# Oil Spills in the Niger Delta Region, Nigeria: Environmental Fate of Toxic Volatile Organics.

**Deinkuro Nimisngha Sanchez** ( chat2nimi@gmail.com )
University of Strathclyde, Glasgow https://orcid.org/0000-0001-9172-2866
**Charles W. Knapp**
University of Strathclyde https://orcid.org/0000-0001-7997-8543
**Raimi Morufu Olalekan**
Niger Delta University, Wilberforce Island, Bayelsa State, Nigeria https://orcid.org/0000-0001-5042-6729
**Nimlang Henry Nanalok**
National Centre for Remote Sensing, Department of Geology, Jos, Nigeria

**Research Article**

**Keywords:** Benzene, Toluene and Naphthalene (BTN), Niger Delta Region (NDR), Organic-carbon partitioning coefficient (Koc), Soil-water distribution coefficient (Kd)

**Posted Date:** June 28th, 2021

**DOI:** https://doi.org/10.21203/rs.3.rs-654453/v1

# Abstract

### Background:

Over the years, the issue of environmental degradation of ecological resources from crude oil pollution and its human health impacts is receiving more global attention. The utilization of environmental models capable of predicting the fate, transport and toxicity of chemicals in spilled crude oil can provide essential knowledge required to deal with the complexity associated with the fate of volatile petroleum chemicals in the environment.

### Objective:

This paper explores environmental fate of toxic volatile organics from oil spill in the Niger Delta Region of Nigeria.

### Methods:

A critical analysis of available literatures/data from PubMed, Scopus, ResearchGate, Google Scholar, Jstor, including expert working group reports and environmental modeling using a screening tool (USEPA EPI Suite™) was carried out to determine the environmental partitioning of Benzene, Toluene and Naphthalene (BTN) respectively. The organic-carbon partitioning coefficient ($K_{oc}$) was computed as a function of soil-water distribution coefficient ($K_d$) and percentage organic matter (%OM). This was utilized to determine the distribution of BTN in the environment and the possible risk posed on delicate ecological resources from crude oil pollution due to exploration and production activities within the Niger Delta Region (NDR), Nigeria.

### Results:

Results from literature implicated sabotage and operational failures from pipelines as primary causes of crude oil spillages. Generation of a fugacity model using EPI Suite™ revealed that the behavior of BTN is greatly influenced by $K_{oc}$ values. The default Molecular Connectivity Index (MCI) showed that benzene and toluene will partition more into the water compartment while naphthalene will partition into the soil compartment. However, user-entered values showed all three chemicals partitioning more into the soil compartment. Aquatic toxicology estimation using Ecological Structural Activity Relationship (ECOSAR) revealed all chemicals not to be toxic even at over-estimated $K_{oc}$ values.

### Conclusion:

This research established the usefulness of screening level environmental modelling tools in assessing environmental risk and hence helpful in developing site-specific models for monitoring chemicals in the environment which can assist governments, policy makers and industries in the design of appropriate regional disaster management plans.

# Introduction

Societal growing concern and man's yearning for development, have fuelled his quest to explore his environment in order to harness its vast but limited resources over the past hundreds of years (Raimi *et al.,* 2019; Raimi *et al.,* 2019; Okoyen *et al.,* 2020). In the current global pandemic situation caused by COVID-19, the pressure on the environment has increased with an intensified release of waste (Raimi *et al.,* 2020; Samson *et al.,* 2020; Raimi and Raimi, 2020; Morufu *et al.,* 2021; Raimi *et al.,* 2021; Morufu *et al.,* 2021). Sadly, much attention was not paid to the environmental impact of the processes carried out (Raimi *et.al.,* 2019; Omidiji and Raimi, 2019; Raimi *et al.,* 2019; Raimi *et al.,* 2020; Olalekan *et al.,* 2020; Adedoyin *et al.,* 2020; Olalekan *et al.,* 2020; Ajayi *et al.,* 2020). Deposits of crude oil can be found in almost all continents of the world. With its discovery, petroleum and its associated products have become the major source of energy that drives the economy of industrialized and developing nations (Premoboere and Raimi, 2018; Ebuete *et al.,* 2019; Suieiman *et al.,* 2019). However, its exploration and exploitation have been accompanied by alarming degree of environmental degradation, hence threatening the health and wellbeing of humans and other vital environmental resources (Raimi *et al.,* 2019; Olalekan et al., 2019; Raimi *et al.,* 2019; Okoyen *et al.,* 2020). It is indubitable that crude oil and gas has contributed immensely to societal development, however, its exploration, exploitation and trade have contributed its own quota in the current global environmental challenges (Premoboere and Raimi, 2018; Olalekan *et al*, 2020).

Before the I960's, little attention was paid on the effects of crude oil spillages. However, three notable incidence sparked international attention namely: the *Torrey Canyon* wreck of 1967 (off the coast of England), the 1989 *Exxon Valdez* spill off the coast of Alaska and the 1991 massive release of crude oil during the *Gulf war.* These led to an increase in environmental research, and the adoption of several national and international control practices such as the Oil Pollution Act of 1990. Despite these controls, environmental hazards, petroleum contamination remains a prevalent issue (Albers, 2002; Premoboere and Raimi, 2018). This awareness has contributed to development in the field of environmental toxicology. The field of environmental toxicology is an element of environmental science and environmental studies, which covers several aspects including; protection of water, soil, fisheries and wildlife management, protection of endangered species, habitat and ecosystem conservation etc. (Albers, 2002; Raimi and Sabinus, 2017; Raimi *et al.,* 2017; Raimi and Sabinus, 2017; Olalekan *et al.,* 2018; Sawyerr *et al.,* 2018; Raimi, 2019; Olalekan *et al.,* 2018; Raimi *et al.,* 2019; Olalekan *et al.,* 2019; Raimi *et al.,* 2019; Okoyen *et al.,* 2020).

In the Nigerian context, oil was discovered in the Niger Delta Region (NDR) in 1956. This resulted in an inflow of several multinational oil companies (MNOCs) to the region to prospect for petroleum and natural gas. With the oil boom of the 1970s, disproportionate exploitation of the region's environmental resources began. These exploration and exploitation of crude petroleum, has become the mainstay of the nation's economy. The impact of the oil boom gradually created a shift of focus by the Nigerian government from Agriculture to crude oil exploration, which created more wealth for the country and more environmental and socio-economic crisis for the NDR. (Akpomuvie, and Orhioghene 2011; Bakare and Fawehinmi, 2011; Dokpesi ,2004). Claims by the MNOCs suggest that most spillages in the NDR is as a result of vandalization/sabotage. However, there have been counter accusation by the public, blaming spill accidents on the corroded pipelines, negligence and poor maintenance by the MNOCs. The 2011 UNEP environmental assessment of oil spill and gas flaring of Ogoniland in the Niger Delta stated that, since the discovery of crude in the region, about 600 million gallons of crude oil have been spilled, which have been either ignored or poorly managed by the oil companies. These spills, have contaminated vast number of lands, damaging farmlands, affecting fisheries and causing food scarcity and suffering of the people. UNEP found the hydrocarbon contamination levels to be over 1000 times higher than the country's standard for drinking water and benzene contamination of about 900 times higher than the WHO level guideline (Osuji *et al*, 2006; UNEP,2011; Olalekan *et al.,* 2018; Olalekan *et al.,* 2020). In the light of these, an evaluation of the fate and partitioning of petroleum chemicals in the environment is imperative, as it can serve as a guide to environmental forensics experts during investigations and also in remediation of contaminated sites.

## Environmental Fate of crude oil

When oil is spilt into the environment, it undergoes weathering process. During the weathering process, some of the hydrocarbons are dissolved in water, while others are adsorbed into the soil and the rest volatilizes. Compared to aliphatic and polyaromatic hydrocarbons, monoaromatic hydrocarbon in crude oil dissolves more in water. This is as a result of their low organic carbon partition coefficients ($K_{oc}$). Conversely, they have the tendency to distribute into groundwater. Polyaromatic hydrocarbon on the other hand has low solubility in water, hence, will partition more into soil and sediment compartment. However, crude oil in general has a low solubility in water (Barakat *et al*, 2001; Potter and Simons, 1998; Irwin *et al*, 1997).

## Toxicity of Petroleum Hydrocarbons

The toxicity of petroleum hydrocarbons increases with the quantity of low boiling compounds (Hayes, 1992) and in ascending order of alkanes, alkenes and aromatics (Clements *et al*, 2009). BTEX, which is an acronym for benzene, toluene, ethyl benzene and xylene isomers are more toxic to the environment than other hydrocarbons. They are the common aromatic compounds of crude oil which are most soluble and most mobile and have greater influence on its physical and chemical properties (Wang *et al*, 2006). BTEX is significant for posing health risks when they seep into soil and groundwater from underground pipelines and storage tanks. It has been classified as hazardous, carcinogenic and neurotic compounds by USEPA and Environment Canada (Wang *et al*., 2006; Todd *et al*, 1999). Researcher in the field of toxicology, have paid more attention to volatile organic compounds (VOCs) such as BTEX, because of the health risk associated with them (San Sabastian *et al*., 2001). A wholesome environment, is the bedrock for existence of life. Life expectation in an environment with poor environmental values is usually low. Air and water borne diseases which is usually associated with chemical pollution in the environment, waste disposal etc. is a global environmental health issue (Raimi *et al.,* 2018; Suleiman *et al.,* 2019; Raimi *et al.,* 2020; Gift and Olalekan, 2020; Gift *et al.,* 2020; Morufu *et al.,* 2021). Acidic groundwater pollution attributed to oil and gas related activities in the Niger Delta region have been predicted to have the tendency to affect human health, depending on the dosage and inherent health status, thereby affecting productivity (Morufu and Clinton, 2017; Raimi and Sabinus, 2017; Olalekan *et al.,* 2018; Raimi *et al*.,2018; Raimi, 2019; Odipe *et al*., 2019)

