International Journal of Science and Research Archive
eISSN: 2582-8185
Cross Ref DOI: 10.30574/ijsra
Journal homepage: https://ijsra.net/

(RESEARCH ARTICLE)

Check for updates

Bio-remediation of hydrocarbon contaminated site using nitrogen, phosphorus, potassium and urea: A case study of Ogoni clean –Up

Sandra Ebere Ezeani * and Winston Ibifubara Bell-Gam

Department of Petroleum Geosciences, Uptonville Oil and Gas Institute, Port Harcourt, Rivers State, Nigeria.

International Journal of Science and Research Archive, 2024, 12(02), 236–246

Publication history: Received on 09 April 2024; revised on 30 June 2024; accepted on 03 July 2024

Article DOI: https://doi.org/10.30574/ijsra.2024.12.2.0892

Abstract

Bioremediation of hydrocarbon contaminated soils is a relatively inexpensive and environmentally friendly technology that is applicable over a large area of contaminated site. The paper is a case study of a successful ex situ bioremediation of a hydrocarbon contaminated site in Ogoni Land, Rivers State. The contaminated soils were excavated, treated in an engineered biocell, and sprinkled with nutrient media to enhance microbial population and biodegradation. The biocell was constructed using laterite material. The floor was lined with High Density Polyethylene material. The treatability study of the contaminated soil was conducted to determine the quantity of nutrient required to boost the microbial population in the affected soil. A Nutrient made up of (Nitrogen, Phosphorus, Potassium) NPK 20-10-10 and urea at a quantity established by the EnviTech Calculator was used for the treatment. Due to varying depths and concentrations of the contaminant, nutrient adjustments necessary to enhance rapid microbial population and degradation were noted and undertaken. Soil sampling and analysis were conducted at the end of every treatment cycle to establish reduction of the Total Petroleum Hydrocarbon to an allowable limit. The project has proven to be successful and beneficial in the clean-up and restoration of Ogoni Land.

Keywords: Biocell; Total Petroleum Hydrocarbon; Bioremediation; High Density Polyethylene; Excavation

1. Introduction

Hydrocarbon environmental pollution has been a major concern for communities in the crude oil operations area. The pollutant contaminates air, land, and water in the affected community. Land contamination by crude oil spills can occur during exploration, transportation, and refining of crude; either from faulty or damaged oil facilities or an accidental spill. The crude oil, when spilled, usually partitions into the liquid and vapour phases [1], which determine its fate and transport in the environment. The potential hazards from oil spill present acute and chronic risks, such as damage to property, flora, fauna, and drinking waters [2]. The remediation of a crude oil contaminated environment can be carried out physical, chemical, thermal or biological methods.

Biological remediation uses microbiota to degrade or transform hazardous contaminants into less-hazardous materials; mainly water, carbon dioxide, inorganic salts and microbial biomass.[3]. Bioremediation technology is relatively inexpensive. It is applicable over a large polluted area, helps in the complete removal of contaminants with minimal impact on the environment[4].

Bio remediation technology is classified as either in situ or ex situ approach. In the in situ process, the cost of material handling and the environmental impacts of moving the material are avoided, although the ability to control and manipulate the physical and chemical environment is limited. In-situ bioremediation technology applicable to hydrocarbon contaminated site can be natural attenuation or enhanced bio remediation. Some enhanced bio remediation technology includes; bioventing, bio-slurping, bio-sparging and microbe assisted phytoremediation [5],

*Corresponding author: Sandra Ebere Ezeani

Vermiremediation[6]. The ex situ remediation approach involves the removal of contaminated media to a controlled treatment facility. Examples of ex situ bioremediation approach are biopile[7], bio-reactors [8], composting[9], etc. The strategies involved in bioremediation are bio-stimulation (addition of nutrient or other amendment), bio-augmentation (addition of microorganism), or bio-attenuation[10]. Some of the media for enhanced bioremediation strategies include; biochar [11] , nitrogen and phosphorus medium [12]. This study considered the use of NPK and urea nutrient media as relatively versatile, sustainable and available for larger area remediation.

1.1. The UNEP Report on Ogoni Clean-up

Ogoni Land located in Niger Delta region of Nigeria, has been plagued with hydrocarbon pollution, since the start of oil operations in the late 1950s. According to the findings on the Environmental Assessments of Ogoni Land[13], hydrocarbon pollution impacted extensively inland, sediment, and swampland. A contamination depth of 5meters was observed in 49 sites, while 41 sites had groundwater with hydrocarbon in excess of the EGASPIN allowable limit. Extensive pollution was observed in some areas of mangroves with bare stems and leaves, and roots coated in bitumen –like substances. This has huge impacts on biodiversity of the mangroves. The report recommended various interventions and clean –up methods due to the nature and extent of the contamination. This means that, despite having same contaminant, site specific remediation method should be employed for each site.

