 14.26$
	Mean Concentration	$\frac{16348.4}{5000} = 3.27$
Polycyclic Aromatic Hydrocarbon (soil)	Maximum Concentration	$\frac{427.70}{40} = 10.69$
	Mean Concentration	$\frac{98.09}{40} = 2.45$
Lead	Maximum Concentration	$\frac{820.53}{530} = 1.55$
	Mean Concentration	$\frac{219.70}{530} = 0.415$
Total Petroleum Hydrocarbon (groundwater)	Maximum Concentration	$\frac{11600}{600} = 19.33$
	Mean Concentration	$\frac{2320.04}{600} = 3.87$

RBCA Tool Kit for Chemical Releases, Version 2.6

RBCA SITE ASSESSMENT						Baseline Risk Summary-All Pathways				
Site Name: PHDA Site Location: EMOLGA, RIVERS STATE			Completed By: NNAMDI MICHAEL AHIAMADU Date Completed: 4-Sep-19			1 of 1				
BASELINE RISK SUMMARY TABLE										
EXPOSURE PATHWAY	BASELINE CARCINOGENIC RISK				BASELINE TOXIC EFFECTS					
	Individual COC Risk Maximum Value	Target Risk	Cumulative COC Risk Total Value	Target Risk	Risk Limit(s) Exceeded?	Hazard Quotient Maximum Value	Applicable Limit	Hazard Index Total Value	Applicable Limit	Toxicity Limit(s) Exceeded?
<b>OUTDOOR AIR EXPOSURE PATHWAYS</b>										
■	5.7E-7	1.0E-5	1.2E-6	1.0E-5	□	3.3E+2	1.0E+0	3.7E+2	1.0E+0	■
<b>INDOOR AIR EXPOSURE PATHWAYS</b>										
■	3.4E-7	1.0E-5	7.5E-7	1.0E-5	□	9.1E+3	1.0E+0	1.0E+4	1.0E+0	■
<b>SOIL EXPOSURE PATHWAYS</b>										
■	8.0E-4	1.0E-5	1.7E-3	1.0E-5	■	2.6E+0	1.0E+0	4.6E+0	1.0E+0	■
<b>GROUNDWATER EXPOSURE PATHWAYS</b>										
■	2.2E-1	1.0E-5	5.6E-1	1.0E-5	■	1.1E+3	1.0E+0	2.0E+3	1.0E+0	■
<b>SURFACE WATER EXPOSURE PATHWAYS</b>										
□	NA	NA	NA	NA	□	NA	NA	NA	NA	□
<b>CRITICAL EXPOSURE PATHWAY (Maximum Values From Complete Pathways)</b>										
	2.2E-1	1.0E-5	5.6E-1	1.0E-5	■	9.1E+3	1.0E+0	1.0E+4	1.0E+0	■
	Groundwater		Groundwater			Indoor Air		Indoor Air		

**Fig. 5. Baseline Risk Summary table**

**4. DISCUSSION**

The concentration indices for TPH and PAH were greater than the acceptable limit of 1 for both the maximum concentration and mean concentrations in soil. Overall, the TPH and PAH values encountered at the site locations are in concentrations above intervention regulatory

limits of 5000 and 40mg/kg for soil. Regulatory intervention value is defined as the value which indicates when the functional properties of the soil for humans, plant and animal life, is seriously impaired or threatened [11]. They are representative of the level of contamination above which there is a serious case of soil contamination [10] or as the concentration of a

contaminant above which is unacceptable [12]. Following these definitions, therefore the soil in the study site is seriously impaired and pose potential human health risk. The environmental health risk associated with the site is unacceptable and therefore requires immediate attention. The health concerns associated with exposure of humans to crude oil spills (TPH and PAH) are enormous and include acute adverse health effects, genotoxicity, and endocrine toxicity.

