Evaluation of Diesel Range Organics of Some Petroleum Polluted Remediated Soils within Rivers, South-East Region, Nigeria.

P. Micheal* and U.J. Chukwu
Department of Pure and Industrial Chemistry, University of Port Harcourt, Rivers State. Nigeria
princeuc01@gmail.com, uche.chukwu@uniport.edu.ng

ABSTRACT

This study evaluated the levels of Diesel range organics (DRO) in soil samples of some petroleum polluted remediated sites within the Rivers State South-East geographical region of Nigeria. The research provides insight into the level of contamination and the effectiveness of remediation efforts in the region. Forty soil samples were collected from eight remediated sites, and were analyzed using Agilent GC equipped with a Flame Ionization Detector. The mean DRO values obtained ranged from 36.10 to 84.75 mg/kg. The results of their mean values were compared to their control values which ranged between 10.96 and 19.32 mg/kg. The DPR, NOSDRA, and EGASPIN standard limits were used to compare the obtained results. The results showed varying levels of DRO in the soil samples, with some sites showing high levels of contamination and others showing successful remediation efforts in the region. It also buttressed the importance of effective regulation of the petroleum industry in Nigeria.

Keywords: (Diesel range organics, Petroleum pollution, Soil Remediation)

INTRODUCTION

The Rivers South-East geographical region is a vital part of Nigeria economy and an important contributor to global energy markets due to its significant reserves of oil and gas with an estimated 23 billion barrels of oil and over 183 trillion cubic feet of natural gas reserves (Giwa *et al.*, 2016). However, the exploration and production activities have led to widespread environmental pollution, particularly in the form of hydrocarbon contamination of soil. Hydrocarbon contamination occurs when petroleum products are spilled or released into the environment, leading to the contamination of soil and water resources (Adewuyi *et al*., 2012). The region has experienced multiple incidents of hydrocarbon contamination, including oil spills and leaks from pipelines. These incidents have had severe consequences for the environment and the people who live in the area, leading to health problems, loss of biodiversity, and damage to the economy (Festus *et al*., 2020).

To address this issue, a number of remediation efforts have been undertaken in the region to clean up contaminated sites and mitigate the environmental impact of hydrocarbon pollution. Remediation is the process of removing or reducing contaminants in the environment to acceptable levels (Okparanma *et al*., 2018; Stroo and Ward, 2010; Reddy and Camselle, 2009; John, 2007; USEPA, 1987). The objective of remediation efforts is to reduce the levels of hydrocarbon contamination in soil and water resources to acceptable limits set by regulatory bodies, in order to protect human health, restore ecological balance, and support sustainable economic development. However, the effectiveness of remediation efforts in the Rivers State, South-East geographical region has been the subject of debate. While some studies have reported significant reductions in hydrocarbon contamination levels following remediation efforts, others have suggested that the efforts have not been successful in reducing contamination levels to acceptable levels (Gbarakoro and Bello, 2022; Okoro *et al*., 2011). There are several factors that can impact the success of remediation efforts, including the type and extent of contamination, the methods used for remediation, and the environmental conditions at the site (Mmom and Deekor, 2010).

Total Petroleum Hydrocarbon (TPH) is the gross amount of petroleum hydrocarbon compounds that are present in an environment. It has a detrimental effect on human health and plant growth when present in the soil (Festus *et al*., 2020; Paiga *et al*., 2012). Diesel range organics is a complex mixture of hydrocarbons ranging from C_{10} – C_{28} or C_{32} derived from crude oil (API, 1994). It is often referred to the group of hydrocarbons in the diesel fuel range, which includes alkanes, alkenes, and aromatic hydrocarbons with carbon chain lengths ranging from C_9 to C_{28} (API, 1994). The carbon ranges for diesel range compounds using a gas chromatography with flame ionization detector (GC/FID) typically includes hydrocarbons with carbon numbers between C_9 and C_{28}. However, the exact carbon range can vary depending on the specific method and regulatory agency classification. The US Environmental Protection Agency (USEPA, 2000) specifies a carbon range of C_9 to C_{36} for diesel range hydrocarbons analysis using GC/FID, while European Committee for Standardization specifies a carbon range of C_9 to C_{40} (CEN, 2002). It is important to consult the specific method and regulatory agency for the appropriate carbon range related to DRO analysis in soil. The most hazardous combinations of organic chemicals that can be discovered in or generated from crude oil can be classified as Diesel range organics and they are very volatile in nature. Many of these products (gasoline, kerosene, and much more) have greasy odour (Gbarakoro and Bello, 2022; Okparanma *et al*., 2018). The DRO could enter the environment through a variety of sources, including crude oil spills, leaks from storage tanks, transportation accidents and human sabotage etc. When toxic organic matter such as DRO is released into the environment, it moves from the soil to the groundwater. Some organisms may break down some of the contaminants into smaller fractions, while some may evaporate into the atmosphere (Okoro *et al*., 2015; ASTDR, 1999). DRO released into the environment, according to the United Nation Environmental Programme, endanger public health and safety by contaminating drinking water, increasing the risk of fire and explosion, lowering the quality of the air and water, impairing agriculture, destroying recreational areas, destroying habitats, destroying food, and wasting non-renewable resources (UNEP, 2011).