## Oil Spillages in Nigeria

Nwilo and Badejo (2005), define oil spillage as the unrestrained flow of petroleum oil or petroleum products into the environment due to operational errors, disasters, failure from equipment and vandalism (sabotage). Majority of oil spills in Nigeria, occur in the NDR with devastating effects, such as: fire out breaks, drinking water contamination, fish kills etc (Morufu and Clinton, 2017; Raimi and Sabinus, 2017; Olalekan *et al.,* 2018; Raimi, 2019; Olalekan *et al.,* 2019; Olalekan *et al.,* 2020; Raimi *et al.,* 2021). The spill of oil and accompanying environmental degradation is still on the rise in the Niger Delta (Raimi *et al.,* 2019; Okoyen *et al.,* 2020). The key conundrum for the Nigerian government is how to arrest the problem, with the burning question of how can they carry out remediation of the polluted environment without first modelling or accurately predicting the volume of oil that have been spilled into the environment over the decades (Mba *et al*, 2019). At the moment, completely avoiding the spill of crude oil into the environment during operations seems implausible, however, the issue in the Niger Delta is with the regularity and volume of the occurrence of spill incidences and the poor control and response time. Terrestrial and marine resources are usually affected whenever oil spills are not properly recovered, as they spread over a large area. Marine habitat, farm lands are the most affected, consequently threatening existence of organism in the affected area (Akpan, 2012; Plessl *et al*. 2017). Apart from crude oil spills, environmental contamination also stems from midstream operations, such refining of petroleum products. Ademiluyi *et al*, (2009), Ademiluyi and Braide, (2012) in their examination of the treatment of wastewater from a refinery using activated carbon, (although focused on the physiochemical phenomenon) confirms the presence of organic pollutants including phenol, benzene, Toluene and Xylene (which are key volatile components in crude petroleum) being discharged with industrial wastewater into the environment.

There have been multiple oil spills in the past. Reports published by Nigerian authorities and oil companies have revealed discrepancies in the number of incidences. In 2006, Shell Nigeria reported an average of 250 incidences per year since 2006 while Nigerian National Oil Spill Detection and Response Agency (NOSDRA) confirmed 327 oil spill cases. The inconsistency of these reports display laxity in harmonising data by regulatory bodies or failure to disclose many oil spill incidents.

## Niger Delta Region (NDR)

On the Southern tip of Nigeria, lies the NDR. it is covered by Equatorial Guinea forests and a renowned "biodiversity hotspot" for regional wildlife. She is bordered on the east by Cameroun and on the South by the Atlantic Ocean. The Niger Delta Region occupies about 12% of the total surface area of Nigeria translating to approximately 112,110 square kilometres, with an estimated 28 million inhabitants, going by the 2006 population census (Myers *et al*, 2000; Wizor and Wali, 2020). Within the NDR is the faunal zone were mangrove swamps and large reserve of oil are situated on a sizable expanse of land and forests Geopolitically, there are nine states in the NDR (Figure 1)

The NDR is an oil rich region located in the south of Nigeria. An estimated one "Exxon Valdez" oil spill enters the NDR ecosystem each year. Over the past one-half of a century, a substantial volume of crude oil has been spilled, which represents fifty times the 1989 Exxon Valdez spill in Alaska (Obot *et al*, 2006). This has brought untold hardship to inhabitants of the region, resulting in agitations, crude oil theft/bunkering and pipeline sabotage.

### Niger Delta: Causes of Oil spills

Spillages occur either from natural causes such as a natural disaster or due to production activities, poor control of oil well, sabotage, poor loading and offloading practices. As stated by Badejo and Nwilo (2004), half of the oil spillages in the NDR is attributed to poor assets quality (corrosion), less than two percent due to production failure/crude transfer operations and twenty-eight percent to sabotage (Kadafa, 2012; Nwilo and Badejo, 2001, 2004; Wizor and Wali,2020). Figure 2, shows the oil spill data from January 2013 – to May 2021, showing the causes of oil spill in the region under review.

**Adapted from**

If the data presented on the SPDC website is anything to go by (as there are counter claims by affected community that spills are results of corroded pipelines), Figure.2 shows sabotage/theft to be the major cause of spill of crude in the Niger Delta, followed by spills due to operations, in a total of 1142 spills.

### Proximity assessment of NDR to spill Hazards

Accidents that are severe in a year are sparse and are assumed to follow a Poisson distribution, hence severe oil spills are assumed to occur less frequently (Eckle *et al*., 2012). For purposes of risk assessment, the probability and severity of environmental pollution on specific areas from hydrocarbons is logically determined by the quantity of spillage of every discharge, the probability of a spill occurring and the level of exposure of vulnerable and delicate resources.

The proximity of ecological resources in the NDR to petroleum pipelines serve as potential hazards for the ecosystem and are by themselves critical in exposure assessment. Hence, there is the urgency to determine the possible degree of damage that can occur in the event of a spill, in order to design a suitable remediation and/or disaster management response approach. Table 1., gives a comparison of the rate of pipeline failure in the NDR compared to other regions in the world.

**Table 1:** Comparison of pipeline failure in Nigeria/Niger Delta and other regions in the world.

| Region | Product | Failure Rate per 1000km-years | Year |
|---|---|---|---|
| United Sates | Gas | 1.18 | 1984-1992 |
| United Sates | Oil | 0.56-1.33 | 1984-1992 |
| Europe | Gas | 1.85 | 1984-1992 |
| Europe | Oil | 0.83 | 1984-1992 |
| Western Europe | Oil | 0.43 | 1991-1995 |
| Western Europe | Gas | 0.48 | 1971-1997 |
| Canada | Oil & Gas | 0.35 | N/A |
| Hungary | Oil & Gas | 4.03 | N/A |
| Nigeria | Oil | 6.4 | 1976-1995 |
| Niger Delta (Nigeria) | Oil | 1.14 | 1999-2005 |

Adapted from Achebe *et al.,* 2012 as cited by Shittu*,* 2014.

From the table 1, it is clear that compared to other regions in the world, there is a high susceptibility for pipeline failure and subsequent spillage of petroleum oil and other associated products in Nigeria and the Niger Delta Region in particular, this trend has not shown any markable reduction even in the past fifteen years. There should therefore be a cause for concern for health and safety of both environmental resources and human health. Furthermore, majority of the NDR experiences periodic flooding as it lies on a very low plain (Odubo and Raimi, 2019). The environmental fate of crude can be enhanced by the direction of flow of both underground and surface water (Morufu and Clinton, 2017; Raimi and Sabinus, 2017; Olalekan *et al.,* 2018; Olalekan *et al.,* 2020). The variation of flow of the water table contributes significantly in material transference including contaminants. During the rainy season, the level of ground water is significant and all water bodies flow southward (UNEP, 2011). This may serve as a significant threat as oil spill during the rainy season will have the tendency to migrate farther, and hence may contaminate very delicate areas within the NDR.

### Environmental Modelling

Environmental modelling of organic compounds is vital in determining chemical behaviour in an exposed environment. It is useful because of the effect created on the ecosystem when these chemical pollutants are transferred from one medium to another depending on material properties of individual medium and on environmental variables such as temperature and humidity. The way chemical pollutants are retained by biotic and abiotic substances are either by adhering to the surface of the material or by dissolving into the molecular network of the particulate matter (Chiou, 2003). These chemical pollutants are usually transported through fluids in their natural biotic or abiotic medium. Knowledge of environmental chemical partitioning of substances released into the environment is vital as it may be difficult to clean up after being released and may result in serious environmental and health damage (Adeolu *et al.,* 2018). Modelling of organic chemicals in the environment is useful in estimating these behaviours and help in holding polluters responsible for toxic chemicals release. For this study, an environmental modelling screening-level tool, EPI Suite $^{TM}$ was used. EPI Suite $^{TM}$ is a screening level software model developed by the USEPA. The model has the ability to predict the partitioning of chemicals in the environment and thus helps in the environment assessment of the possible effects of chemicals in the environment. Three crude oil chemicals: benzene, toluene and naphthalene were selected.

## Methods

Bibliographical databases such as Google Scholar, ResearchGate, Pub Med, Jstor and Scopus were reviewed. This review includes relevant articles published between 1976 and 2021. Thus, understanding the risk associated with the exploration of a complex mixture such as petroleum crude is crucial, as it requires a way to estimate the proportion of toxic components that can be in the air, water and soil over a period of time (chemical fate and transport). Such estimates are key to ascertaining the short- and long-term hazards of substances in the environment and its possible long-term impacts on ecological resources and/or human health (environmental modelling). Several mathematical modelling tools (screening level tools) integrated into computer programmes and having default exposure factors have been developed and used to provide technical assistance in risk exposure assessment (USEPA, 2012). These tools are designed to be fast, handy and convenient. They are usually utilized whenever suitable empirical data from monitoring or exposure linked data are unavailable and mostly employed in assessing risk at the screening level (US EPA, 2010). The most notable drawback common to these tools is the overestimation of exposure values.

This can sometime be misleading, as substances that pose no concern, may appear otherwise due to the exaggeratedly high estimation averages. However, this prejudice increases the confidence level, as substances termed to be below the threshold value and with no environmental effects, will present no concerns (US EPA, 2010). Although, several environmental models are accessible, the fugacity model was utilised in this study, as it is easy to use and readily available. Fugacity models estimates the propensity of substances to distribute into soil, water and sediment in the environment (partition). The model utilises mass balance equations and partition coefficient to predict the partitioning and transport of contaminants (Mackay, 1979). The fugacity model is incorporated into the United States Environmental Protection Agency's (USEPA) screening level computer modelling tool-Estimation Programs Interface (EPI) SuiteTM (USEPA, 2012). A Level III fugacity model is integrated into the EPI Suite TM, infers both a steady state condition and homogeneity of all the compartment (soil, sediment, air and water), however, the partitions are not in equilibrium.