1.2. The Hydrocarbon Pollution and Remediation Project (HYPREP)

HYPREP was established under the Federal Ministry of Environment to determine the scope, means and modalities of remediation of soil and ground water contamination in impacted communities in the Niger Delta region. In addition, they are mandated to enhance local capacity for better environmental management, and promote awareness of sound environmental management, and ensure livelihoods and sustainable development [14].

The HYPREP oversees the remediation intervention and clean-up activities in Ogoni land in Rivers state. This includes guiding remediation companies on the Remediation Action Plan (RAP) of individual contaminated sites. The ex-situ biocell containment strategy suggested in the UNEP assessment report on Ogoni land is recommended by HYREP for the treatment of contaminated Site A at Ogoni land.

1.3. Remediation Action Plan

1.3.1. Brief Site History

The Site A is located in Ogoni-Land of River State. (Figure 1). Soil investigations reported by UNEP (table 1) in 2011 and baseline investigation of (table 2) **of 2018** indicate the presence of hydrocarbon impacts within an area of 5,224 SQM and extending to a depth of 8.20 mbgs (meter below ground surface). The volume of impacted soil to be treated is estimated to be 52,700m³ with a measured Total Petroleum Hydrocarbon (TPH) concentration ranging from 3.26 mg/kg to 3,390.95 mg/kg. No remedial activities have previously been undertaken to remediate the hydrocarbon-impacted soil at this site.

1.3.2. Baseline Study

The determination of the area and depth of hydrocarbon contamination at the site formed the basis for the delineation of the impacted areas. However, an independent assessment was carried out to generate comparative baseline contamination condition of the site before the commencement of the remediation works.Table4 results from the above exercise indicated maximum Total Petroleum Hydrocarbon (TPH) values of 7,620mg/kg (table 1), 3,390.95mg/kg (table 2) and 2,156mg/kg (table 4**).**The baseline investigation revealed that the site consists of "Recent alluvial deposits made up ofunconsolidated and semi-consolidated sediments, clays, and various intercalations of clays, silt, and sand. The soil profiles show the following litho-stratigraphy: Sandy Silt, Silty Sand, Silty Clay, Clayey Sand, Sandy Clay to about 5.80mbgs (meter below ground surface) as shown in the various trial pits.

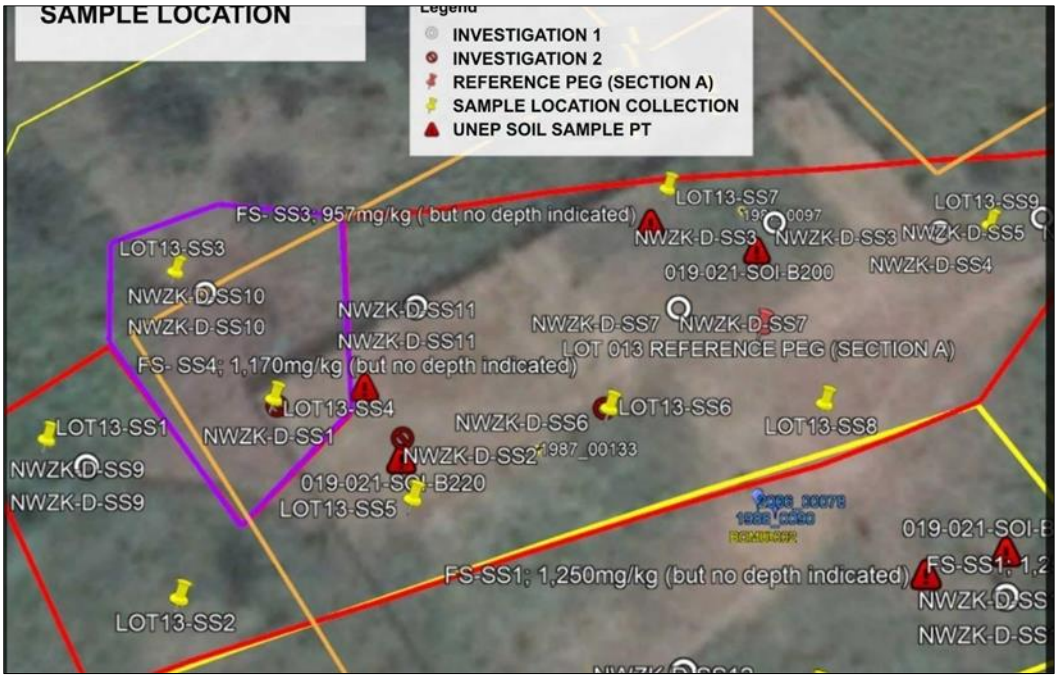

Figure 1 Delineation Map of the contaminated land (Site A at Ogoni Land)

An extra site was earmarked for the construction of the biocell and erecting of a site office and other temporary structures. The site for biocell was positioned adjacent to the contaminated site for easy entry and exit of heavy equipment carrying excavated or treated soil.