In recent years, there has been growing concern about the impact of hydrocarbon contamination on the health and livelihoods of people living in the Rivers South-East geographical region. The contamination has led to the loss of crops and fish stocks, which has had a significant impact on the economy of the region. It has also been linked to health problems, including respiratory illnesses, skin diseases, and cancer (Adewuyi *et al*., 2012). This has led to calls for more effective remediation efforts in the region, in order to protect the health and livelihoods of local communities and support sustainable economic development. The DRO compounds are particularly harmful to plant and animal life and could contaminate the groundwater, air, and soil. The United Nations Environmental Programme (UNEP) conducted an assessment report on some communities affected by hydrocarbon pollution in Rivers South-East geographical region, Nigeria between 2009 and 2011 (UNEP, 2011). Recommendations from the report led to the establishment of the Hydrocarbon Pollution Remediation Project (HYPREP) by the Federal Government of Nigeria (FGN). The body established aims to oversee the environmental remediation process and the restoration of livelihoods in the Niger Delta region of Nigeria, starting with Rivers South-East geographical region.

This research aims to fill a significant gap in the current literature by evaluating the concentrations of DRO in petroleum polluted remediated sites in the Rivers South-East geographical region. While previous studies discussed TPH in general, none have specifically address Diesel range fraction of TPH in the region, making this study relatively. Furthermore, the study provided insight into the effectiveness of remediation approaches in reducing contamination levels to acceptable limits set by regulatory bodies in Nigeria. This is crucial for ensuring the safety of both the environment and human health. By focusing on several remediated sites in the region that have experience hydrocarbon contamination due to oil spills or pipeline leakages, this research had provided valuable data that would be used to improve future remediation methods. The results of this research have the potential to significantly impact current practices in the field of environmental remediation in Nigeria and beyond.