### Model Justification

EPI Suite™ has been validated independently, using external validation sets. Details of these are available in the Help files. There is also a complete list of references provided to users, to assist in the examination of the employed statistics. EPI Suite$^{TM}$ have been reviewed in several technical journals and also panel reviewed by the Science Advisory Board (SAB)[1]. The board described the software as sufficiently accurate to be used as a regulatory screening tool, user friendly, cost effective and based on sound scientific work.

Assumptions:

For simplification and to compensate for the unavailability of experimental data, the following assumptions were made:

- A substantial volume of crude oil is expected to be released into the environment, based on legacy of spill episodes in the NDR.
- The concentration of each of the constituents of interest (benzene, toluene and naphthalene) in an event of a spill will be less than the detection limit (DL) in water (due to their volatile nature), however some concentration will be expected to be in the sediment, which presents possible bioaccumulation. Research by Lindén and Pålsson (2013) puts the concentration of polyaromatic hydrocarbon (PAH) in Ogoniland[2] (Naphthalene) at 8.0 mg/kg, Benzene 9.0 mg/kg (UNEP, 2011) and Toluene 7.2 mg/kg respectively. These chemicals were chosen due to their high toxicity profile.
- The wind speed, river depth and current velocity for stream and river systems for study area were assumed to fall within the assigned default values in EPI Suite$^{TM}$.

### Estimation of Organic carbon partitioning coefficient ($K_{oc}$)

To estimate the $K_{oc}$ for each of the component of interest, equation 2 was used. Results obtained was used as input into EPI Suite $^{TM}$ fugacity model. Range of values for soil organic matter (OM) percentage concentration was sourced from literatures. For all the land use type (forest vegetation, grass vegetation, continuous cultivated lands), the OM% in the NDR ranges from 2.21 to 3.81 % (Oguike and Mbagwu, 2009). Also, Soil-water distribution coefficient ($K_d$)[3] was used to compute $K_{oc}$ values, using equation 2. It is important to note that $K_d$ are usually empirically determined site specific values. Hence, simulated or actual ground water is utilized (USEPA, 1999). The soil-water distribution coefficient ($K_d$) values was computed from the octanol-water partition coefficient ($K_{ow}$) using equation 1 (Andersen *et al.*,2005). The values for $K_{ow}$ were varied based on different analytical methods (absorption spectrometry, radiochemical, gas-liquid chromatography, high pressure liquid chromatography and recommended values) as presented by Sangster (1989). $K_{ow}$ values were assigned at the researchers' discretion. $K_d$ values were also calculated using equation 1.

**$K_d = 0.39 + 0.67 \times K_{ow}$ (1)**

For instance, *log*$K_{ow}$ value for Benzene absorption spectrometry was obtained to be 2.04 (Sangster, 1989),

**But, $K_{ow} = 10\hat{}\ (2.04)$ (2)**

**Therefore, $K_d = 0.39 + 0.67 \times 109.6 = 73.8$** (Table 2)

Corresponding values for $K_{oc}$ were computed using equation 3

$$\mathbf{Koc} = \frac{\mathbf{Kd}}{\mathbf{OM\%}} \times \mathbf{100\%} \qquad \mathbf{(3)}$$

Where; $K_{oc}$ is the Organic carbon partition coefficient

$K_d$, the soil-water distribution/partition coefficient

OM, Organic matter/fraction

**Table 2:** Assigned %OM and calculated $K_d$ values for BTN.

| | Distribution coefficient ($K_d$) | | |
|---|---|---|---|
| **%Organic Matter** | **Benzene** | **Toluene** | **Naphthalene** |
| 2.2 | 73.8 | 217 | 686 |
| 2.5 | 88.7 | 293 | 1680 |
| 3.17 | 90.8 | 360.2 | 1888.7 |
| 3.49 | 90.8 | 385.9 | 1535.3 |
| 3.81 | 68.9 | 583.9 | 1500.3 |

**Table 3**: EPI Suite™ entry data for BTN

| Name of Chemical | CAS Number | SMILES Notation |
|---|---|---|
| Benzene | 000071-43-2 | c(cccc1)c1 |
| Toluene (Benzene, methyl-) | 000108-88-3 | c(cccc1)(c1)c |
| Naphthalene | 000091-20-3 | c(c(ccc1)ccc2)(c1)c2 |

## Results

### Oil Spills

A careful examination of literatures and data from several sources about the spill of crude in the Niger Delta, revealed an average of over 229.5 spill incidents to have occurs annually in the past 46 years with a total of over 3.5 million barrels spilled into the various media (land, water, swamp etc.). This value is debatable as there have been conflicting results as regard the number and/or amount of crude that is spilled into the environment by the major oil industry key players. It is believed to be higher than the recorded values. Figure 3 and 4 shows the trend of oil spill incidents in the region under review (volume and number of spills).

Data from oil spill episodes in the Niger Delta, has been one that is described as consistently unreliable. For instance, in 2014, a total of 204 spills was reported by SPDC, whereas Eni (Italian oil giants) reported 349 to have occurred in the same year. Both companies admitted that over 550 spills have occurred in the Niger Delta the previous year. Contrasting this to the just 10 spills occurring in the whole of Europe annually from 1971 to 2011, the Niger Delta situation ought to have been declared as a national environmental emergency. The implication of this is that people in the region live in pollution daily. Claims by the oil company operators puts the volume of crude spill in this period to be about 5 million liters, however, this figure is most likely to be significantly higher, owing the poor reporting of incidence in the country (Amnesty International. 2016). Globally, the pollution profile of Nigeria ranks amongst the worst, in comparison with other oil-production nations. Over 63 million liters of crude have been spilled into the Niger Delta environment between the 1970s and 2006, as reported by UNDP; with only about 30% recovered. These spills literally occur on a daily bases, and have been on for over six decades. Hence, it will be right to infer that there is significant damage to the environment and a worrisome public and environmental health impact in the region. (USEIA, 2014; UNDP,2016; Udoh,2018).

This is indicative that the MNOC are not showing the needed concern for the effect of spilled crude in the environment. There were also results indicating no recoverable oil on site, even when as much as approximately 19 barrels of crude was spilled. The only rational explanation will be poor response time/logistics or negligence. These results reveal that a significant amount of crude is being spilled into the environment, hence, justifying this study to ascertain the partitioning of carcinogenic volatile organics in the environment to predict their potential hazards on delicate environmental resources.

### Environmental Fate of Volatile Organics

The environmental partitioning of chemical substances is affected by several factors, of which the physical and chemical properties are very important. In order to estimate the partitioning of the chemicals, EPA's EPI Suite™ was utilized. Fugacity model for two sources $K_{oc}$ was employed (default MCI-based and user-entered $K_{oc}$). The fugacity model was chosen as the basis for assessment of the chemicals of interest as it presents a clearer picture of how each component in the substances will distributed in the environment. Table 4 presents a descriptive statistic of BTN.

**Table 4:** Descriptive Statistics: % Organic Matter, Benzene, Toluene, Naphthalene (Minitab).

| Variable | Mean | SE Mean | StDev | Median |
|---|---|---|---|---|
| %Organic Matter | 3.04 | 0.30 | 0.66 | 3.17 |
| $K_d$ (Benzene) | 82.6 | 4.7 | 10.5 | 88.7 |
| $K_d$ (Toluene) | 368 | 61.4 | 137 | 360 |
| $K_d$ (Naphthalene) | 1460 | 205 | 458 | 1540 |

Results obtained for the default Level III fugacity model with MCI based soil $K_{oc}$ and the user-entered values are shown in Table 5 and 6 respectively.

**Table 5**: Default Level III Fugacity model EPI Suite™ (MCI based soil $K_{oc}$)

| Chemical | Mass Amounts (%) | | | Half-Life (Hrs) | | | Emissions (Kg/hr) |
|---|---|---|---|---|---|---|---|
| | $C_6H_6$ | $C_7H_8$ | $C_{10}H_8$ | $C_6H_6$ | $C_7H_8$ | $C_{10}H_8$ | |
| Air | 31.8 | 19 | 0.89 | 209 | 43 | 11.9 | 1000 |
| Water | 41.1 | 41.2 | 11.5 | 900 | 360 | 900 | 1000 |
| Soil | 26.7 | 39.4 | 86.6 | 1800 | 720 | 1800 | 1000 |
| Sediment | 0.37 | 0.44 | 0.998 | 8100 | 3240 | 8100 | 0 |
| Persistent Time(hr) | 197 | 153 | 873 | | | | |

**Table 6**: Level III Fugacity model EPI Suite™ (User-entered $K_{oc}$)

| Chemical | Mass Amounts (%) | | | Half-Life (Hrs) | | | Emissions (Kg/hr) |
|---|---|---|---|---|---|---|---|
| | $C_6H_6$ | $C_7H_8$ | $C_{10}H_8$ | $C_6H_6$ | $C_7H_8$ | $C_{10}H_8$ | |
| Air | 8.53 | 4.7 | 0.57 | 209 | 43 | 11.9 | 1000 |
| Water | 13.5 | 14.8 | 7.77 | 900 | 360 | 900 | 1000 |
| Soil | 75.9 | 75.2 | 71 | 1800 | 720 | 1800 | 1000 |
| Sediment | 2.08 | 5.3 | 20.7 | 8100 | 3240 | 8100 | 0 |
| Persistent Time(hr) | 599 | 420 | 1210 | | | | |

Figure 5 and 6 shows a representation of the fugacity models (MCI-based and user-entered $K_{oc}$) which shows the trend of how each chemical distributes in the environment.