The risk assessment of Lead found in the soil for site PHDA indicated a concentration index greater than 1 for the maximum concentration of Lead and less than one for the mean (most likely scenario). Lead is among the 10 chemicals identified by the World Health Organization as major public health concern, which requires action to protect the health of workers, children, and women of reproductive age [13]. According to [13] Lead can be taking into the human body through inhalation of Lead particles in soil and ingestion of Lead contaminated soil and can cause impaired children brain development resulting in reduced intelligence quotient (IQ), increased antisocial behavior and reduced educational attainment. Lead exposure has also been associated with anaemia, hypertension, renal impairment, immunotoxicity and toxicity to the reproductive organs. The neurological and behavioral effects of Lead are believed to be irreversible [13]. Lead being a cumulative toxicant has no level of exposure that is known to be without harmful effects [14]

The concentration indices of TPH and PAH in the groundwater in the site were greater than 1 for all concentrations (maximum, mean). The risk posed by these contaminants in the groundwater is unacceptable. As mentioned earlier, the human health implications of exposure to hydrocarbons are enormous. It is important to note that most of the community members from the area of this research rely on shallow groundwater for potable water and are hence seriously exposed. Worthy of note is the fact that some components of the PAH are carcinogenic [15] in nature bringing to bear on potential cancer exposure to the population.

The result from the Fraction approach showed that the carcinogenic risk is identified for the site through the soil and groundwater exposure pathways as the Total Risk Values for soil ( $1.7 \times 10^{-3}$ ) and groundwater ( $5.6 \times 10^{-1}$ ) are higher than the target risk of  $1.0 \times 10^{-5}$ , while toxic risks

are identified for all pathways in the site with Total Health Risk Index for all four pathways greater than the applicable limit of 1.0. The major contributing exposure pathways to overall risks of site are groundwater for carcinogenic risk having the highest risk value of  $5.6 \times 10^{-1}$  and Indoor Air for toxic effects having the highest Health Risk Index of  $1.0 \times 10^4$ .

The findings of this research align with the works of [16] which identified inhalation of indoor air as a major exposure pathway contributing to risks, [17] identified ingestion of contaminated water as a major exposure pathway, [18] also identified consumption of contaminated drinking water as major pathway of exposure and [19] using RBCA Tool Kit identified ingestion of contaminated water as primary exposure pathway. Contrary to these findings, [19] working with CSOIL Tool identified ingestion of contaminated soil as the major exposure pathway to overall risk while [20] identified ingestion of contaminated fish and outdoor inhalation as principal contributing exposure pathways. In another study, [21] identified consumption of vegetables as contributing about 99% of total risk on that site.

## 5. CONCLUSION

This research concludes that the exposure of human population to crude oil in the studied site poses significant carcinogenic and non-carcinogenic health risk to the exposed population particularly through ingestion of groundwater for carcinogenic risk and inhalation of indoor air for non-carcinogenic risk. It should be noted that this assessment produces baseline risk, which is risk associated with a contaminated site where no remedial or institutional measures are applied to protect human population. We, therefore, recommendation that immediate remedial activities be commenced at the site to avert human health impact. This study provides a good overview of the Niger Delta, which has several crude oil polluted sites within human habitations, farmlands, and fishing water.

## DISCLAIMER

The products used for this research are commonly and predominantly use products in our area of research and country. There is absolutely no conflict of interest between the authors and producers of the products because we do not intend to use these products as an avenue for any litigation but for the advancement of



knowledge. Also, the research was not funded by the producing company rather it was funded by personal efforts of the authors.

### COMPETING INTERESTS

Authors have declared that no competing interests exist.