The contaminated area was divided into two parts Section I and II. The site was arranged in such a way that one part of the contaminated site was first excavated, treated and backfilled before proceeding to the second part.

Figure 2 Conceptual Site Layout

The contaminated and treatment sites were gated with two gates - a clean and dirty gate. Non-treated soils go through the dirty gate, were treated in the biocell and transported through the clean gate to be backfilled. A third gate is provided at the north of the site layout for entry and exit of personnel and equipment.

Areas of interest outlined in the site layout (figure 2) include; air compressor, dirt gate, clean gate, eye wash, muster point, heavy equipment parking area, decontamination area, cloak room, and rest room. Other temporary structures include; a generator house, a water treatment unit, water supply, a security office and monitoring bore holes.

2. Material and Method

About 52,700 $m^{3.}$ of hydrocarbon-impacted soil was excavated at the project site, in an attempt to remove the source contaminant. The magnitude and depth of contamination necessitate the ex situ treatment in the constructed biocell facility.

2.1. Health Safety and Environment considerations

Site was cleared of bushes, shrubs, and other debris, appropriately disposed of at a designated and secured disposal facility. Scanning and Identification of all underground facilities or utilities around the work area were carried out, before any construction or excavation commenced. The iidentified underground facilities were well secured with warning signs. No mechanical excavation was allowed within 30 cm of an existing facility. Adequate access and egress points were established in all excavations deeper than 1meter. Walls of the excavation were sloped appropriately to prevent cave-ins. Excavation deeper than 1.2 meters were sloped at an angle not steeper than 3 horizontals to 4 verticals in a hard and compact soil, and 1 horizontal to 1 vertical or 45 degrees, prior to allowing human access. Open excavations were adequately marked and barricaded to prevent accidental entry by livestock, wildlife, and personnel. Excavations were bermed to minimize surface flow into them. Excavated soil were stockpiled a minimum of 1 meter away from the edge of the excavation before being transported and heaped in windrows inside the treatment cell

2.2. Construction and Operation of Engineered Biocell

The method of used by [15]was adopted and modified to adapt to the local conditions. The designated area measuring 25mx70m was cleared, compacted, and graded to drain from north to south at 2% slope. The wall of the biocell was constructed using naked embankments of 80-90% clean laterite. An ingress and regress point was constructed to enable loading of the contaminated soils and offloading of the treated soils from the biocell. Sandbags were paced at four sides to stablise the embankment running from 2meter at the top to 1meterat the opposite end. The floor of the biocell was well graded with a steel wheeled roller to provide a smooth surface upon which protective geotextile liner was placed. A single layer High Density Polyethylene (HDPE) protective liner of minimum thickness 40 mm thick, with a density of 0.94 g/cm^3 was installed. A second layer of 200µm thick of Low Density Polyethylene (LDPE) with a water absorption rate of 0.03% over 24 hours' period and an impact strength of 13kj/m^2 at 23°C. A layer of silt soils was placed over protective HDPE liner to serve as a conduit to the leachate sump, which was constructed along the south side of the biocell. The leachate collection pipe was made up of 4-inch perforated pipe covered with a fabric, positioned lengthwise along the entire length of the collection basin. The covering of the leachate pipe prevents blocking of the pipe by silt or mud and allows for easy collection and pumping of the leachate. The leachate draining point was protected with gravel enclosed in a wide netted fabric to provide a very porous media for the free flow of liquid into a single drain tank with a 2000-litters capacity.

2.3. Treatability Study

The site A covers an area of 6,720 m^2 and with approximately 57,200 m^3 of contaminated soil. Sampling and analysis of the contaminated media were conducted to establish the soil type and general characteristics. Indigenous hydrocarbon utilizing bacteria were identified and isolated. The variation in the contaminant range obtained from base baseline investigations, in Tables 1 and 2 was attributed to natural attenuation. Excavation of the highest contaminated point and homogenization of the media was carried out to establishthe overall average contaminant. The optimum nutrient requirement was determined by the EnviTech Calculator (Figure 3). The computation was based on an average soil bulk density of 1400 kg/m^3 for sandy clay and C: N: P ratio of 100:10:1.