STUDY AREA

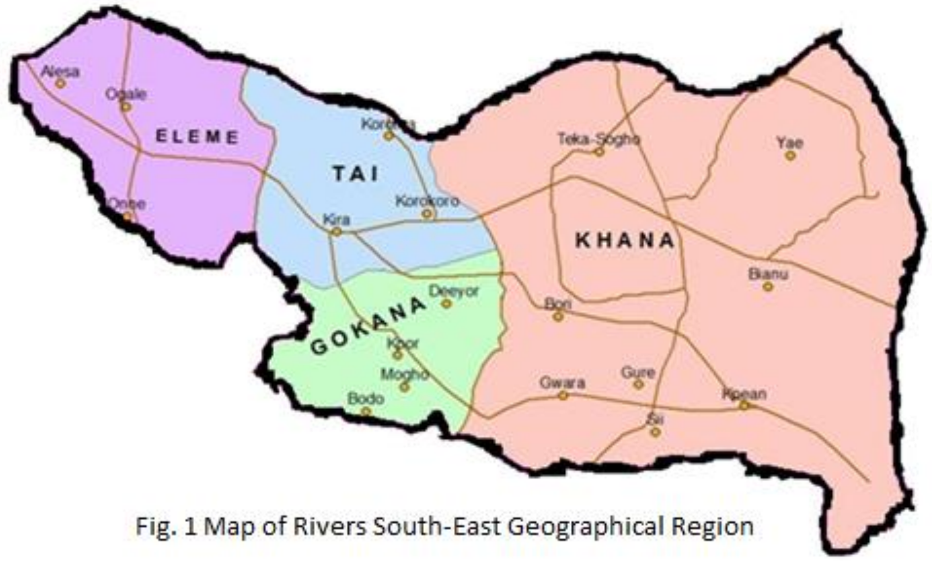

Fig. 1 Map of Rivers South-East Geographical Region

Along the Rivers State coast in the Niger Delta region of Nigeria, the Rivers South-East geographical region area is located between Latitude 4° 40’5” N and 4° 43’ 19.5” N and Longitude 7° 22’ 53.7” E and 7° 27’ 9.8” E of the equator (Nkpaa *et al*., 2017). It is located in the Gulf of Guinea’s Niger Delta basin, covering an area of 1,000 square kilometres (UNEP, 2011). There are four Local Government Areas (LGA) in Rivers South-East geographical region, namely Eleme, Gokana, Khana, and Tai (see Fig.1). It is a tropical rainforest belt with light shrubs and farmlands that are home to a variety of species as secondary vegetation, most of the land is covered in dense bush and bogs (Nkpaa *et al*., 2017). The East-West highway also passes through the neighbourhood, which results in major vehicular traffic congestion. The region also produces oil and is home to numerous significant domestic and international oil and gas industrial facilities, refineries, petrochemical facilities, and fertilizer factories among others (Giwa *et al*., 2016). Local livelihoods, ecology, fish breeding grounds, and public health have all been impacted by oil contamination in Rivers South East geographical region. In addition, the spills had wiped out almost 1,000 hectares of mangroves, a vital habitat for fish nidification and reproduction as well as a very valuable carbon sinks (UNEP, 2011). The study area consists of eight remediated sites located in four LGA impacted by crude oil spills over the years. Akpajo and

Okuluegu are located in Eleme LGA, Gbogozor and Vuruvuru are located in Gokana LGA, Wiiboora and Wiikaragu are located in Khana LGA while Korokoro and Kporghor are located in Tai LGA.

MATERIALS AND METHODS

The effectiveness of the remediation efforts was evaluated by measuring the levels of DRO in soil samples collected from the remediated sites, as well as from nearby control sites where no hydrocarbon contamination has occurred and remediation has not been undertaken.

Sampling and Collection

The sampling methodology adhered to the standard guidelines outlined in (ASTM D1452 – 09; D4547-98 USEPA 2020; NESREA B 796, Part III: 27; Popek, 2003). The sample points were located using a Garmin etrex10 GPS device (model GS284), and 40 points were mapped out across various locations, with 5 points chosen from each community, consisting of 4 points from the impacted site and 1 point from the control site. The selected points were drilled to a depth of 5 meters using a manual drilling auger, in line with the excavation depth during the remediation process. Discrete samples were collected at each drilled point, and control samples were obtained from a location 120 meters away from the remediated sites. Sample collection was performed immediately after removing the auger head from the hole and the samples were deposited in a 100 ml wide-mouthed amber-colored glass bottle, filled to the brim to avoid headspace and minimize volatilization. The amber-colored glass bottle was used to prevent photochemical reactions with the soil sample. The samples were transferred to an insulated cooler containing ice blocks at a temperature of 4ºC to maintain sample integrity. Prior to sampling at each depth, the auger head was washed with distilled water and rinsed with methanol before collecting the sample. Each sample was labelled and identified by community name and point number as follows; AJO-1 to AJO-4 denote samples from Akpajo, with the corresponding control point labelled as AJO-C. OBU-1 to OBU-4 represent samples from Okuluegbu, accompanied by OBU-C as the control point. Similarly, GOR-1 to GOR-4 signify samples from Gbogozor, with GOR-C as the control point. VRU-1 to VRU-4 denote samples from Vuruvuru, linked to VRU-C as the control point. WRA-1 to WRA-4 represent samples from Wiiboora, accompanied by WRA-C as the control point. WGU-1 to WGU-4 signify samples from Wiikaragu, with WGU-C as the control point. KRO-1 to KRO-4 represent samples from Korokoro, linked to KRO-C as the control point. Lastly, KOR-1 to KOR-4 signify samples from Kporghor, with KOR-C as the control point. After the sampling process, a total of 40 soil samples were collected and promptly shipped to the laboratory for analysis.