### Aquatic Ecotoxicology-ECOSAR

Predicting the toxicology of chemicals in water was carried out using the ECOSAR model. Using three stand-in species: fish (freshwater, daphnid) planktonic crustaceans and green algae, ECOSAR predicts the possible toxicity of chemicals on overall aquatic community. The lethal concentration that will kill 50% of the organism ($LC_{50}$) is used to predict for fish and daphnid, while effective concentration that will kill 50% of the organism ($EC_{50}$) is used to predict for green algae. The model also calculates chronic values (Chv) for earthworms (Mayo-Bean *et al.*, 2012). Table 7 gives a summary toxicity prediction of BTN.

**Table 7**: Ecotoxicity prediction

| ECOSAR Class | Organisms | Endpoint (Time) | Prediction(ppm) | | |
|---|---|---|---|---|---|
| | | | $C_6H_6$ | $C_7H_8$ | $C_{10}H_8$ |
| Neutral Organics | Fish | $LC_{50}$(96-hr) | 65.1 | 24.8 | 9.4 |
| Neutral Organics | Daphnid | $LC_{50}$(48-hr) | 36.9 | 14.8 | 5.9 |
| Neutral Organics | Green Algae | $EC_{50}$(96-hr) | 27.5 | 13.5 | 6.9 |

### Bioconcentration/Bioaccumulation and Biodegradation

The bioaccumulation/bioconcentration of substances is the build-up of toxic chemicals in living organisms, which may have subsequent toxic effects on higher predators and humans and may lead to biomagnification through the food chain. The determination of the susceptibility for an organic substance to bioaccumulate is usually carried out using the $K_{ow}$ (Gruiz *et al*, 2015). **Table 8** gives the bioaccumulation and biodegradation of the chemicals under review.

**Table 8**: Bioaccumulation and Biodegradation probability

| Chemical | BCF (L/kg wet weight) | | $log K_{ow}$ | | BIOWWIN5 (MITI) | |
|---|---|---|---|---|---|---|
| | MCI | User | MCI | User | MCI | User |
| $C_6H_6$ | 11.8 | 11.8 | 2.13 | 2.13 | 0.73 | 0.53 |
| $C_7H_8$ | 29.4 | 29.4 | 2.73 | 2.73 | 0.52 | 0.52 |
| $C_{10}H_8$ | 69.9 | 69.9 | 3.3 | 3.3 | 0.40 | 0.45 |

## Discussion

Results from Table 2 for $K_d$ of Benzene, Toluene and Naphthalene using Minitab shows there is partial concentration of data around the mean, which is indicative of the minimum variation between the data set. For Naphthalene, the standard deviation appears to be more significant, indicating the importance of acquiring as much data as possible for research work that involves comparison between models. A comparison of the concentration results for chemicals in water computed from Table 5 and 6 shows a decrease in concentration for all three chemicals. This implies fewer chemicals (BTN) in water (River or lake) in the event of crude oil spill. However, this also indicates more of the contaminants will be in the sediment and soil, which creates the potential for possible environmental persistence. Also, with more of the chemical in the sediments, there will be increased ingestion potential for mud dwelling organisms such as crabs, catfish etc. and consequently a tendency for **biomagnification through the food chain.**

Generally, there is a well-defined trend from the results that the weaker the $K_{oc}$ values, the weaker the sorption ability on soil for each chemical and vice versa. The much larger values obtained for the user-entered $K_{oc}$ values is most likely due to overestimation of the $K_{ow}$ and consequently $K_d$ values. A critical observation of the results for both MCI and user-entered models shows a clear trend that higher $K_{oc}$ values, increases the tendency for the chemicals to partition more into soil and sediment compartments. Similar results were gotten by Helen *et al* (2008). Their study revealed that very strong $K_{oc}$ values is an indication that contaminants will stick more to soil organics and most likely persist in the environment. However, this may result in such chemicals not being bioavailable.

From Figure 5, components for benzene and Toluene are predicted to partition into the water and soil compartment. Naphthalene shows a larger partition into the soil compartment (86.6%), which suggests minimum biodegradability. In the MCI model (Table 6), although the mass amount in the sediment compartment tends to increase from Benzene to Naphthalene, the half-life and persistent time of Toluene is less than that for Benzene, indicating that while a chemical may be present in a smaller amount, it can be more persistent. Except for the air compartment, the half-lives for Benzene and Naphthalene are identical.

Furthermore, with regards to sampling for BTN, more attention should be paid on the water compartment for Benzene and Toluene as more of the chemicals will remain in water. However, concern should be drawn to the sediment compartment for Naphthalene. The MCI gave an indication that sample collection should be focused on the water compartment for Benzene and Toluene, but on the soil compartment for Naphthalene.

The figure (Figure 6) above corresponds to Table 7 and presents the distribution of BTN for the user-entered values in the environment. Compared to the default model, there is a significant migration of mass amount into the soil compartment for all chemicals. This high value is clearly due to the non-empirical data used in the determination of $K_{oc}$ values. As the mass distributes more into the soil compartment, it is being subtracted more from the water compartment-mass balance. If this scenario does occur in real life, it creates the possibility for plant uptake of the chemicals along with nutrients with possible harmful effects on mammals within the area of interest. As with the default model, the half-life for each of the chemicals remained unchanged, however there is 32.8%, 36.2% and 72.1% increase in the persistent time for BTN respectively. This further establishes the effect of $K_{oc}$ values on the partitioning behaviour of chemicals in the environment.

Table 7, reveals the chemicals will not be toxic on surrogate species at 96 and/or 48 hours respectively (estimated ECOSAR values are higher). However, effect may be anticipated in mud dwelling organisms.

Based on the criteria provided by REACH, none of the chemicals will bioaccumulate ($BCF < 2000$). Also, the $logK_{ow}$ values obtained for both models also support the prediction for the BCF criteria (BCF not $\geq 4$). This is also collaborated by the criteria set in Annex D[1]of the Stockholm convention. Results in Table 8, indicates that Benzene and Toluene are readily biodegradable (MITI non regression probability $\geq$ 0.5- BIOWWIN 5), whereas Naphthalene will tend to persist more in the environment (BIOWWIN 5, < 0.5). There is no change between the BCF and $logK_{ow}$ values for both models.

**Environmental Persistence**

According to the criteria for persistent chemicals contained in “Annex D” of the “Stockholm Convention”, a chemical is categorised as “persistent” if there is evidence that the half-life in the water compartment is >2 months or if the half-life in the soil compartment is > 6 months. None of the chemicals can be categorized as a POP. This is because, their persistent times in water and soil compartment ranged from 15 to 37.5 days for the water compartment and 30 to 75 days for the soil compartment respectively (Table 5 and 6).

## Conclusion

Judging from all reviewed literatures, online data, this research work has revealed that exploration activities in the NDR have resulted in significant degradation of environmental resources. Agitation and vandalization/sabotage of petroleum installations is as result of dissatisfaction of the outright disregard for human right by MNOCs and government’s complacency in addressing issues of serious environmental degradation in the area. Oil spill in the NDR stems from several sources. However, reports from MNOCs claim that sabotage and operational activities is the major causes. This can clearly be seen as result of poor disaster management plan and response time on the part of the government agencies (Raimi et al., 2021) and the MNOCs and the non-implementation of statutory laws.

For the fugacity modelling, results showed that several physiochemical factors, including: $K_{oc}$ and $K_{ow}$ and have significant effects of the disposition of chemical substances in the environment. Prediction from the default model shows the chemicals under investigation will partition more into the air component (except for naphthalene, which will partition more into the soil compartment), indication that the chemical is less soluble in water. Model prediction for the user defined model indicated that all chemicals (BTN) will partition more into the soil compartment (Fig. 6). This is clearly due to the overestimated soil $K_{oc}$ values for the user-entered model (95%, 98% and 97% increase respectively, compared to the default MCI values) for BTN which is a function of their $K_d$ and $K_{ow}$ values. $K_d$ values are site specific and usually experimentally determined. This shows the importance of $K_{oc}$ values. Changing the $K_{oc}$ values can be used to obtain site specific values.

Possible toxicity ranking of the chemicals (based on the two EPI Suite™ models) from least to most toxic follows: $C6H6 < C7H8 < C10H8$. This indicates that naphthalene will tend to be more persistent in the environment. However, BTN may generally not cause instant toxic effect on higher mammals at these concentrations in the event of a spill. This is acknowledged by Clements et al., (2009). They stated that the release of hydrocarbons to surface and subsurface soil undergoes rapid weathering, hence losing the toxic and bioavailable components. Results also indicate that neither of the chemicals will bioaccumulate nor bioconcentrate. Estimation of possible toxicity effects on surrogate species (fish, daphnid and green algae) was carried out with ECOSAR model (Table 7). ECOSAR $LC_{50}$ and $EC_{50}$ prediction for the species (user-entered model) revealed a $LC_{50}$ of 98%, 95%, 93% higher than the estimated concentration for fish at 96 hours, 96%, 91%, 88% higher for daphnid (at 48 hours) and 94%, 90%, 90% for green algae ($EC_{50}$) for BTN. Similarly, for the default MCI model, a 79%,70% and 89% $LC_{50}$ (96 hours) was predicted for fish,63%,50%,82% for daphnid ($LC_{50}$-48 hours) and 50%,45%,85% $EC_{50}$ at 96 hours for green algae.