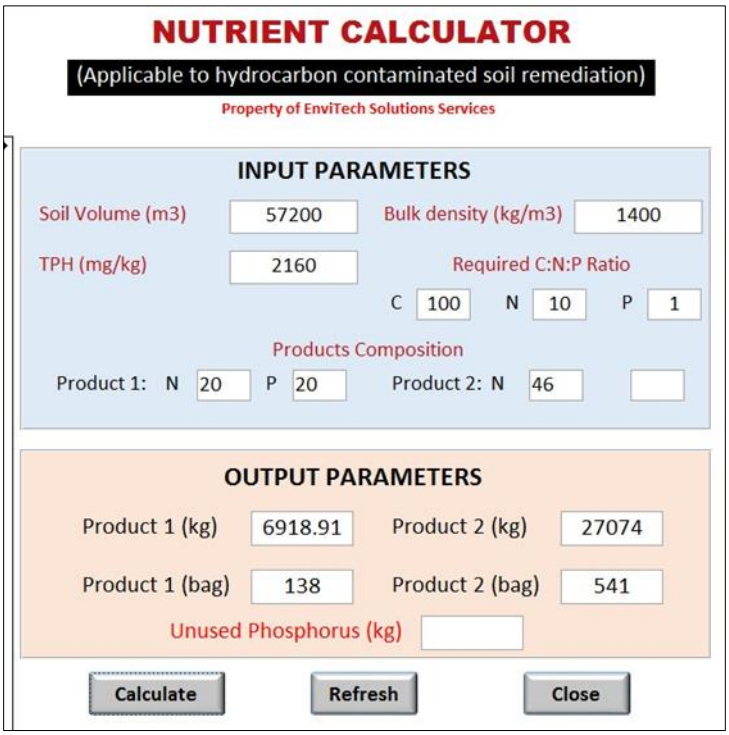

Figure 3 EnviTech nutrient calculator

Table 1 UNEP Baseline Soil Investigation

Sample Location	X	Y	Start Depth(m)	End Depth(m)	TPH Value(mg/kg)
Section A					
019-021-SOI-B200:	309532	515671	0.0	0.4	2,630
019-021-SOI-B200:	309532	515671	0.4	0.5	1,380
019-021-SOI-B200:	309532	515671	0.5	1.2	3,080
019-021-SOI-B200:	309532	515671	1.2	2.0	2,470
019-021-SOI-B200:	309532	515671	2.0	2.6	1,790
019-021-SOI-B200:	309532	515671	2.6	3.2	475
019-021-SOI-B200:	309532	515671	3.2	4.0	449
019-021-SOI-B200:	309532	515671	4.0	5.2	1,690
019-021-SOI-B200:	309490	515637	0.0	0.5	3,390
019-021-SOI-B200:	309490	515637	0.5	0.9	6,160
019-021-SOI-B200:	309490	515637	0.9	2.0	4,420
019-021-SOI-B200:	309490	515637	2.0	2.8	7,620
019-021-SOI-B200:	309490	515637	2.8	4.0	2,170
019-021-SOI-B200:	309490	515637	4.0	5.2	2,720
D-SS2	309488	515640	0.3	1.3	3.26
D-SS2	309488	515640	1.3	4.2	1,450.07

D-SS2	309488	515640	4.2	6.4	1,250.38
D-SS2	309488	515640	6.4	6.8	1,106.50
D-SS3	309535	515676	0.0	0.3	3,390.95
D-SS3	309535	515676	2.8	3.0	1,695.47
D-SS4	309556	515669	6.0	6.6	377.96
D-SS5	309572	515672	4.8	5.2	390.42
D-SS6	309510	515641	1.0	2.2	588.17

Table 2 Baseline Soil Investigation 2

Sample Location	**X**	**Y**	**Start Depth(m)**	**End Depth(m)**	**TPH Value(mg/kg)**
Section i					
SS6	309510	515641	2.2	6.0	607.09
SS6	309510	515641	6.3	6.7	213.00
SS7:	309522	515661	0.0	5.5	443.87
SS7:	309522	515661	5.5	5.8	742.28
SS9:	309443	515635	0.4	6.1	593.83
SS9:	309443	515635	6.1	6.6	1,332.53
SS11	309483	515656	0.4	5.6	410.33
Section ii					
SS1:	309468	515644	0.5	4.8	500.15
SS1:	309468	515644	6.2	7.6	295.48
SS1:	309468	515644	4.2	6.4	235.24
SS10:	309457	515665	0.0	0.6	589.30
SS10:	309457	515665	5.5	8.2	874.74