Sample Extraction

The samples were extracted according to the ASTM D5765 procedures, whereby 10 grams of each sample were weighed with Denver analytical balance (model TP-214) and transferred to a 250 ml conical flask. A 50:50 mixtures of Dichloromethane (DCM) and Acetone, with 99.8% and 99.9% assay respectively, both procured from Sigma-Aldrich, was employed as the extracting solvent. The samples were then left to stand overnight, followed by agitation for 2 hours using a Jinotech HY-4 flask shaker (model H033AU) to ensure thorough mixing.

Subsequently, a No.41, 150 mm Whatman filter paper containing 5 grams of anhydrous Na_2SO_4 (99%) procured from Loba Chemie was utilized to remove moisture content from the extracts. A clean-up process involving the addition of 5 ml of the extracting solvent to the filter papers was also performed. The extracts were concentrated to 1 ml in a fume cupboard and then transferred to a 2 ml vial, which was sealed to preserve the sample integrity and avoid volatizing. This rendered the extracts ready for instrument analysis.

Sample Analysis and Instrument Condition

The analysis of samples for Total Diesel range hydrocarbons quantification was carried out using an Agilent GC 6890N (model G150N) equipped with a Flame Ionization Detector. The method used was in accordance with (USEPA Method 8015C; API, 1994; Pikoyskii, 2017). The GC/FID was equipped with an HP-519091J-413 capillary column, with a length of 30 m, a diameter of 0.32 mm, and a film thickness of 0.25 μm. The injection mode was set to split less, with an injection volume of 1.0 μl. Nitrogen gas was used as the carrier gas at a flow rate of 1.2 ml/min while Hydrogen flame was used for the ionization. The injection temperature was maintained at 290°C, while the oven temperature was programmed to ramp up from 50°C to 300°C at a rate of 6°C per minute, and then held at 300°C for 2 minutes. The flame ionization detector temperature was set at 300°C.

Following the analysis of the samples, the chromatogram results were generated, providing a comprehensive profile of the concentrations of a wide range of non-halogenated volatile organic compounds, semi-volatile organic compounds, and petroleum hydrocarbons. In summary, the Agilent GC 6890N with Flame Ionization Detector was found to be an efficient and reliable method for the quantification of Diesel range hydrocarbons.

Statistical analysis and data processing

Utilizing Microsoft Excel 2016, a comprehensive statistical analysis was executed to derive both mean concentration values and mean standard deviations for each individual sample. The mean concentration values effectively encapsulate the average DRO hydrocarbon concentration prevailing at each distinct site under consideration. Concurrently, the mean standard deviation values serve to elucidate the magnitude of concentration variance from the established mean.

Noteworthy is sample AJO, which prominently exhibits the highest DRO concentration level, manifesting an average concentration value of 84.74 mg/kg (Table 1). Complimenting this concentration, the mean standard deviation of ±1.13 unveils a considerable degree of variance around the mean, thus underscoring substantive heterogeneity in the concentration spread. Conversely, sample GOR emerges with the lowest DRO concentration, denoting an average value of 36.19 mg/kg (Table 1). Notably, the accompanying mean standard deviation of ±0.50 signifies a relatively constrained concentration spectrum, indicative of a more tightly clustered distribution around the mean.

RESULTS AND DISCUSSION

Table 1. The DRO concentration, their permissible limit and intervention values

S/N	Sample ID	∑DRO Conc.mg/kg	Mean Values mg/kg	Regulatory Bodies	
				DPR, NOSDRA, EGASPIN	
				Permissible Limit	Intervention Value
				50 mg/kg	5000 mg/kg
1	AJO-1	78.15	AJO 84.75 ±1.13		
2	AJO-2	84.62			
3	AJO-3	93.78			
4	AJO-4	82.45			
5	AJO-C	10.96			
6	OBU-1	33.40	OBU 39.23 ±1.19		
7	OBU-2	38.11			
8	OBU-3	48.78			
9	OBU-4	36.62			
10	OBU-C	14.10			
11	GOR-1	39.04	GOR 36.10 ±0.50		
12	GOR-2	35.71			
13	GOR-3	32.51			
14	GOR-4	37.15			
15	GOR-C	17.07			
16	VRU-1	76.17	VRU 83.01 ±0.85		
17	VRU-2	85.49			
18	VRU-3	83.47			
19	VRU-4	86.91			
20	VRU-C	19.32			
21	WRA-1	40.71	WRA 38.86 ±0.36		
22	WRA-2	38.53			
23	WRA-3	36.32			
24	WRA-4	39.88			
25	WRA-C	15.42			
26	WGU-1	83.49	WGU 83.10 ±0.42		
27	WGU-2	79.88			
28	WGU-3	82.99			
29	WGU-4	86.06			
30	WGU-C	12.60			
31	KRO-1	82.85	KRO 84.62 ±1.05		
32	KRO-2	78.01			
33	KRO-3	87.43			
34	KRO-4	90.22			
35	KRO-C	14.47			
36	KOR-1	37.88	KOR 40.18 ±0.53		
37	KOR-2	40.87			
38	KOR-3	38.21			
39	KOR-4	43.75			
40	KOR-C	13.47			

