International Journal of Scientific Research and Engineering Development-– Volume 6 Issue 6, Nov- Dec 2023

Available at ***www.ijsred.com***

RESEARCH ARTICLE OPEN ACCESS

Geological Sustainability: A Major Focus on the Geological Impact of Bioremediation Involving Excavation in Comparison with Non-Excavation Bioremediation Methods

Chidinma Uzochukwu*, SeleghaE. Abrakasa**Hycienth O. Nwankwoala***, Leo C. Osuji****

*(World Bank Ph.D Scholar, Department of Petroleum Geology, World Bank Africa Centre of Excellence in Oil Field Chemicals Research (ACE-CEFOR), University of Port Harcourt, Port Harcourt, Nigeria)
** (Department of Geology, University of Port Harcourt)
*** (Department of Geology, Rivers State University, Port Harcourt, Nigeria)
*** (Department of Pure and Industrial Chemistry, University of Port Harcourt)
Email: joysplendid@gmail.com

--************************----------------------------------

Abstract:

The main focus of environmental sustainability has been on remaining natural resources for next generation use and eliminating or reducing contamination into the atmosphere, land, surface and ground water as we harness natural resources for human use. Little or no emphasis has been made on geological sustainability especially in response to oil spill which is one of the negative impacts of the oil and gas industry activities. Geological sustainability entails preserving geology of an area and avoidance of human induced geological change. If one studied the geology of an area; can the next person study the geology of the same area sometime in the future and make similar findings? If a change exist, can that change be explained by geology alone being free of human influence? RENA involving excavation of impacted soil and back-filling of the treated soil has become the norm in the remediation of crude oil contaminated land; a major question of concern is whether geological sustainability is in view during the excavation and back-filling process. Are there measures to ensure that the various layers of soil in the soil profile are kept and remediated separately? Are there measures to ensure that each remediated soil layer is taken back to its subsurface position during the back-filling process? What are the likely geological impacts in situations where back-filling is done with soil obtained from elsewhere? These questions suggest the need for the geological society to flag-off geological sustainability campaign and say no to human induced geological change. This study made use of geological findings from two remediated sites as well as a bench scale study of the effectiveness of non-excavation remediation methods utilizing biostimulation and phytoremediation. Soil profiles from sampling points in the understudied remediated sites indicated non correlation within the remediated area in comparison with areas outside the remediated section, except for deeper depths not included in the remediation execution. Applied biostimulation and phytoremediation approach showed great potential in reducing the initial TPH value to up to 73% of the initial at monitoring and 79.2% of the remaining TPH at close out for the phytoremediation approach; up to 63% of the initial TPH was degraded at monitoring and up to 78.7% of the remaining TPH was degraded at close out for the biostimulation approach; and up to 90% of the starting TPH was degraded at monitoring and up to 57.6% of the remaining TPH degraded at close out for the integration of both. The result re-directs the mind on the need to narrow down environmental sustainability to geological sustainability especially in the area of remediation of crude oil contaminated land involving excavation and back-filling.

Keywords **—Bioremediation, Biostimulation, Phytoremediation, Geological sustainability.**

--************************----------------------------------

1.INTRODUCTION

Geological sustainability entails preserving geology and avoidance of human induced geological change. Environmental sustainability led to the emergent of oil spill response and remediation using eco-friendly methods mainly bioremediation employing land farming of excavated soil; while this sustains the environment in terms of removal of the contaminant of concern from the environment to as low as reasonably possible, it may not sustain the geology of the remediated area if geological sustainability is not in view. If one studied the geology of an area; can the next person study the geology of the same area sometime in the future and make similar findings? If a change exist, can that change be explained by geology alone being free of human influence? Excavation and back-filling has become the norm in the remediation of crude oil contaminated land in the Niger Delta particularly in Ogoni; a major question of concern is whether geological sustainability is in view during the excavation and back-filling process. The report on the environmental assessment of Ogoni pointed out that the only remediation method observed in Ogoni is Remediation by Enhanced Natural Attenuation (RENA); according to the report, the method has proven not to be effective. RENA usually involves excavation and land farming of spill impacted soil which threatens geological sustainability as it alters soil structure and properties such as porosity and permeability. There are usually no conscious steps taken to ensure that impacted soil is excavated and land farmed separately based on soil strata and that they are returned back to their true subsurface position during back filling. In January 2010, SPDC (Shell Petroleum Development Company of Nigeria) adopted a new remediation management system, while the report commended the method as an improvement, it still noted that the method does not meet local regulatory requirements or international best practices. Ten out of the 15 investigated sites which SPDC recorded as remediated sites still have pollution exceeding SPDC and government remediation closure values. Contamination at eight out of these ten sites has migrated to groundwater. This shows that there is still a gap to be filled. Also, in areas characterised by shallow unconfined aquifer and heavy rainfall such as Ogoni, RENA may encourage lateral and vertical migration of spill and this is a threat to groundwater as well as public health (that is, threat to people who uses groundwater for domestic purposes).