Table 3 Base line Soil investigation 3

PARAMETERS		**BTEX**	**PAH**	**TPH**
		1 x 10^{-3}µg/kg	**1 x 10^{-3} (Mg\/kg)**	**1 x 10^{-4}(Mg\/kg)**
Sample Location	**Depth (m)**	**Head-Space GCMS**	**GCMS**	**GCFID**
SS-1	3	BDL	3.20	19.99
SS-1	6	BDL	0.01	7.26
SS-2	3	BDL	2.25	10.67
SS-2	6	BDL	0.20	4.17
SS-3	3	0.09	1.51	60.20
SS-3	6	0.05	6.42	282.40
SS-4	3	0.68	3.12	49.89

SS-4	6	BDL	0.26	5.70
SS-5	3	BDL	0.80	6.07
SS-5	6	BDL	0.70	15.15
SS-6	3	BDL	1.67	66.33
SS-6	6	BDL	0.66	3.01
SS-7	3	BDL	0.21	6.92
SS-7	6	BDL	0.23	2.60
SS-8	4	BDL	BDL	0.61
SS-8	8	BDL	2.31	51.41
SS-9	3	BDL	1.33	9.42
SS-9	6	BDL	1.28	6.10
SS-10	3	BDL	1.39	54.63
SS-10	6	BDL	4.01	34.07
SS-11	3	0.01	4.19	11.63
SS-11	6	BDL	3.96	142.32
SS-11A	3	BDL	1.89	11.38

Table 4 Baseline Soil Investigation 4

PARAMETERS		**BTEX**	**PAH**	**TPH**
Sample ID	**Depth (M)**	**1 x 10^{-3} µg/kg**	**1 x 10^{-3} (Mg/kg)**	**(Mg/kg)**
SS-1	3	BDL	< 0.80	< 10
SS-2	6	BDL	4.96	120
SS-3	3	BDL	8.15.	3100
SS-4	3	BDL	< 0.80	2700
SS-5	6	BDL	< 0.80	1258
SS-6	8	BDL	< 0.80	230
SS-7	8	BDL	< 0.80	450
SS-8	8	BDL	< 0.80	2250
SS-9	6	BDL	< 0.80	1610
SS-10	3	BDL	< 0.80	1506
SS-11	6	BDL	< 0.80	2300

2.4. Treatment Process

Nutrient made up of NPK 20-10-10 and urea at quantity established by the EnviTech Calculator (Figure 3) was used. Homogenising the bulk of the soil was done to reduce TPH to values below 2,000 mg/kg as shown within range of Investigations 2 box plot (Figure 4). Providing for allowance of 20% addition to the stated value, the homogenised TPH average was calculated to be 2,400 mg/kg. The baseline results analysis showed moderate soil TPH concentration; hence, a total mixture of 6921.2kg and 27,170kg of NPK and Urea respectively was used to treat entire soil volume.

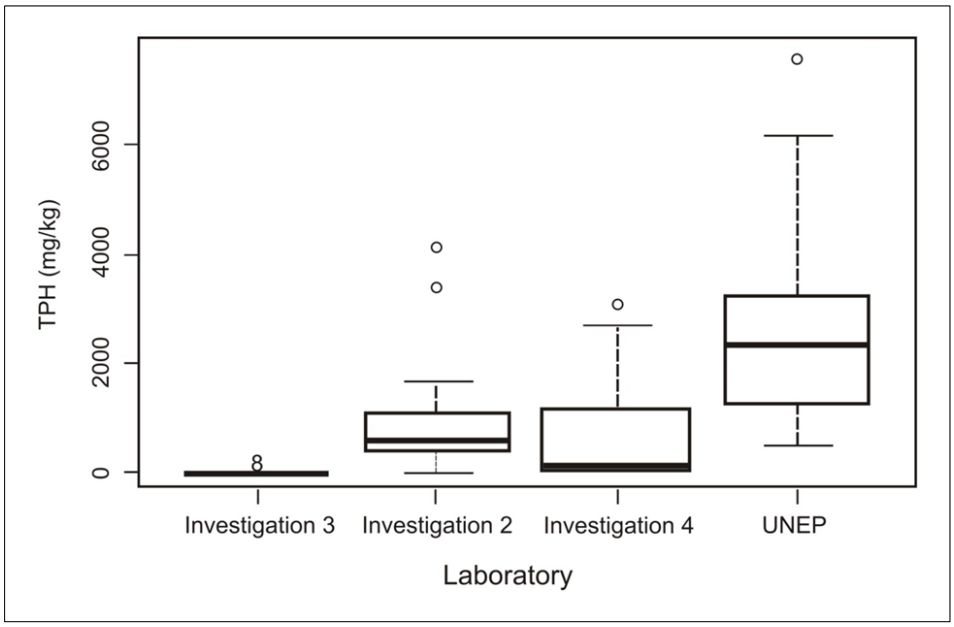

Figure 4 Baseline investigations of the contaminated soil at Site A (Ogoni-Land)

2.4.1. Treatment Cell

The top soil was first removed and stockpiled in a nearby area designated area for re-application after backfilling. The subsoil were mechanically excavated, homogenised and moved into the constructed biocell for treatment. The contaminated media was arranged in windrows piles of 1meter high and 3meters wide.The turning frequency of the piles was once every 3 days. Each pile was turned a total of 9 times during the treatment cycle in the biocell. The contaminated media was covered with thick polyethylene material during the raining season, to prevent dilution and run –off of the applied nutrients. Optimal moisture was maintained during the dry season by intermittent fresh water spray on the contaminated media. Microbial count, residual TPH, pH, monitored on a routinely weekly basis.