[DPR, 2018; NOSDRA, 2011; EGASPIN, 2022]

The results of this research provide important insights into the level of DRO concentration in soil samples from various sites within the Rivers South-East geographical region. Table 1 showed the various limits for DRO as well as values in which it is presume in excess and requires remediation actions. In Nigeria, these values are set by regulatory bodies. The regulatory bodies include: Department of Petroleum Resources (DPR), National Oil Spill Detection and Response Agency (NOSDRA), Environmental Guidelines and Standards for the Petroleum Industry in Nigeria (EGASPIN). DRO limits can vary depending on the region where they are studied. This is because different regions may have different environmental conditions, cultural practices, and regulatory frame works which DRO can be managed and regulated.

The results revealed that the DRO mean concentrations in the soil samples for the remediated sites ranged from 36.10 to 84.75 mg/kg (Table 1). The highest concentration was observed at AJO with a value of 84.75 mg/kg while the lowest concentration was observed at GOR with a value of 36.10 mg/kg. The second highest concentration was observed at KRO with a value of 84.63 mg/kg while the second lowest concentration value was observed at WRA with a value of 38.86 mg/kg. The third highest concentration was observed at WGU with a value of 83.10 mg/kg while third lowest concentration was observed at OBU with a value of 39.23 mg/kg. The results for the control sites ranged from 10.96 to 19.32 mg/kg.