### REFERENCES

1. D'Andrea MA, Reddy GK. Crude Oil Exposure and Human Health Risks. *JOEM*, 2014; 56:1029–1041
2. Ahiamadu NM. Sustainable Remediation in Nigeria. A Master of Research Dissertation submitted to the Department of Geography, University of Nottingham, Nottingham, UK; 2017.
3. Ahiamadu NM, Suripno, S. Bioremediation of Crude Oil Contaminated Soil by Composting using Wood Shavings as Bulking Agent. A paper presented at the 2009 Asia Pacific Health, Safety, Security and Environment Conference and Exhibition held in Jakarta, Indonesia; 2009. Available: <https://www.onepetro.org/download/conference-paper/SPE-122744-MS?id=conference-paper%2FSPE-122744-MS>
4. Alvarez PJJ, Illman, WA. Bioremediation and Natural Attenuation: Process Fundamentals and Mathematical Models. John Wiley & Sons, Inc., Hoboken, New Jersey; 2006.
5. United Nations Development Programme. Delta Human Development Report. UNDP, Abuja, Nigeria. Available: <http://www.bebor.org/wp-content/uploads/2012/09/UNDP-Niger-Delta-Human-Development-Report.pdf>
6. Nriagu J, Udofia EA, Ekong I, Ebuk G. Health Risks Associated with Oil Pollution in the Niger Delta, Nigeria. *International Journal of Environmental Research and Public Health*. 13:346. DOI: 10.3390/ijerph13030346
7. United States Environmental Protection Agency. Acute Exposure Guideline Level (AEG) for Airborne Chemicals; 2012.
8. Interstate Technology & Regulatory Council. Decision Making at Contaminated Sites: Issues and Options in Human Health Risk Assessment. RISK-3. Washington, D.C.:Interstate Technology & Regulatory Council, Risk Assessment Team; 2015.
9. Total Exploration and Production Nigeria. Oil Spill Contingency Plan; 2019.
10. Dehez, S. Ibewa Hydrogeological Model Report. Submitted to Total E&P Nigeria; 2014.
11. Environmental Guidelines and Standards Nigeria. Revised Edition ed. Lagos: Department of Petroleum Resources; 2018
12. Pinedo J, Ibáñez R, Lijzen JPA., Irabien Á. Human Risk Assessment of Contaminated soils by oil products: Total TPH Content vs. Fraction Approach, Human and Ecological Risk Assessment: An International Journal, DOI: 1080/ 10807039.2013.831264, Page 1-35
13. World Health Organization. <https://www.who.int/news-room/fact-sheets/detail/lead-poisoning-and-health>
14. World Health Organization. Lead—environmental aspects. Geneva, World Health Organization; 1989. (Environmental Health Criteria, No. 85).
15. Cocarta, DM., Stoian, MA and Badea, A. Human Health Risk Assessment: A case Study involving Polycyclic Aromatic Hydrocarbons Soil Contamination and Human Exposure in the proceedings of 46th The IIER International Conference, Brussels, Belgium, 28th November. 2015; 22-27 ISBN: 978-93-85832-51-2
16. Brand E, Otte PF, Lijzen JPA, CSOIL 2000: An exposure model for human risk assessment of soil contamination - A model description, RIVM report 711701054; 2007.
17. Popescu I, Stanescu R, Biasioli M, Marsan FA. Assessing human risks through CSOIL exposure model for a soil contamination associated to heavy metals. *UPB Scientific Bulletin, Series B: Chemistry and Materials Science*. 75(1):81-94
18. McKnight US, Finkel M. A system dynamics model for the screening-level longterm assessment of human health risks at contaminated sites, *Environmental Modelling & Software*. 2013;40:35-50, DOI: 10.1016/j.envsoft.2012.07.007.
19. Pinedo J, Ibanez R, Lijzen JPA, Irabien A. Risk Assessment of Contaminated Soils by Oil Products: Total TPH Content versus Fraction Approach. *Human and Ecological Risk Assessment*. 2014;20:1231-1248 DOI: 10.1080/10807039.2013.831264.
20. Qu C, Li B, Wu H, Wang S, Giesy JP. Multi-pathway assessment of human health risk posed by polycyclic aromatic hydrocarbons, *Environ Geochem Health*; DOI: 10.1007/s10653-014-9675-7.

21. Cocarta DM, Stoian MA, Badea A. Human Health Risk Assessment: A case study involving polycyclic aromatic hydrocarbons soil contamination and human exposure, International Journal of Advances in Science, Engineering and Technology. 2016;4:144-149  
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