With the lower concentration of the chemicals in the freshwater system, it can be deduced that even at very high estimated $K_{oc}$ values, toxic effects will not be expected for all chemicals. However, while the user-entered model predicts a defined trend of a concentration increase from benzene to naphthalene (suggesting naphthalene to exist in higher concentration), the default model seem erratic (suggesting benzene to be more concentrated in freshwater). Furthermore, experimental database prediction using EPI Suite™, puts the solubility of benzene and naphthalene as 1790 mg/L and 31 mg/L respectively, which shows benzene to be more soluble and hence should pose more toxicity threat in water. Results obtained with the user-entered values suggest that the methodology proposed for estimating $K_{oc}$ values from other sources other than from experimentation was not entirely successful as it gave an over estimation of the actual effects of the chemicals than what is contained in literatures and the EPI Suite™ model. Hence, experimentation should be given precedence in future attempt of models’ comparison. Results analysed has further established the usefulness of EPI Suite™ and its application and effectiveness in creating site specific models even for non-empirical values. This also indicates that accuracy of the model will likely improve with the availability of more experimentally determined values. Thus, the current scenario of a worsening trend in environmental pollution in the Niger Delta require greater political, business, and social commitment to seek alternative solutions to the use of highly toxic contaminants and increased investment in research, prevention and remediation. In addition, clear channels of communication are required between academia, policy makers, and society to ensure that timely, science-based information on the potential threats posed by toxic volatile organics from oil spill in the Niger Delta is made available to policy makers and other stakeholders.

## Recommendation

Pollution is a global problem that knows no borders as contaminants are found in every continent even in the most remote areas, and are readily transported from one country to another. While, thousands of different toxic volatile organics from oil spill and naturally existing elements with possible potential toxicity have been released into the Niger Delta milieu through human activities since ancient times. These contaminants tend to have residence times in the environment in the order of hundreds to thousands of years and are distributed throughout the planet. Indeed, based on the findings from reviewed literatures, it can be deduced that oil spillages in the NDR affects not only the environment including threats to soil health but its impacts go far beyond the soil dimension and soil contaminants can have irreparable consequences on human and ecosystem health, loss of ecosystem services, and has cause huge financial/economic losses and social inequities for both the indigenous Niger Deltans, MNOCs and the federal government, all of which jeopardise the achievement of the 2030 Agenda on Sustainable Development (Morufu *et al.*, 2021). It is therefore recommended that a multi-dimensional disaster management technique be employed. This approach should encompass both proactive and reactive response to disasters, including, rehabilitation/remediation of affected spill sites. An effective disaster management system is one which integrates legislative decisions and operational actions. For it to be holistic it will also incorporate non-governmental institutions, advocacy groups and regional/community-based organizations.

## Further Studies

In the course of this research work, several areas have been identified for further research work. These include:

- Geographic Information systems (GIS) mapping of oil wells within the NDR to evaluate hazard prone environmental resources.
- Development of a site/regional specific model for the prediction of toxic chemicals from crude oil in the NDR.
- Modelling and investigation of the toxicity of higher molecular weight aromatic hydrocarbons in crude oil.

## References

Ademiluyi, F.T. and Braide, O., (2012). Effectiveness of Nigerian bamboo activated with different activating agents on the adsorption of BTX. *Journal of Applied Sciences and Environmental Management*, *16*(3).

Ademiluyi, F.T., Amadi, S.A. and Amakama, N.J., (2009). Adsorption and Treatment of Organic Contaminants using Activated Carbon from Waste Nigerian Bamboo. *Journal of Applied Sciences and Environmental Management*, *13*(3).

Ademiluyi, F.T., Amadi, S.A. and Amakama, N.J., (2009). Adsorption and Treatment of Organic Contaminants using Activated Carbon from Waste Nigerian Bamboo. *Nigerian Society of Chemical Engineers. 30th Conf. Proc.CRP04.*

Adeolu T., Odipe O. E. and Raimi M. O. (2018). Practices and Knowledge of Household Residents to Lead Exposure in Indoor Environment in Ibadan, Oyo State, Nigeria. *Journal of Scientific Research & Reports 19(6): 1-10, 2018; Article NO. JSRR.43133 ISSN: 2320-0227.*

Adedoyin OO, Olalekan RM, Olawale SH, *et al* (2020). A review of environmental, social and health impact assessment (Eshia) practice in Nigeria: a panacea for sustainable development and decision making. *MOJ Public Health.* 2020;9(3):81‒87. DOI: 10.15406/mojph.2020.09.00328.https://medcraveonline.com/MOJPH/MOJPH-09-00328.pdf.

Ajayi Folajimi Ajibola, Raimi Morufu Olalekan, Steve-Awogbami Oluseyi Catherine, Adeniji Anthony Olusola, Adebayo Patrick Adekunle (2020) Policy Responses to Addressing the Issues of Environmental Health Impacts of Charcoal Factory in Nigeria: Necessity Today; Essentiality Tomorrow. *Communication, Society and Media.* Vol 3, No 3.
DOI: https://doi.org/10.22158/csm.v3n3p1. http://www.scholink.org/ojs/index.php/csm/article/view/2940.

Akpan, N.S., (2012). From agriculture to petroleum oil production: What has changed about Nigeria's rural development? *International Journal of Developing Societies*, *1*(3), pp.97-106.

Akpomuvie, O.B. and Orhioghene, B., (2011). Tragedy of commons: Analysis of oil spillage, gas flaring and sustainable development of the Niger Delta of Nigeria. *Journal of Sustainable Development*, *4*(2), pp.200-210.

Albers, P.H., (2002). Petroleum and individual polycyclic aromatic hydrocarbons. In *Handbook of ecotoxicology* (pp. 365-396). CRC Press.

Amnesty International, (2016). *Nigeria: Hundreds of oil spills continue to blight Niger Delta,* viewed 30 May,2021, *https://www.amnesty.org/en/latest/news/2015/03/hundreds-of-oil-spills-continue-to-blight-niger-delta/*

Andersen, H.R., Hansen, M., Kjølholt, J., Stuer-Lauridsen, F., Ternes, T. and Halling-Sørensen, B., (2005). Assessment of the importance of sorption for steroid estrogens removal during activated sludge treatment. *Chemosphere*, *61*(1), pp.139-146.

Bakare, A.S. and Fawehinmi, F.O., (2011). An econometric study of the contribution of oil sector to the standard of living in Nigeria: 1975-2008. *Asian Journal of Business and Management Sciences*, *1*(3), pp.01-08.

Barakat, A.O., Qian, Y., Kim, M. and Kennicutt II, M.C., (2001). Chemical characterization of naturally weathered oil residues in arid terrestrial environment in Al-Alamein, Egypt. *Environment international*, *27*(4), pp.291-310.

Chiou, C.T., (2003). *Partition and adsorption of organic contaminants in environmental systems*. John Wiley & Sons.

Clements, L., Palaia, T. and Davis, J., (2009). *Characterisation of sites impacted by petroleum hydrocarbons: national guideline document*. CRC CARE.

Dokpesi, A.O., (2004). Environmental degradation and the prospects of remediation in the Niger Delta. *Social problems: Theoretical paradigms in contemporary sociology*, pp.88-106.

Ebuete Abinotami Williams, Raimi Morufu Olalekan, Ebuete Ibim Yarwamara & Oshatunberu Modupe (2019) Renewable Energy Sources for the Present and Future: An Alternative Power Supply for Nigeria. *Energy and Earth Science*. Vol. 2, No. 2, 2019. URL: http://dx.doi.org/10.22158/ees.v2n2p18. http://www.scholink.org/ojs/index.php/ees/article/view/2124.

Eckle, P., Burgherr, P. and Michaux, E., (2012). Risk of large oil spills: a statistical analysis in the aftermath of Deepwater Horizon. *Environmental science & technology*, *46*(23), pp.13002-13008.

Gift R A, Olalekan RM (2020). Access to electricity and water in Nigeria: a panacea to slow the spread of Covid-19. *Open Access J Sci.* 2020;4(2):34. DOI: 10.15406/oajs.2020.04.00148. https://medcrave.com/index.php?/articles/det/21409/.

Gift RA, Olalekan RM, Owobi OE, Oluwakemi RM, Anu B, Funmilayo AA (2020). Nigerians crying for availability of electricity and water: a key driver to life coping measures for deepening stay at home inclusion to slow covid-19 spread. *Open Access Journal of Science*. 2020;4(3):69–80. DOI: 10.15406/oajs.2020.04.00155.

Gruiz, K., Meggyes, T. and Fenyvesi, É. eds., 2015. *Engineering tools for environmental risk Management: 2. Environmental toxicology*. CRC Press.

Hayes, M.O., Hoff, R., Michel, J., Scholz, D. and Shigenaka, G., (1992). *Introduction to coastal habitats and biological resources for oil-spill response* (No. PB-92-187590/XAB; HMRAD-92-4). National Oceanic and Atmospheric Administration, Seattle, WA (United States). Coastal Monitoring and Bioeffects Assessment Div.

Irwin, R.J., Specialists, S.A.C., Van Mouwerik, M.A.R.K., Stevens, L., Seese, M.D. and Basham, W., (1997). Environmental contaminants encyclopedia: benzene entry. *National Park Service Water Resources Divisions, Water Operations Branch, Fort Collins Colorado*.

Kadafa, A.A., (2012). Oil exploration and spillage in the Niger Delta of Nigeria. *Civil and Environmental Research*, *2*(3), pp.38-51.

Keenan, H.E., Sakultantimetha, A. and Bangkedphol, S., (2008). Environmental fate and partition co-efficient of oestrogenic compounds in sewage treatment process*. Environmental research, 106(3), pp.313-318.*

Lindén, O. and Pålsson, J., (2013). Oil contamination in ogoniland, Niger Delta. *Ambio*, *42*(6), pp.685-701.

Mackay, D., (1979). Finding fugacity feasible. *Environmental Science & Technology*, *13*(10), pp.1218-1223.

Mayo-Bean, K., Moran, K., Meylan, B. and Ranslow, P., (2012). Methodology document for the ecological structure-activity relationship model (ECOSAR) class program. *US-EPA, Washington DC*, p.46.

Mba, I.C., (2019). Application of the stochastic Markov model in predicting the volume of oil spill in Nigeria: a case of the Niger-Delta region. *670216917*.