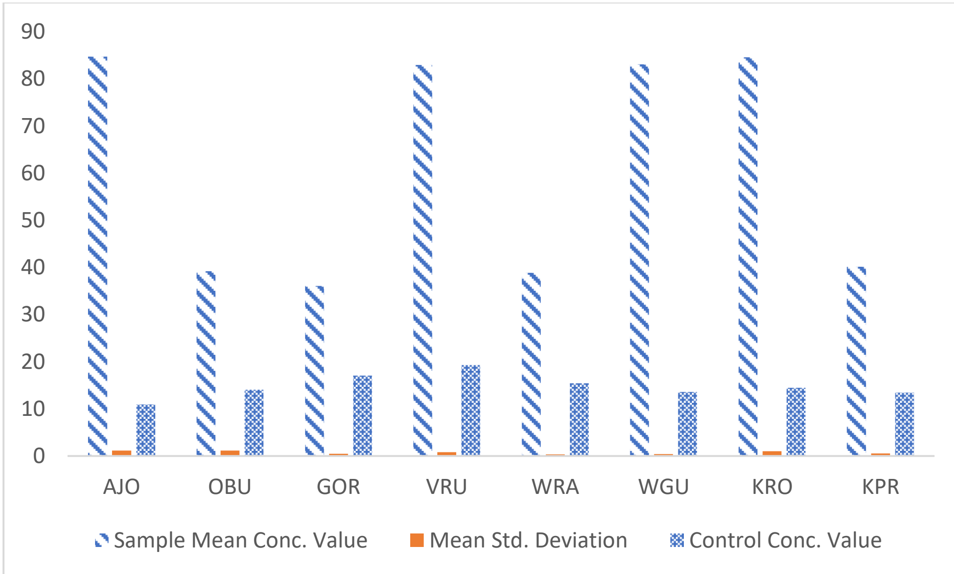

Fig. 2 Chart showing DRO mean values from the various sites

The results obtained in the remediated sites were compared to the concentrations obtained from their control values. The results showed that samples from AJO, OBU, GRO, VRU, WRA, WGU, KRO, and KOR where above their control values (see Figure 2). Also, comparing the results to the permissible limit set by regulatory bodies in Nigeria, it was observed that sample OBU, GOR, WRA, and KOR were below the permissible limit. The low concentration of DRO observed suggests that these sites may have undergone successful remediation efforts. The success of remediation efforts in these sites may be due to a range of factors, including the effectiveness of the remediation technique used, the time taken to implement the remediation effort, and the level of support from stakeholders. However, it was observed that at AJO, VRU, WGU, and KRO the total DRO values were above the permissible limit but below the intervention value of 5,000 mg/kg. The high concentration observed suggests that these sites may have been heavily contaminated with oil spill. Also it indicates that the remediation efforts carried out in this sites may not have been effective in completely removing the DRO in the sites, since the aim of the remediation activity is to bring down these hydrocarbons below the permissible limit. According to DPR, NOSDRA, and EGASPIN, the maximum allowable limit for

Total petroleum hydrocarbon (TPH) including DRO in soil is 50 mg/kg. The contamination of these sites may be as a result of some factors, including the proximity of the sites from oil production activities, transportation routes and storage facilities. The contamination may also be due to inadequate storage and disposal of petroleum products. The high concentration results indicated that the study area is still contaminated with petroleum hydrocarbons despite remediation efforts.

It is important to note that the DRO concentrations observed in this study are consistent with those reported in other studies on TPH contamination in Nigeria and other parts of the world. A study by Samuel and Omoleomeo (2016) found TPH concentrations ranging from 4.51 to 76.68 mg/kg in soil samples from oil production facilities in Niger Delta region, Nigeria. Another study by UNEP (2011) reported TPH concentrations ranging from 2.88 to 1,040.00 mg/kg in soil samples from oil spill sites in the same region. The similarity in TPH concentrations reported in these studies suggests that TPH contamination remains a significant environmental problem in the Niger Delta region.

In addition, the DRO concentrations observed in this study are also consistent with those reported in other studies on TPH contamination in other regions of the world. A study by Paiga *et al*., (2012) found TPH concentrations ranging from 1.00 to 9,230.00 mg/kg in soil samples from different locations in north Portugal. Another study by Lin *et al*., (2010) reported TPH concentrations ranging from 380.00 to 7,380.00 mg/kg in soil samples from oil-contaminated sites in Taiwan. These studies suggest that TPH contamination is a global environmental problem that requires urgent attention.

Several studies have reported that the use of bacteria and fungi can be effective in the remediation of hydrocarbon-contaminated soils. According to a study by Ahmad *et al*., (2022), bacteria and fungi have the potential to degrade hydrocarbons through enzymatic reactions. The study found that indigenous bacteria and fungi can effectively degrade hydrocarbons in contaminated soils, and the use of bio augmentation can further enhance the remediation process. In another study by Lai *et al*., (2014), it was found that a combination of bio augmentation and phytoremediation can significantly reduce the TPH concentration in contaminated soils. The results of these studies buttressed the use of bioremediation techniques as an effective way for remediating hydrocarbon-contaminated soils.

The research findings suggest that continued investment in effective remediation strategies can help to mitigate the negative impacts of hydrocarbon pollution in the Rivers South-East geographical region. This could include strategies such as bioremediation and phytoremediation, which have shown to be effective in reducing TPH concentrations in contaminated sites.

In addition, this study highlights the importance of ongoing monitoring and evaluation of remediated sites to ensure that the effectiveness of the remediation strategies is maintained over time. This could involve regular sampling and analysis of soil samples to assess DRO concentrations, as well as other indicators of soil health and ecosystem function.

CONCLUSION

This research provides important insights into the level of Diesel range hydrocarbons in soil samples from remediated sites within the Rivers South-East geographical region. The results of the research suggest that some of the sites may have been heavily contaminated with oil spill. The research also found that some of the sites may have undergone successful remediation efforts. The findings of this research highlight the need for continued monitoring and remediation efforts in the region. The results could also be used to inform policy decisions related to the regulation of the petroleum industry particularly in Nigeria. The study also highlights the importance of effective storage and disposal of petroleum products to prevent environmental pollution.

Statements and Declarations

Funding: The authors confirm that no form of financial support, grants, or funding was received for the preparation of this manuscript.

Competing Interests: The authors have no relevant financial or non-financial interests to Disclose. The authors declare that they have no conflict of interest.

Author Contributions: Uche John Chukwu designed the experimental frame work and wrote the draft manuscript while Prince Micheal carried out the sampling and conducted the laboratory experiments. All authors read and approved the final manuscript.