Non-excavation bioremediation approaches adopted in this study are Biostimulation and phytoremediation. Biostimulation and phytoremediation are in-situ remediation approaches that eliminates the need for excavation of the spill impacted soil which threatens geological sustainability; the approaches support geological sustainability as it offers no alteration of soil structure/properties, rather, it protects the local geology. This re-directs the mind on the need to involve geologists in the assessment and remediation of spill impacted sites. Addition of phytoremediation to the remediation approach is necessary to overcome the possibility of or inhibit groundwater contamination and migration of the contaminant plume as they accumulate and concentrate the spilled oil in their roots, stem or harvestable part. Uzochukwu, (2022) demonstrated the use of phytostabilizer (phytoremediation) as a proactive containment and remediation tool using Bodo Creek in Ogoni as case study. The study focused on areas dominated with chikoko sediments which represented a matured root system of a phytostabilizer. Surface and subsurface samples were analysed for TPH and the results indicated that chikoko sediments inhibited vertical migration of spilled crude.

It is vital to as much as possible adopt remediation approaches that will encourage geological sustainability. Unfortunately, most people involved in environmental restoration of impacted sites are non-geologists; hence, their major concern and goal is to reduce the TPH levels to target values without recourse to geological consequences of their adopted approach. This emphasizes the need to include geologists in the assessment and remediation team. A Conceptual Site Model (CSM) aids the remediation action plan and an accurate and detailed conceptual site model cannot be designed without a geologist. A conceptual site model is a model that describes the biological, physical and chemical processes that control the actual or potential impact the contaminant may have on soil, ground water or surface water as well as the direct and indirect risk it poses to receptors such as people living around the impacted area. The model is iterative and as such is developed and refined as new site data is obtained and is usually updated throughout the site investigation for remedial action. According to California Environmental Protection Agency (June, 2012), conceptual site model has been expanded to include elements such as geology and hydrogeology. CSM should include detailed geology and hydrogeology (site characterization) that may affect the distribution and migration of the contaminant plume or affect the duration of the restoration of the concerned environmental media. Knowledge of soil type, depth to groundwater, type and extent of aquifers, and groundwater flow direction constitute vital input in the remediation action plan of spill impacted sites; these data can only be provided accurately by a geologist. Even though one would immediately attribute spill impacted site assessment and remediation using biostimulation and phytoremediation approach role to a microbiologists or a plant scientist since it involves the use of microorganisms and plants; they, however, do not understand geology as a professional geologist would and therefore cannot accurately uphold geological sustainability, their interest lies only on reduction or removal of the contaminant of interest from the contaminated media in focus caring less on the consequence of their adopted approach to geology of the area in focus and by extension the surrounding area. Traditionally, Conceptual Site Model (CSM) involves source of spill, the pathways, and receptors. A receptor can be farmland, surface water, or residential area. When the pathway does not link the source to a receptor, it is usually said that there is no risk to the receptor; hence, in terms of risk ranking, the site is ranked low and, in most cases, low risk sites are not included in the priority list and as such its remediation is usually delayed. The spill may not pose a risk to the receptor, but how about the risk it is posing to the geology of the impacted area? In a wider perspective it is advantageous, for the expansion of conceptual site model by California Environmental Protection Agency to include geology and hydrogeology. According to American Geosciences Institute (AGI), geoscience does not only inform all aspects of petroleum production but also all aspect of environmental protection. Geoscientists alongside other disciplines' professionals such as biology and environmental sciences forecast the short and long term of environmental contamination to identify the relative hazards from different issues and inform decisions about monitoring, mitigation and remediation. Geoscientists study the groundwater and soil in the spill impacted area to identify potential migration pathways, to check if the spill plume is localized within the impacted area or if there is offsite migration. Geoscientists use their understanding of hydrogeology to provide insight into how a source of contamination may spread through ground or surface water, and provide the same expertise to help mitigate the impact of spills and guide cleanup operations. According to AGI, many state and federal regulators (in America) are geoscientists with the knowledge and experience to develop and enforce laws that are consistent with the local and regional geologic conditions and protect the environment as well as human health. Our present day and future understanding of the environment as well as its remediation when impacted by spill depends on well-trained geoscientists as geology and hydrogeology (groundwater modelling) is what informs a remedial design. A remediation project, therefore, should involve an interdisciplinary team with geologist working in close collaboration with other disciplines to reduce risk as well as uphold geological sustainability. This explains why we have companies such as 'Geoscience and Remediation Services', an environmental services company based in United States (US) and 'Vista geoscience', a leading company in environmental site investigation and remediation field services also based in the US.