Morufu Olalekan Raimi, Aziba-anyam Gift Raimi, Teddy Charles Adias (2021). Evidence-based Environmental and Public Health Practices to Respond to the COVID-19 Crisis, 07 May 2021, PREPRINT (Version 1) available at Research Square [https://doi.org/10.21203/rs.3.rs-504983/v1] https://europepmc.org/article/PPRID/PPR335534; EMSID:EMS123969.

Morufu Olalekan Raimi, Ebikapaye Okoyen, Tuebi Moses, Aziba-anyam Gift Raimi, Adedoyin Oluwatoyin Omidiji, Aishat Funmilayo Abdulraheem, Mariam Oluwakemi Raimi, Beatrice Oka Joseph (2021) Do Weak Institutions Prolong Crises? [#ENDSARs] in the Light of the Challenges and opportunities beyond COVID-19 Pandemic and the Next Normal in Nigeria. *Communication, Society and Media.* ISSN 2576-5388 (Print) ISSN 2576-5396 (Online) Vol. 4,No.2,DOI: https://doi.org/10.22158/csm.v4n2p1. http://www.scholink.org/ojs/index.php/csm/article/view/3790.

Morufu Olalekan Raimi, Tonye Vivien Odubo, Ogah Alima, Henry Akpojubaro Efegbere, Abinotami Williams Ebuete (2021) Articulating the effect of Pesticides Use and Sustainable Development Goals (SDGs): The Science of Improving Lives through Decision Impacts. *Research on World Agricultural Economy.* Vol 2, No. 1. DOI: http://dx.doi.org/10.36956/rwae.v2i1.347.

Morufu Raimi, Timothy Kayode Samson, Ajayi Bankole Sunday *et al* (2021). Air of Uncertainty from pollution profiteers: Status of ambient air quality of sawmill industry in Ilorin Metropolis, Kwara State, Nigeria, 25 February 2021, PREPRINT (Version 1) *available at Research Square* [https://doi.org/10.21203/rs.3.rs-270757/v1]

Morufu Raimi and Clinton Ezekwe (2017), Assessment of Trace Elements in Surface and Ground Water Quality (2017) LAP Lambert Academic Publishing. Mauritius. ISBN: 978-3-659-38813-2. www.omniscriptum.com.

Myers, N., Mittermeier, R.A., Mittermeier, C.G., Da Fonseca, G.A. and Kent, J., (2000). Biodiversity hotspots for conservation priorities. *Nature*, *403*(6772), pp.853-858.

Nwilo, P.C. and Badejo, O.T., (2001), October. Impacts of oil spills along the Nigerian coast. In Proceedings of the 1st International Congress on Petroleum Contaminated Soils, Sediments and Water, (PCSSW'01), Imperial College, London (pp. 27-39).

Nwilo, P.C. and Badejo, O.T., (2004). Management of oil spill dispersal along the Nigerian coastal areas.

Odipe, O.E., Raimi, M., Deinkuro, N.S., Funmilayo, A.A., innocent Edewor, O.P., Lateefat, H.M. and Fadeyibi, M., (2019). Assessment of Environmental Sanitation, Food Safety Knowledge, Handling Practice among Food Handlers of Bukateria Complexes in Iju Town, Akure North of Ondo-State, Nigeria. *Acta Scientific Nutritional Health*, *3*(6).

Odubo Tonbra Robert and Raimi Morufu Olalekan (2019) Resettlement and Readjustment Patterns of Rural Dwellers During and After Flood Disasters in Bayelsa State Nigeria. *British Journal of Environmental Sciences* Vol .7, No .3, Pp. 45-52, July 2019. www.eajournals.org.

Oguike, P.C. and Mbagwu, J.S.C., (2009). Variations in some physical properties and organic matter content of soils of coastal plain sand under different land use types. *World journal of agricultural sciences*, *5*(1), pp.63-69.

Okoyen E, Raimi M O, Omidiji A O, Ebuete A W (2020). Governing the Environmental Impact of Dredging: Consequences for Marine Biodiversity in the Niger Delta Region of Nigeria. *Insights Mining Science and technology* 2020; 2(3): 555586. DOI: 10.19080/IMST.2020.02.555586. https://juniperpublishers.com/imst/pdf/IMST.MS.ID.555586.pdf.

Olalekan RM, Oluwatoyin OA, Olawale SH, Emmanuel OO, Olalekan AZ (2020) A Critical Review of Health Impact Assessment: Towards Strengthening the Knowledge of Decision Makers Understand Sustainable Development Goals in the Twenty-First Century: Necessity Today; Essentiality Tomorrow. *Research and Advances: Environmental Sciences*. 2020(1): 72-84. DOI: 10.33513/RAES/2001-13. https://ospopac.com/journal/environmental-sciences/early-online.

Olalekan R. M, Oluwatoyin O and Olalekan A (2020) Health Impact Assessment: A tool to Advance the Knowledge of Policy Makers Understand Sustainable Development Goals: A Review. *ES Journal of Public Health*; 1(1); 1002. https://escientificlibrary.com/public-health/in-press.php.

Olalekan R. M, Dodeye E. O, Efegbere H. A, Odipe O. E. Deinkuro N. S, Babatunde A and Ochayi E. O (2020) Leaving No One Behind? Drinking-Water Challenge on the Rise in Niger Delta Region of Nigeria: A Review. *Merit Research Journal of Environmental Science and Toxicology* (ISSN: 2350-2266) Vol. 6(1): 031-049 DOI: 10.5281/zenodo.3779288.

Olalekan RM, Adedoyin OO, Ayibatonbira A, *et al* (2019). "Digging deeper" evidence on water crisis and its solution in Nigeria for Bayelsa state: a study of current scenario. *International Journal of Hydrology.* 2019;3(4):244–257. DOI: 10.15406/ijh.2019.03.00187.

Olalekan RM, Omidiji AO, Williams EA, Christianah MB, Modupe O (2019). The roles of all tiers of government and development partners in environmental conservation of natural resource: a case study in Nigeria. *MOJ Ecology & Environmental Sciences* 2019;4(3):114–121. DOI: 10.15406/mojes.2019.04.00142.

Olalekan, R. M., Omidiji, A. O., Nimisngha, D., Odipe, O. E. and Olalekan, A. S. (2018). Health Risk Assessment on Heavy Metals Ingestion through Groundwater Drinking Pathway for Residents in an Oil and Gas Producing Area of Rivers State, Nigeria. *Open Journal of Yangtze Gas and Oil, 3, 191-206.* https://doi.org/10.4236/ojogas.2018.33017.

Olalekan R. M, Vivien O. T, Adedoyin O. O, *et al.* (2018). The sources of water supply, sanitation facilities and hygiene practices in oil producing communities in central senatorial district of Bayelsa state, Nigeria. *MOJ Public Health*. 2018;7(6):337–345. DOI: 10.15406/mojph.2018.07.00265.

Omidiji A. O and Raimi M. O (2019) Practitioners Perspective of Environmental, Social and Health Impact Assessment (ESHIA) Practice in Nigeria: A Vital Instrument for Sustainable Development. Paper Presented at the Association for Environmental Impact Assessment of Nigeria (AEIAN) On Impact Assessment: A Tool for Achieving the Sustainable Development Goals in Nigeria, 7th and 8th November, 2019 In University of Port Harcourt. https://aeian.org/wp-content/uploads/2019/08/EIA-Presentations-Portharcourt.pdf.

Osuji, L.C., Egbuson, E.J. and Ojinnaka, C.M., (2006). Assessment and treatment of hydrocarbon inundated soils using inorganic nutrient (NPK) supplements: II. A case study of eneka oil spillage in Niger Delta, Nigeria. *Environmental monitoring and assessment*, *115*(1), pp.265-278.

Plessl, C., Otachi, E.O., Körner, W., Avenant-Oldewage, A. and Jirsa, F., (2017). Fish as bioindicators for trace element pollution from two contrasting lakes in the Eastern Rift Valley, Kenya: spatial and temporal aspects. *Environmental science and pollution research*, *24*(24), pp.19767-19776.

Potter, T.L. and Simmons, K.E., (1998). *Composition of petroleum mixtures* (Vol. 2). Massachusetts: Amherst Scientific Publishers.

Premoboere Edna Ateboh and Raimi Morufu Olalekan (2018). Corporate Civil Liability and Compensation Regime for Environmental Pollution in the Niger Delta. *International Journal of Recent Advances in Multidisciplinary Research Vol. 05, Issue 06, pp. 3870-3893, June, 2018.*

Raimi Morufu Olalekan, Emeka Chisom Lucky, Ebikapaye Okoyen, Angalabiri Clement, Christopher Ogbointuwe, Atoyebi Babatunde (2021) COVID-19 Decision Impacts: Vaccine Hesitancy, its Barriers and Impact Studies: Taking Bayelsa State as an Example., 27 May 2021, PREPRINT (Version 1) available at Research Square [https://doi.org/10.21203/rs.3.rs-566532/v1]

Raimi Morufu Olalekan, Ayinla Lateefat Olajumoke, Ogah Alima (2021) First to Respond, Last to Leave: The Role of Para-Military Agencies in Disaster Management: Evidence from Nigeria. *Sumerianz Journal of Medical and Healthcare*, 2021, Vol. 4, No. 2, pp. 96-100 ISSN(e): 2663-421X, ISSN(p): 2706-8404 Website: https://www.sumerianz.com DOI: https://doi.org/10.47752/sjmh.42.96.100. https://www.sumerianz.com/?ic=journal-home&journal=31&info=archive-detail&month=06-2021&issue=2&volume=4.

Raimi Morufu Olalekan & Raimi Aziba-anyam Gift (2020). The Toughest Triage in Decision Impacts: Rethinking Scientific Evidence for Environmental and Human Health Action in the Times of Concomitant Global Crises. *CPQ Medicine,* 11(1), 01-05.