REFERENCES

Adewuyi G. O., Etchie A. T., and Etchie. O., T (2012). Evaluation of Total Petroleum Hydrocarbon of some related Heavy Metals in Soil and Ground water of Ubeji Settlement, Warri Metropolis. Nigeria Journal of Terrestrial and Aquatic Environmental Toxicology. Global Science Book. 6(1):61-65.

Agency for Toxic Substances and Disease Registry (ASTDR) (1999). Toxicological profile of Total Petroleum Hydrocarbon (TPH). Atlanta, GA: US, Department of Health and Human Services, Public Health Service. www.astdr.cdc.gov Date accessed 18/02/2023.

Ahmad H. J., Shamsul R. M. K., Ibrahim M. L., Nasiru A., Azmatullah N., Baker N. S. A., Abdullahi K. U., Ahmad B., Sule A., Abdullahi H. B., Ibrahim U., and Aminu S. Y (2022). Diverse sustainable materials for the treatment of petroleum sludge and remediation of contaminated sites: A review. Journal of Cleaner Waste Systems. Published by Elsevier. Available at https://doi.org/10.1016/j.clws.2022.100010 Date accessed 18/02/2023.

American Petroleum Institute (API) (1994), Inter laboratory Study of Three Methods for Analysing Petroleum Hydrocarbons in Soils. API Publication Number 4599. American Petroleum Institute, Washington, DC. Heathland Environmental Sciences Department. www.api.org Date accessed 18/02/2023.

American Society for Testing and Materials (ASTM) (1998). Method D 4547–98: Standard Guide for Sampling Waste and Soils for Volatile Organic Compounds. Annual Book of ASTM Standards. www.astm.org Date accessed 16/03/2023.

American Society for Testing and Materials (ASTM) (2010). Method D5765: Solvent Extraction of Total Petroleum Hydrocarbons from Soils and Sediments. Annual book of ASTM. Volume 00.01, ASTM Stock Number: S000110 www.astm.org Date accessed 16/03/2023.

American Society for Testing and Materials (ASTM) D1452 – 09; Standard Practice for Soil Exploration and Sampling by Auger Borings (2009). Annual book of ASTM standards. Philadelphia, PA, USA. www.astm.org Date accessed 16/03/2023.

Department of Petroleum Resources (DPR) (2018). Environmental Guideline Table VIII-G. Third Edition. 184.

Environmental Guidelines and Standards for the Petroleum Industries in Nigeria (EGASPIN) (2022). Table VIII-F1. Issued by the Department of Petroleum Resources. Revised Edition 372.

European Committee for Standardization (CEN) (2002). EN 12619: Determination of mineral oil and other petroleum products- Method by gas chromatography.

Festus C., Chukwuogene U., Chukwu E., and Onisogen S (2020). Levels of Total Petroleum Hydrocarbons in Asphalt contaminated soil from selected areas of Port Harcourt Chemistry Research Journal.5(3):130-135 ISSN: 2455-8990 CODEN(USA): CRJHA5.

Gbarakoro T. N., and Bello A. D (2022). Assessment of the concentration of Petroleum Hydrocarbon in Oily Wastes Residual ash at Bodo-Ogoni Remediation Site, Nigeria. Journal of GeoScience and Environment Protection. 10:1-15. ISSN: 2327-4336, eISSN: 2327-4344.

Giwa S. O., Nwaokocha C. N., and Layeni A. T (2016). Assessment of Millennium Development Goal in the Niger Delta Region of Nigeia Via Emission Inventory of Flared Gas. Nigeria Journal of Technology. 35(2):249-359. ISSN: 0331-8443, eISSN: 2467-8821.

John P (2007). Fundamentals of Site Remediation for Metal and Hydrocarbon-Contaminated Soils Second Edition. Government Institutes an imprint of The Scarecrow Press, Inc. ISBN-13: 978-0-86587-154-0.

Lai W. L., Lee F. Y., Chen C. S., Hseu Z., and Kuo Y. L (2014). The Removal Efficacy of Heavy Metals and Total Petroleum Hydrocarbons from Contaminated Soils by Integrated Bio-phytoremediation. Journal of

Soil and Groundwater Environment. 19(5):35-44. Available at https://doi.org/10.7857/JSGE.2014.19.5.035 Date accessed 08/06/2023.