2.4.2. Mixture and Application`

The nutrient application system consisted of a 100meters pressure hose with a 1/4" high pressure spray gun attached to a sprayer. A broadcast sprayer nozzle was attached to spray the contaminated media until saturation. The water distribution system was engineered to help ensure that the entire surface area of the treatment cell would be sprayed with water. A 1000-litre water tank was arranged adjacent to the cell and the water used by the sprayer system was drawn from the tank. The tank was filled with water, drawn from sunk borehole in uncontaminated area.

A nutrient solution was made by dissolving 475kg of urea and 121kg of NPK 20-10-10 in 1000liters water. The solution was sprayed over the soil and allowed to percolate through the contaminated media. The mixing and aeration of the contaminated media were done manually using a spade forks and shovels. The leachate was closely monitored for microbial activity, pH and nutrient availability. Adjustments were made within the leachate tank where necessary before reentering the spray distribution system as supplementary nutrients and bio-surfactants.The average treatment cycle was weeks' days, after which sampling and total hydrocarbon testing was conducted to establish the residual TPH level before backfill.

2.4.3. Data Presentation

The site remediation activities lasted for 80weeks made up of 16 biocell treatment cycle. Each cycle consists of 5 weeks' treatment process. The result presented is the mean values of the treatment cycles.

3. Results and Discussions

Table 5 Microbial Count with TPH reduction and Soil pH level

Period (wks.)	TPH (mg/Kg)	Microbial count(cfu/g)	pH
Baseline	3200	<1.00 × 101	5.10
Week 1	2950	1.00 × 102	5.25
Week 2	2600	2.40 × 102	5.73
Week 3	1050	7.10 × 106	6.90
Week 4	525	9.05 × 105	7.40
Week 5	485	5.65 × 106	7.55

The base line study of the Site A at Ogoni Land indicated soil type at varying depth made up of sandy loam and sandy clay from the ground surface to 8meters below the ground surface (Investigations 4 report). The basic soil chemistry of the contaminated media at the project site was found to be lacking in all inorganic nutrients. Considering the time lapse between UNEP report (2011) table 1 and table 2 (2018) assessments, natural attenuation could have made their results incomparable, therefore the recent baseline assessment could be considered more reliable. The results of the baseline soil analysis (Table 3 and Table 4) and Table 2 analysis can be compared to a certain extent though both shows statistical significant difference at 95% confidence level using the R-Studio Statistical Package. Considering the analysis, table 2 results were used as baseline data for the computation of nutrient requirements compared to table 4, based on the number of samples analysed. The remediation of hydrocarbon contamination soil with combination of NPK and urea showed that the hydrocarbon utilizing bacteria population can be enhanced with appropriate nutrient application. Although a nutrient calculator was used to estimate the required nutrient, several adjustments were made in the course of the treatment due to the different variations of TPH levels at various points in the site. The gradual TPH reduction over time and increase in microbial population indicate that bio-stimulation was achieved with NPK and urea applications.

3.1. Total Microbial Count

The baseline microbial count in the contaminated soil at the onset of the remediation process was found to be very low ($<1.00 \times 10^2$cfu/g) as seen in Table 5. This is an indication of no microbial activity in the contaminated soil. The application of nutrients (NPK and urea) stimulated increase in microbial population up to 1.00×10^2cfu/g at the end of week 1. Study by [16] found that compared to Urea or NPK alone, the combination of urea and NPK bio stimulate microbial counts in bioremediation of hydrocarbon contaminated soil is more effectively. There was a constant increase in the microbial population, as the organisms adapted to the nutrient-rich and favourable environment. The exponential increment in microbial count (at the end of week 3) of 7.10×10^6cfu/g and (week 4) of 9.05×10^5cfu/g suggests the availability of substrates, mainly the short-chain hydrocarbon, which are easily degrade by hydrocarbon utilizing bacteria to produce less toxic water and carbon dioxide, leading to decrease in the residual TPH of the affected soil. On the other hand, the decline in the microbial population (5.65×10^4cfu/g) was observed at the end of week 5. This result agrees with the studies by [17] and [18], which recorded exponential increment of hydrocarbon-degrading bacteria occurring in the first 30 days of bio stimulation, resulting in a low residual TPH of the affected soil.