Raimi Morufu Olalekan, Moses Tuebi, Okoyen Ebikapaye, Sawyerr Henry Olawale, Joseph Beatrice Oka, Oyinlola Bilewu Olaolu (2020) "A Beacon for Dark Times: Rethinking Scientific Evidence for Environmental and Public Health Action in the Coronavirus Diseases 2019 Era" *Medical and Research Microbiology,* Vol. 1, Issues 3.

Raimi Morufu Olalekan, Ihuoma Blossom Adindu, Esther Onyinyechi Udensin, Abdulraheem Aishat Funmilayo, Opufou Tarekebi, Deinkuro Nimisingha Sanchez, Adebayo Patrick Adekunle and Adeniji Anthony Olusola (2020) "Health Impact Assessment: Expanding Public Policy Tools for Promoting Sustainable Development Goals (SDGs) in Nigeria". *EC Emergency Medicine and Critical Care* 4.9 (2020).

Raimi Morufu Olalekan, Adio Zulkarnaini Olalekan, Odipe Oluwaseun Emmanuel, Timothy Kayode Samson, Ajayi Bankole Sunday & Ogunleye Temitope Jide (2020) Impact of Sawmill Industry on Ambient Air Quality: A Case Study of Ilorin Metropolis, Kwara State, Nigeria. *Energy and Earth Science* Vol. 3, No. 1, 2020. URL: http://dx.doi.org/10.22158/ees.v3n1p1. www.scholink.org/ojs/index.php/ees ISSN 2578-1359 (Print) ISSN 2578-1367 (Online).

Raimi Morufu Olalekan, Bilewu Olaolu Oyinlola, Adio Zulkarnaini Olalekan, Abdulrahman Halimat (2019) Women Contributions to Sustainable Environments in Nigeria. *Journal of Scientific Research in Allied Sciences*. 5(4), 35-51. ISSN NO. 2455-5800. DOI No. 10.26838/JUSRES.2019.5.4.104.

Raimi M O, Suleiman R M, Odipe O E, Salami J T, Oshatunberu M, et al (2019). Women Role in Environmental Conservation and Development in Nigeria. Ecology & Conservation Science; 1(2): DOI: 10.19080/ECOA.2019.01.555558. Volume 1 Issue 2 - July 2019. https://juniperpublishers.com/ecoa/pdf/ECOA.MS.ID.555558.pdf.

Raimi M. O, Omidiji A. O, Adio Z. O (2019) Health Impact Assessment: A Tool to Advance the Knowledge of Policy Makers Understand Sustainable Development Goals. Conference paper presented at the: Association for Environmental Impact Assessment of Nigeria (AEIAN) On Impact Assessment: A Tool for Achieving the Sustainable Development Goals in Nigeria, 7th and 8th November, 2019 in University of Port Harcourt. DOI: 10.13140/RG.2.2.35999.51366 https://www.researchgate.net/publication/337146101.

Raimi Morufu Olalekan (2019) 21st Century Emerging Issues in Pollution Control. 6th Global Summit and Expo on Pollution Control May 06-07, 2019 Amsterdam, Netherlands.

Raimi M. O, Abdulraheem A. F*,* Major Iteimowei, Odipe O. E, Isa H. M, Onyeche Chinwendu (2019). The Sources of Water Supply, Sanitation Facilities and Hygiene Practices in an Island Community: Amassoma, Bayelsa State, Nigeria. *Public Health Open Access* 2019, 3(1): 000134. ISSN: 2578-5001. DOI: 10.23880/phoa-16000134.

Raimi Morufu Olalekan, Omidiji Adedoyin O, Adeolu Timothy Adedotun, Odipe Oluwaseun Emmanuel and Babatunde Anu (2019) An Analysis of Bayelsa State Water Challenges on the Rise and Its Possible Solutions. *Acta Scientific Agriculture* 3.8 (2019): 110-125. DOI: 10.31080/ASAG.2019.03.0572.

Raimi Morufu Olalekan, Adeolu Adedotun Timothy, Enabulele Chris E, Awogbami Stephen Olalekan (2018) Assessment of Air Quality Indices and its Health Impacts in Ilorin Metropolis, Kwara State, Nigeria. *Science Park Journals of Scientific Research and Impact Vol. 4(4), pp. 060-074, September 2018 ISSN 2315-5396*, DOI: 10.14412/SRI2018.074.http://www.scienceparkjournals.org/sri/pdf/2018/September/Olalekan_et_al.pdf. http://www.scienceparkjournals.org/sri/Content/201

Raimi Morufu Olalekan and Sabinus Chibuzor Ezugwu (2017) An Assessment of Trace Elements in Surface and Ground Water Quality in the Ebocha-Obrikom Oil and Gas Producing Area of Rivers State, Nigeria. *International Journal for Scientific and Engineering Research (Ijser)*: Volume 8, Issue 6, July Edition. ISSN: 2229-5518.

Raimi, M. O, Pigha, Tarilayun K and Ochayi, E. O (2017) Water-Related Problems and Health Conditions in the Oil Producing Communities in Central Senatorial District of Bayelsa State. *Imperial Journal of Interdisciplinary Research (IJIR) Vol-3, Issue-6, ISSN: 2454-1362.*

Raimi Morufu Olalekan, and Sabinus Chibuzor Ezugwu. (2017) Influence of Organic Amendment on Microbial Activities and Growth of Pepper Cultured on Crude Oil Contaminated Niger Delta Soil. *International Journal of Economy, Energy and Environment.* Vol. 2, No. 4, 2017, pp. 56-76. DOI: 10.11648/j.ijeee.20170204.12.

Samson T.K., Ogunlaran O.M., Raimi O.M. (2020); A Predictive Model for Confirmed Cases of COVID-19 in Nigeria. *European Journal of Applied Sciences*, Volume 8, No 4, Aug 2020;pp:1-10. DOI: 10.14738/aivp.84.8705. DOI: https://doi.org/10.14738/aivp.84.8705.

San Sebastián, M., Armstrong, B., Córdoba, J.A. and Stephens, C., (2001). Exposures and cancer incidence near oil fields in the Amazon basin of Ecuador. *Occupational and environmental medicine*, *58*(8), pp.517-522.

Sangster, J., (1989). Octanol-water partition coefficients of simple organic compounds. *Journal of Physical and Chemical Reference Data*, *18*(3), pp.1111-1229.

Sawyerr O. H, Odipe O. E, Olalekan R. M, *et al*. (2018) Assessment of cyanide and some heavy metals concentration in consumable cassava flour "*lafun*" across Osogbo metropolis, Nigeria. *MOJ Eco Environ Sci.* 2018;3(6):369–372. DOI: 10.15406/mojes.2018.03.00115.

Shittu, W.J.A., (2014). *Mapping oil spill human health risk in rivers state, Niger Delta, Nigeria* (Doctoral dissertation, University of Nottingham).

SPDC, (2021). *Oil Spill Data,* viewed, 16 May, 2021, https://www.shell.com.ng/sustainability/environment/oil-spills.html.

Suleiman Romoke Monsurat, Raimi Morufu Olalekan and Sawyerr Henry Olawale (2019) A Deep Dive into the Review of National Environmental Standards and Regulations Enforcement Agency (NESREA) Act. *International Research Journal of Applied Sciences*. pISSN: 2663-5577, eISSN: 2663-5585. DOI No. Irjas.2019.123.123. www.scirange.com.  https://scirange.com/abstract/irjas.2019.108.125.

Todd, G.D., Chessin, R.L. and Colman, J., (1999). Toxicological profile for total petroleum hydrocarbons (TPH).

Udoh, I.A., (2018). Public health emergency, UNEP environmental assessment and the cleanup of Nigeria's Niger Delta. *Arts and Humanities Open Access Journal*, *2*(6), pp.386-389.

UNDP, (2016). *Niger Delta Human Development Report.* viewed 31 May,2021, http://hdr.undp.org/sites/default/files/nigeria_hdr_report.pdf

UNEP, (2011). Environmental Assessment of Ogoniland. Viewed 2 June, 2021, http://postconflict.unep.ch/publications/OEA/UNEP_OEA.pdf.

USEIA, (2014). Nigeria analysis. *US Energy Information Administration.* Viewed 30 May,2021, https://www.eia.gov/analysis/

USEPA, (2010). Exposure Assessment Tools and Models, Screening Level Tools. Viewed 3 June,2021, http://www.epa.gov/oppt/exposure/pubs/screen.htm

USEPA., (1999). Understanding Variation in Partition Coefficient, Kd, Values, Viewed 31 May, 2021 http://www.epa.gov/radiation/docs/kdreport/vol1/402-r-99-004a.pdf.

USEPA., (2012). Estimation programs interface suite™ for Microsoft® windows, v 4.11. *United States Environmental Protection Agency, Washington, DC, USA.*

Wang, Z., Stout, S.A. and Fingas, M., (2006). Forensic fingerprinting of biomarkers for oil spill characterization and source identification. *Environmental Forensics*, *7*(2), pp.105-146.

Wizor, C.H. and Wali, E., (2020). Crude Oil Theft in the Niger Delta: The Oil Companies and Host Communities Conundrum.

## Footnotes

[1] A 2007 "Quality Review Draft" can be accessed on the USEPA website on: http://www.epa.gov/sab/panels/epi_suite_review_panel.htm.

[3] $K_d$ values employed here may be overestimated. Empirical $K_d$ values may vary greatly for a particular contaminant.

[4] Stockholm Convention, Annex D. Available at: http://chm.pops.int/Home/tabid/2121/Default.aspx.

## Declarations

Competing Interests: The authors declare no competing interests.