Lin T. C., Pan P. T., and Cheng S., S (2010). Ex situ Bioremediation of oil-contaminated soil. Journal of Hazardous Materials. 176:27-34.

Mmom P. C., and Deekor T (2010). Assessing the effectiveness of land farming in the remediation of Hydrocarbon polluted soils in the Niger Delta, Nigeria. Research Journal of Applied Sciences, Engineering and Technonogy. 2(7):654-660 ISSN:2040-7467.

National Environmental Standard and Regulations Enforcement Agency (NESREA) B 796, Part III: 27 – Sampling for Analysis (2010). Federal Republic of Nigeria official Gazette. 102(141):10.

National Oil Spill Detection and Response Agency (NOSDRA) (2011). Oil Spill Recovery, Clean-up, Remediation and Damage Assessment Regulations B 810 Part III: 38 Containment and Recovery. Federal Republic of Nigeria official Gazette. 98(68):10.

Nkpaa K. W., Amadi B, A., and Wegwu M. O (2017). Trace Element levels in drinking wter from Gokana, Ogoniland Rivers State Nigeria. International journal of Hydrology. 1(2):55-57.

Okoro D., Oviasogie P. O., and Oviasogie F. E (2011). Soil quality assessment 33 months after crude oil spillage and clean-up. Journal of Chemical Speciation and Bioavailability. 23(1). ISSN: 0954-2299 (Print) 2047-6523.

Okparanma R. N, Solomon E. Ukpenevi S. E, and Ayotamuno J. M (2018). Analytic network process in petroleum hydrocarbon decontamination management in

Nigeria. Journal of Engineering and Technology Research. 10(4): 26-37, DOI: 10.5897/JETR2018.0644.

Paíga P., Mendes L., Albergaria J. T, and Cristina M. D (2012). Determination of total petroleum hydrocarbons in soil from different locations using infrared spectrophotometry and gas chromatography. Journal of Chemical Papers. Chemical Papers. 66(8):711–721 DOI: 10.2478/s11696-012-0193-8.

Pikovskii Yu. I., Korotkov L. A., Smirnova M. A., and Kovach R. G (2017). Laboratory analytical methods for the determination of the hydrocarbon status of soils (a review). Journal of Eurasian Soil Science. 50:1125-1137

Popek, E, P (2003). Sampling and Analysis of Environmental Chemical Pollutants: A Complete Guide Academic Press an imprint of Elsevier Science. First edition. ISBN: 0-12-561540-X

Redddy K. R., and Cameselle C (2009). Electrochemical Remediation Technologies for Polluted Soils, Sediments and Groundwater. A John Wiley & Sons, Inc., C Publication. ISBN 978-0-470-38343-8 (cloth).

Samuel B. O., and Omoleomeo O. O (2016). Environmental Impact Assessment of selected Oil Production Facilities in Parts of Niger Delta, Nigeria. Journal of Water Resources and Protection. 8:237-242. Available at https://doi.org/10.4236/jwrap.2016.82020 Date accessed 08/06/2023.

Stroo H. F., and Ward H. C (2010). In Situ Remediation of Chlorinated Solvent Plumes. ISBN: 978-1-4419-1400-2 e-ISBN: 978-1-4419-1401-9 DOI 10.1007/978-1-4419-1401-9 Springer New York Heidelberg Dordrecht London.

United Nation Environment Programme (UNEP) (2011). Environmental assessment of Ogoniland Site Specific Fact sheets Kpite (009-

001). https://wedocs.unep.org/20.500.11822/23002 Date accessed 18/02/2023.

United Nations Environment Programme (UNEP) (2011). Environmental Assessment of Ogoniland. First published. ISBN: 978-92-807-3130-9 Job No.: DEP/1337/GE.

United State Environmental Protection Agency (USEPA) (1987). Data Quality Objectives for Remedial Response Activities. EPA/540/G-87/003.

United State Environmental Protection Agency (USEPA) Method 8015C: Non-Halogenated Organics by GC/FID (2000). Part of Test Methods for Evaluating Solid Waste, Physical/Chemical Methods SW-846 Manual. Government Printing Office, Washington.

United State Environmental Protection Agency (USEPA) (2020). Laboratory Services and Applied Science Division (LSASDPROC-300-R4); Soil Sampling Operating Procedure, Athens, Georgia.