2. MATERIALS AND METHODS

This study made use of geological findings from two remediated sites in Ogoni, Niger Delta. The geological study of the two sites involved boring of holes into the subsurface using hand auger to a maximum depth of 10m at various locations within the sites to obtain the soil profile at the different drilled locations for correlation. Control locations were chosen outside the remediated area; this is to enable comparison of soil profile within and outside the remediated area.

For demonstration of the effectiveness of non-excavation bioremediation methods (biostimulation and phytoremediation) in remediating crude oil impacted soils, a bench scale study was conducted using 75 plastic containers each containing 4kg of soil. Three different soil types (clayey silty sand, silty sand, and sand) as indicated by particle size and hydrometer analysis were used in the study. Spill simulation was achieved by spiking the soils with crude oil. The set-up was to be divided into scenario A and B consisting of only category A (if seeds planted directly in the contaminated soil fails to germinate) or category A and B (if seeds planted directly in the contaminated soil germinates). The study consisted of category A and B because seeds planted directly in the contaminated soils and in the nursery both germinated.

In scenario A set-up, the soil sample was spiked with 30ml of crude oil while scenario B set-up soil sample was spiked with 60ml of crude oil. This was done to experimentally measure the effectiveness of biostimulation and phytoremediation in low and high concentration of spill impacted soil sample.

Category A consisted of 7 set-ups each containing 4kg of spill impacted soil. Each container had two replicas for error correction. Maize and cow pea seeds were planted in a nursery and also directly in the spill impacted soil at the same time. The nursery was set up in nursery bags consisting of uncontaminated soil. The nursery was to act as a back-up for transplanting of maize and cow pea after germination, into the spill impacted soil if seeds planted directly in the contaminated soil fails to germinate. Because seeds planted directly in the contaminated soil survived, category B was initiated. Category B consisted of container 1 to 3. Category B was essentially a phytoremediation set-up to ascertain if transplanted plants have more phytoremediation potential than plants that germinated and grew in the impacted soil and vice versa. Category B made use of maize and cowpea transplanted from the nursery.

Category C involved subjection of the set up to limiting conditions outside acceptable range; this was to enable the achievement of the second technical objective of this research which is to find out how the limiting factors of biostimulation and phytoremediation play a role in the remediation process. This was based on phytoremediation utilizing maize and cowpea with 4kg soil sample per container each spiked with 30ml of crude oil.

There were 12 control set-ups containing spill impacted soil sample (4kg per container) and they were classified into two groups, each group containing 6 set-ups. In each group, 3 were spiked with 30ml of crude oil to serve as control for scenario A and the remaining 3 were spiked with 60ml of crude oil to serve as control for scenario B. Biostimulation and phytoremediation were not performed in the controls, however, whatever disturbance that was done in the experimental set-up was also performed on group one control set-up while group two was made to sit undisturbed. This implies that group one control set-up involved only enhanced natural attenuation while group two control set-up involved only natural attenuation. Both the experimental and control set-up were exposed to the same natural environmental conditions. The essence of the control set-up was to accurately rule out the contribution of enhanced natural attenuation and natural attenuation process in the experimental result and arrive at a precise conclusion on how much input proposed biostimulation and phytoremediation approach made in remediating the spill impacted soil.