3.2. Effect of pH on Bioremediation

The pH level of an environment affects the biological processes of microorganisms, such as enzyme activities and microbial mass. This study observed a change in the pH level of the contaminated soil from 5.75 in week 1 to maximum pH of 7.65 in week 5 of the treatment, as presented in table 5. It shows a gradual increment in the pH level, which corresponds with an increase in microbial count and decrease in the residual TPH of the affected soil. This result suggests that the pH level of the soil increases with remediation time as a result of decrease in TPH. The study by [19]and [20] found that heterotrophic bacteria performs better in near-neutral (5.5) to alkaline (8.0) environment. Hence, the optimum hydrocarbon biodegradation rate was recorded by [21]at a pH level of 7.5. Additionally, microbial mineralization of most hydrocarbon derivatives occurs between pH of 5.0-8.0 with the highest mineralization rate at pH 8.0 [22]. There is a correlation between the pH level, microbial population, and residual TPH of the contaminated medium. Therefore, maintaining optimum pH is crucial in enhancing microbial growth and biodegradation of hydrocarbon.

3.3. Residual Total Petroleum Hydrocarbon

The rate of biodegradation of hydrocarbon pollutants determines the concentration of the residual Total Petroleum hydrocarbon in the treated soil. The residual Total Petroleum Hydrocarbon concentration was analysed on a weekly basis over a period of 5 weeks. The result shows gradual reduction from initial concentration of 3200mg/kg to 2600mg/kg at the end of week 2 (table 5). Rapid biodegradation resulting in lower residual TPH of 1050mg/kg and 525mg/kg occurred between week 3 and week 4 of the treatment process. Table 5 also shows an increase in microbial count in week 3 and week 4 indicating optimal nutrient availability and other environmental factors. Studies by [23], and [17] suggests that the high rate of hydrocarbon degradation is related to the increase in microbial count andlow residual TPH over a time period. The bio-stimulation of indigenous microbes with the combination of NPK and Urea was found to have most degradation rate and lower residual TPH relative to NPK or urea alone [16].

4. Conclusion

The use of NPK and urea as bio stimulants is found to be effective, relatively cheaper, and environmentally friendly option for remediation of hydrocarbon polluted soil, especially in Niger Delta region of Nigeria, where hydrocarbon pollution is prevalent due to crude oil exploration activities. A significant reduction of Total Petroleum Hydrocarbon (within EGASPIN guidelines) was achieved by adding the (nutrient) bio-stimulant to the contaminated soil. The bio-stimulant offers faster remediation and restoration of the soil (within 5 weeks of treatment) when compared with that undergoing natural attenuation.The success of this study implies that this remediation approach can be a promising solution for tackling similar hydrocarbon polluted sites in the Niger Delta region and other affected regions. However, while this approach has its benefits, it also has some limitations. Among the limitations are the site-specific factors. The effectiveness of the bio-stimulant depends on the soil type, climate, concentration and depth of the contaminant. As a result of varied contaminant concentration in the study site, the nutrient application rate was adjusted severally, thus the application rate varies for each cycle. Secondly, it was a time intensive process. The treatment process took up over 24 months from site clearing to close-out, to achieve significant result. This lengthy duration may not be practical for urgent site clean-up. Finally, the cost of biocell construction, machinery and equipment; for soil excavation, biocell loading, offloading, and backfill can be a limiting factor for large scale remediation.

Recommendations

The treatability study of a contaminated site is crucial for the development of a site-specific treatment programme. This allows for modifications and adjustments to the treatment process during the implementation of the programme. Further research on the impact of combined bio augmentation and bio-stimulant on the degradation rate of hydrocarbon polluted soil is required. Secondly, study of a cost comparatively analysis of in-situ and two ex-situ bioremediation process is needed.

Compliance with ethical standards

Acknowledgements

This project was funded by the Ogoniclean-up funds provided by the Nigeria government through the Hydrocarbon Pollution Remediation Project.

Disclosure of conflict of interest

No conflict of interest to be disclosed.

References

[1] M. Anderson, "Influence of Surfactants on Vapor-Liquid Partitioning," Environ. Sci. Technol., pp. 2186-2191, 1992.

[2] W. Muhlbauer, "Leak Impact Factor," in Pipeline Risk Management Manual; Ideas, Techniques, and Resources, London, British Library Cataloguing-in-Publication Data, 2004, p. 7.

[3] EPA, "In Situ and Ex Situ Biodegradation Technologies for Remediation of Contaminated Sites," US EPA Engineering Issue, pp. 1-22, 2006.