## Figures

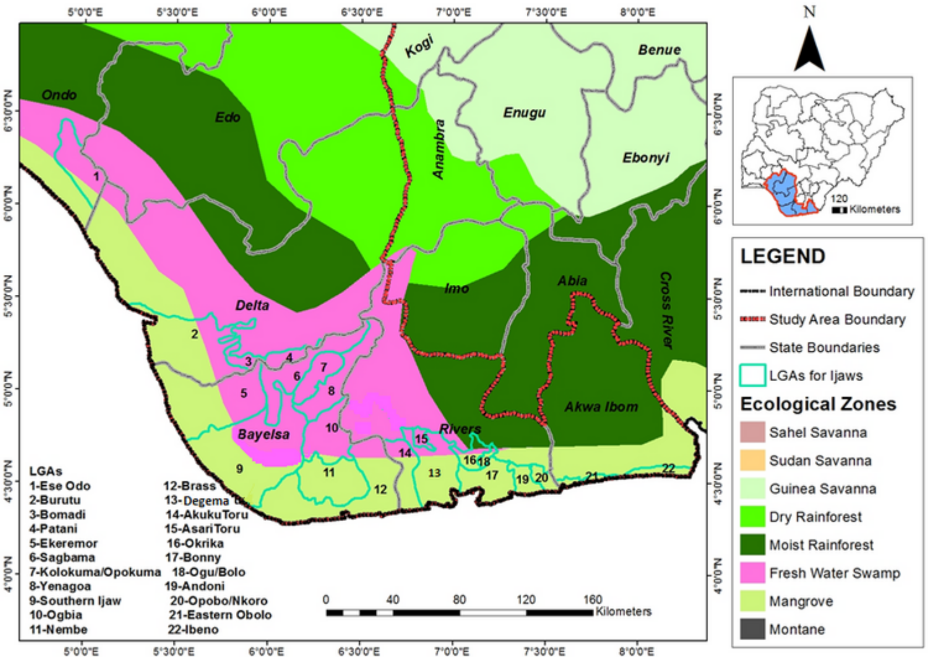


**Figure 1**

Map of Niger Delta Region (NDR)

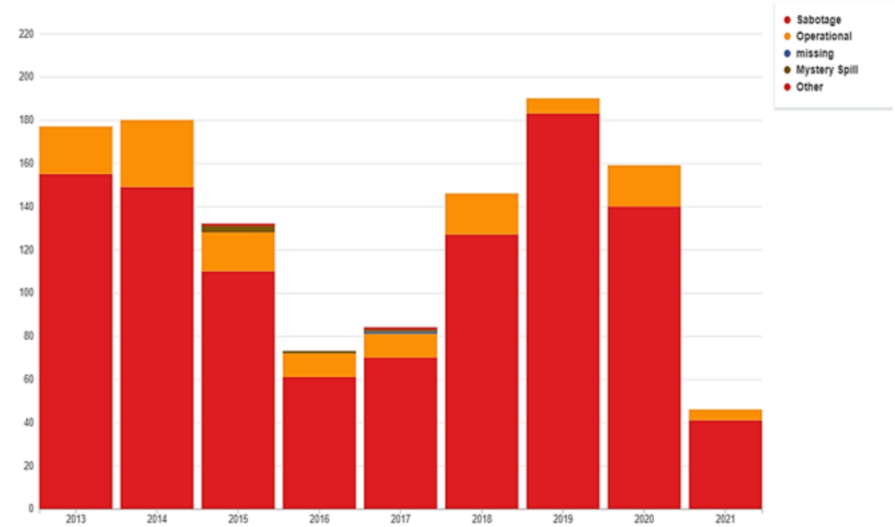


**Figure 2**

Annual oil spill incidences by cause for 2013-2021 (SPDC, 2021)

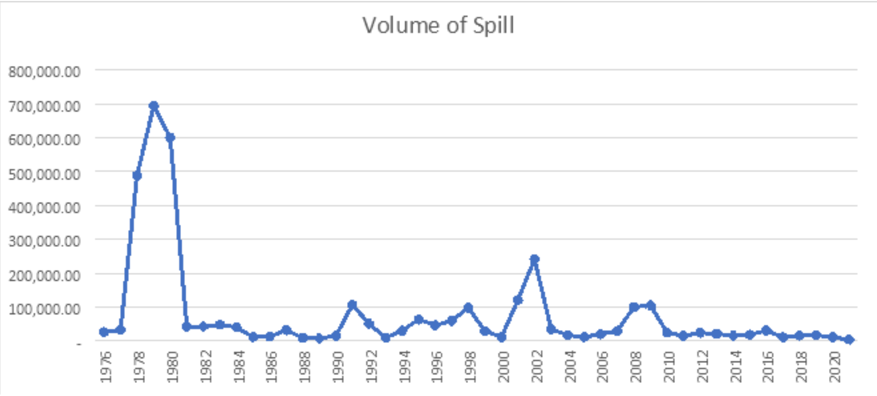


**Figure 3**

Volume of Spilled Oil in the Niger Delta, 1976- May,2021.

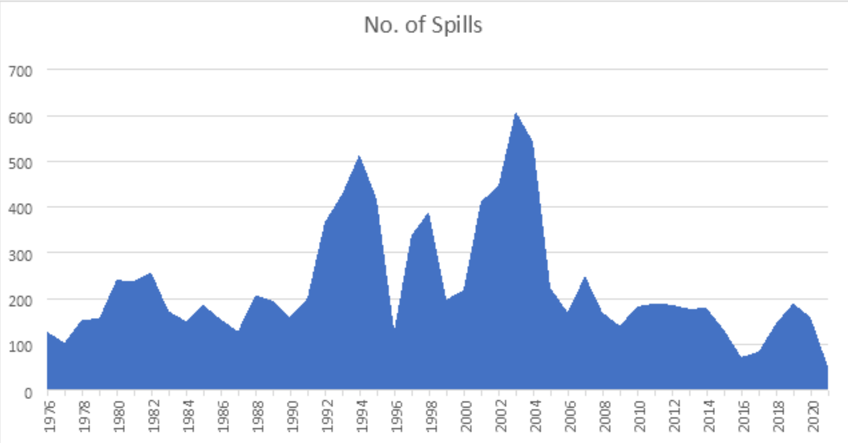
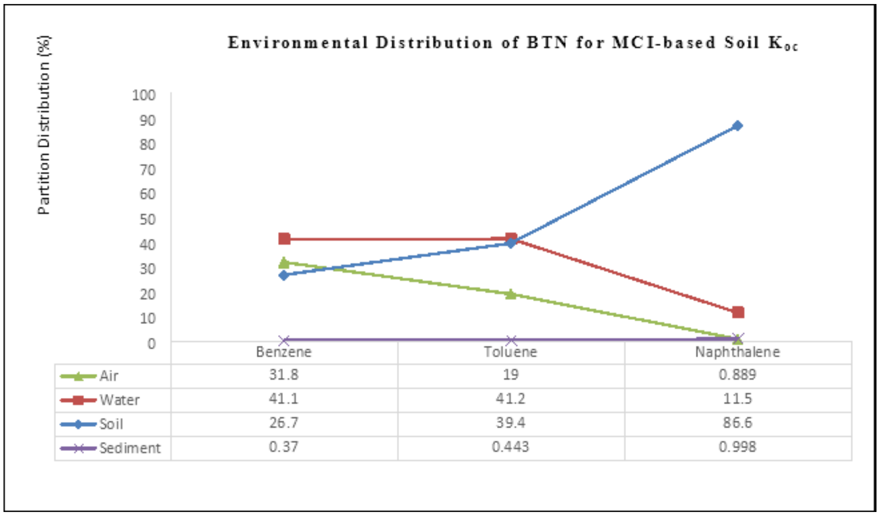


**Figure 4**

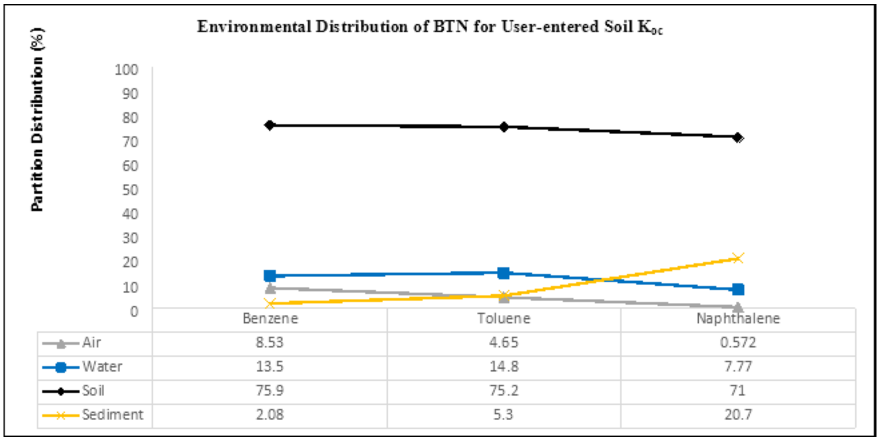
Number of Oil Spills in the Niger Delta from 1976 - May,2021



| | Benzene | Toluene | Naphthalene |
|---|---|---|---|
| Air | 31.8 | 19 | 0.889 |
| Water | 41.1 | 41.2 | 11.5 |
| Soil | 26.7 | 39.4 | 86.6 |
| Sediment | 0.37 | 0.443 | 0.998 |

**Figure 5**

Environmental Distribution of BTN for MCI-based Soil Koc



| | Benzene | Toluene | Naphthalene |
|---|---|---|---|
| Air | 8.53 | 4.65 | 0.572 |
| Water | 13.5 | 14.8 | 7.77 |
| Soil | 75.9 | 75.2 | 71 |
| Sediment | 2.08 | 5.3 | 20.7 |

**Figure 6**

Environmental Distribution of BTN for User-entered Soil Koc

## Supplementary Files

This is a list of supplementary files associated with this preprint. Click to download.

- OILSPILLDATA2011202119762010.xlsx