Monitoring involved collection of soil sample for analysis of parameters of interest which included Total Petroleum Hydrocarbon (TPH) to ascertain degradation rates and the changes in monitored parameters.

Parameters of interest were measured based on approved methods in EGASPIN and APHA standard. Contaminated soil sample (spiked soil) used in this study was first analysed for parameters of interest before commencement of the remediation process. The soil samples were analysed again following the monitoring plan and after the remediation process.

The biostimulation approach made use of NPK fertilizer while the phytoremediation approach made use of maize and cowpea and analysis for TPH reduction was the indices to check for the effectiveness of deployed bioremediation approaches.

3. RESULTS AND DISCUSSION

Findings from the remediated sites in Ogoni (site 1 and 2, as detailed below, see figure 1 and 3 for a sketch of site overview) revealed that excavation and back filling activities performed on visited sites changed the geology of the study area. The applied remediation approach which is excavation of contaminated soils for remediation by enhanced natural attenuation (landfarming of contaminated soils) altered the soil profile, a thin foreign layer of contaminated clay soil was observed at one of the assessment borehole locations (sampling points) which is believed to have been erroneously introduced during the back filling process. There was also indication (based on the analysis of soil profile within the remediated area in comparison to soil profile outside the remediated area) that soils obtained from elsewhere were introduced in the backfilling process. Details of findings from site 1 and 2 are outlined below.

Site 1

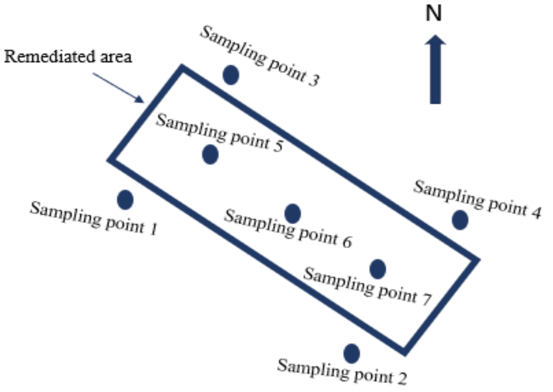
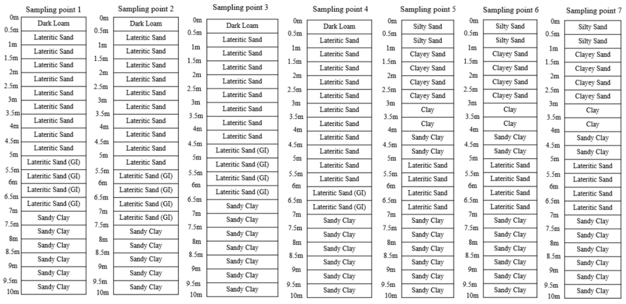


Fig. 1:Sketch of site 1 overview

Good correlation of soil profiles was obtained atsampling points outside the remediated area. Thisis, however, not the case for soil profiles at sampling points within the remediated area (see figure 2 for soil profile at the various soil sampling points). This implies that during the backfilling process, there was no measure put in place to ensure that various soil strata are remediated separately and are taken back to their subsurface position during backfilling. There was also indication (based on the analysis of soil profile within the remediated area in comparison to soil profile outside the remediated area) that soils obtained from elsewhere were introduced in the backfilling process.

At a particular bole hole location within the remediated area (sampling point 6), thin layer of medium hydrocarbon contaminated clay (based on visual and olfactory assessment) was observed in the soil at depth 3m to nearly 3.5m below ground level. The clay layer was a little less than 0.5m thick and no hydrocarbon contamination exist above and below it. Correlation of the soil profile at the different borehole locations (sampling points) revealed that the thin clay layer is missing at other locations and no contamination was observed at any other location. This suggests that the clay layer may have been erroneously introduced during the backfilling process and is probably localized around the bore hole location where it was observed.