[4] W. Frankenberger Jr., "The need for a laboratory feasibility study in bioremediation of petroleum hydrocarbons," in Hydrocarbon contaminated soils and groundwater, Lewis, Boca Raton, 1992, p. 237–293.

[5] EPA., "Bioventing Principles and Practices, Volume 2 Bioventing Principles (Manual)," National Service Center for Environmental Publications (NSCEP), pp. 1-88, 1995.

[6] O. A. Ekperusi and F. I. Aigbodion, "Bioremediation of petroleum hydrocarbons from crude oil-contaminated soil with the earthworm: Hyperiodrilusafricanus," Biotech, p. 5:957–965, 2015.

[7] T. LIn, P. Pan and S. Cheng, "Ex situ bioremediation of oil-contaminated soil," Journal of Hazardous Materials, pp. 27-34, 2010.

[8] T. Ambaye, A. Chebbi, F. Formicola, A. Rosatelli, S. Prasad, F. Gomez, S. Sbaffoni, A. Franzetti and M. Vaccari, "Ex-situ bioremediation of petroleum hydrocarbon contaminated soil using mixed stimulants: Response and dynamics of bacterial community and phytotoxicity," Environ. Chem. Eng., p. 108814, 2022.

[9] J. Marı´n, J. Moreno, T. Herna´ndez and C. Garcı´a, "Bioremediation by composting of heavy oil refinery sludge in semiarid conditions," Biodegradation, p. 251–261, 2006.

[10] F. Bento, F. Camargo, B. Okeke and W. Frankenberger, "Comparative bioremediation of soils contaminated with diesel oil by natural attenuation, biostimulation and bioaugmentation," Bioresource Technology, vol. Volume 96, no. Issue 9, Pages 1049-1055, pp. 1049-1055, 2005.

[11] G. Ambaye, F. Formicola, S. Sbaffoni, C. Milanese, A. Franzetti and M. Vaccari, "Effect of biochar on petroleum hydrocarbon degradation and energy production in microbial electrochemical treatment," Environmental Chemical Engineering, p. 110817, 2023.

[12] C. Cristorean, V. Micle and I. Sur, "A critical analysis of ex-situ bioremediation technologies of hydrocarbon polluted soils," Environmental Research and Protection, pp. 17-29, 2016.

[13] UNEP, "Environmental Assessment of Ogoniland," United Nations Environment Programme, Nairobi, 2011.

[14] https://hyprep.gov.ng/about-us, "HYPREP," Hydrocarbon Pollution Remediation Project, Port Harcourt, 2022.

[15] M. Ratliff, "Construction and Operation of a Biological Treatment Cell for the Treatment of Hydrocarbon-Contaminated Soil in Alaska," SPE 25998, Texas, 1993.

[16] E. Nwadiokwu, I. Oladimeji, A. Zabi, Uyi, O.S., A. Okakwu, A. Akinola, B. Olubusoye and D. Odogwu, "Bioremediation of Crude Oil Polluted Soil Using NPK 15:15:15 and Urea as a Biostimulant," vol. 9, no. 01, 2023.

[17] M. Chorom, H. Sharifi and H. Motamedi, "Bioremediation of a Crude Oil-Polluted Soil by Application of Fertilizers," Vols. 7,pp 319-326, no. 4, 2010.

[18] I. Sang-Hwan, l. Seokho, k. DaeYaeon and k. jeong- gyu, "Degradation characteristics of waste lubricantsunder different nutrient condition," vol. 143, no. Issues 1–2,, 2007.

[19] J. Adedeji, E. Tetteh, M. Amankwa, D. Asante-Sackey, S. Frimpong, E. Armah, S. Rathilal, A. Mohammadi and C. Manimagalay, "Microbial Bioremediation and Biodegradation of Petroleum Products—A Mini Review," 2022.

[20] K. Singh and S. Chandra, "Treatment of petroleum hydrocarbon polluted environment through bioremediation: Review,," Pakistan Journal of Biological Sciences: , vol. 17, no. 1 pp. 1–8,, pp. 17(1), 1-8., 2014..

[21] R. Pawar, "The Effect of Soil pH on Bioremediation of Polycyclic Aromatic Hydrocarbons (PAHS)," vol. 06, no. 3, 2015.

[22] G. Hambrick, R. DeLaune and W. Patrick, "Effect of Estuarine Sediment pH and Oxidation-Reduction Potential on Microbial Hydrocarbon Degradation," vol. 4, no. 2, 1980.

[23] A. Amenaghawon, P. Asegame and K. Obahiagbon, "Potential Application of Urea and NPK 15:15:15 Fertilizers as Biostimulants in the Bioremediation of Domestic Wastewater," Vols. Vol. 1, , no. No. 4, 91-95, 2013.