	Sampling point 1	Sampling point 2	Sampling point 3	Sampling point 4	Sampling point 5	Sampling point 6	Sampling point 7
0m	Dark Loam	Dark Loam	Dark Loam	Dark Loam	Silty Sand	Silty Sand	Silty Sand
0.5m	Lateritic Sand	Lateritic Sand	Lateritic Sand	Lateritic Sand	Silty Sand	Silty Sand	Silty Sand
1m	Lateritic Sand	Lateritic Sand	Lateritic Sand	Lateritic Sand	Clayey Sand	Clayey Sand	Clayey Sand
1.5m	Lateritic Sand	Lateritic Sand	Lateritic Sand	Lateritic Sand	Clayey Sand	Clayey Sand	Clayey Sand
2m	Lateritic Sand	Lateritic Sand	Lateritic Sand	Lateritic Sand	Clayey Sand	Clayey Sand	Clayey Sand
2.5m	Lateritic Sand	Lateritic Sand	Lateritic Sand	Lateritic Sand	Clayey Sand	Clayey Sand	Clayey Sand
3m	Lateritic Sand	Lateritic Sand	Lateritic Sand	Lateritic Sand	Clay	Clay	Clay
3.5m	Lateritic Sand	Lateritic Sand	Lateritic Sand	Lateritic Sand	Clay	Clay	Clay
4m	Lateritic Sand	Lateritic Sand	Lateritic Sand	Lateritic Sand	Sandy Clay	Sandy Clay	Sandy Clay
4.5m	Lateritic Sand	Lateritic Sand	Lateritic Sand (GI)	Lateritic Sand	Sandy Clay	Sandy Clay	Sandy Clay
5m	Lateritic Sand (GI)	Lateritic Sand	Lateritic Sand (GI)	Lateritic Sand	Lateritic Sand	Lateritic Sand	Lateritic Sand
5.5m	Lateritic Sand (GI)	Lateritic Sand (GI)	Lateritic Sand (GI)	Lateritic Sand	Lateritic Sand	Lateritic Sand	Lateritic Sand
6m	Lateritic Sand (GI)	Lateritic Sand (GI)	Lateritic Sand (GI)	Lateritic Sand (GI)	Lateritic Sand	Lateritic Sand	Lateritic Sand
6.5m	Lateritic Sand (GI)	Lateritic Sand (GI)	Sandy Clay	Lateritic Sand (GI)	Lateritic Sand	Lateritic Sand	Lateritic Sand
7m	Sandy Clay	Lateritic Sand (GI)	Sandy Clay	Sandy Clay	Sandy Clay	Sandy Clay	Sandy Clay
7.5m	Sandy Clay	Sandy Clay	Sandy Clay	Sandy Clay	Sandy Clay	Sandy Clay	Sandy Clay
8m	Sandy Clay	Sandy Clay	Sandy Clay	Sandy Clay	Sandy Clay	Sandy Clay	Sandy Clay
8.5m	Sandy Clay	Sandy Clay	Sandy Clay	Sandy Clay	Sandy Clay	Sandy Clay	Sandy Clay
9m	Sandy Clay	Sandy Clay	Sandy Clay	Sandy Clay	Sandy Clay	Sandy Clay	Sandy Clay
9.5m	Sandy Clay	Sandy Clay	Sandy Clay	Sandy Clay	Sandy Clay	Sandy Clay	Sandy Clay
10m							

Fig. 2: Soil profile at the various sampling depths in site 2

Site 2

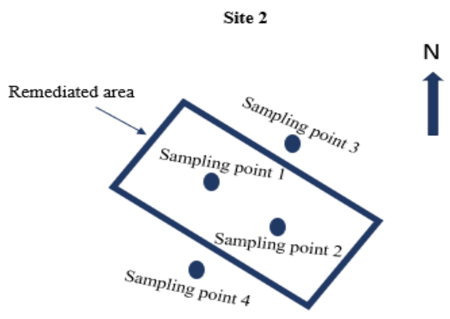


Fig. 3: Sketch of site 2 overview

At site 2, backfilling made use of soil obtained from elsewhere. This made the geology of the oil spill previously impacted area different from the surrounding geology. Soil profile of the remediated area is silty clay from the surface down to the total remediation depth (4.5m), which is different from surrounding soil profile where top loamy soil exists at the surface down to at least 0.5m depth (see figure 4 for soil profile at the various soil sampling points). Remediation was executed to a depth of 4.5m below ground surface, analysis of obtained soil profile indicates non correlation from 0m to 4.5m below ground surface in comparison with soil profile outside the remediated area while good correlation was obtained from 4.5m depth to the final sampling depth.

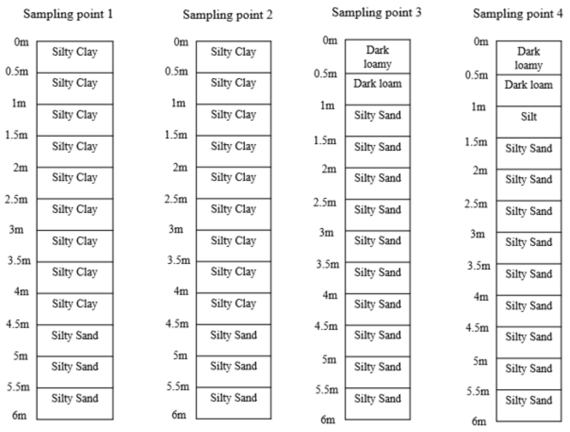


Fig. 4: Soil profile at the various sampling depths in site 2

Biostimulation and phytoremediation approaches

All samples were analysed for Total Petroleum Hydrocarbon (TPH) at the laboratory using Gas Chromatography - Flame Ionization Detection (GC – FID) and were also subjected to RemScan analysis. RemScan results usually gives consistently higher TPH values, this can be attributed to the fact that RemScan dictates TPH higher than C_{40} while laboratory analysis will likely not be able to dictate the heavier fraction, in other words, the consistently higher RemScan values may indicate that the contaminant in the samples contains material heavier than what the laboratory analytical GC – FID method can dictate.

The soil samples were subjected to analysis for other parameters such as pH, temperature, nitrogen, phosphorous, potassium, manganese, ammonia, Total Hydrocarbon Bacteria (THB) and Hydrocarbon Utilizing Bacteria (HUB). However, for the purpose of this publication, emphasis is on TPH parameter based on RemScan analysis.

Sample ID's and the results of the analysis for TPH parameter at initial, monitoring and close out stages of the research are detailed in table 1 to 7 while the performance review of the applied remediation approaches is outlined in table 8 to 21.

Comparison of TPH values of initial, monitoring, and close out RemScan analysis

Table 1:TPH for Category A, Scenario A soil samples (Comparison of initial, monitoring, and close out analysis)

	Sample ID	TPH (mg/kg)					
		Initial analysis	Mean TPH	Monitoring analysis	Mean TPH	Close out analysis	Mean TPH
1	CASACon1 E1	5888	5684	1000	1500	1000	1000
2	CASACon1 E2	5930		2400		1100	
3	CASACon1 K	5235		1100		900	
4	CASACon2 E	5878	5405	3500	2133	1100	1033
5	CASACon2 K1	5147		1100		900	
6	CASACon2 K2	5192		1800		1100	
7	CASACon3 E1	5892	5661	1600	1700	900	833
8	CASACon3 E2	5902		1600		800	
9	CASACon3 K	5191		1900		800	
10	CASACon4 G1	11,269	11,145	5900	4066	1000	867
11	CASACon4 G2	10,986		4600		1000	
12	CASACon4 G3	11,181		1700		600	
13	CASACon5 G1	11,270	11,174	1100	1366	800	750
14	CASACon5 G2	11,051		1700		700	
15	CASACon5 G3	11,202		1300		750	
16	CASACon6 G1	11,122	11,132	1700	2066	800	900
17	CASACon6 G2	11,309		2000		1000	
18	CASACon6 G3	10,966		2500		900	
1	CASACon7	11,040	11,06	1200	1100	500	467

9	G1		5				
20	CASACon7 G2	11,011		1000		400	
21	CASACon7 G3	11,144		1100		500	

Table 2: TPH for Category A, Scenario B soil samples (Comparison of initial, monitoring, and close out analysis)

	Sample ID	TPH (mg/kg)		
		Initial analysis	Monitoring analysis	Close out analysis
22	CASBCon1 E1	12,317	3900	3400
23	CASBCon1 E2	12,381	4300	3200
24	CASBCon1 K	10,126	6800	3200
25	CASBCon2 E	12,278	6300	4200
26	CASBCon2 K1	10,016	4300	4100
27	CASBCon2 K2	10,141	6600	4150
28	CASBCon3 E1	12,351	7400	3900
29	CASBCon3 E2	12,423	4600	3200
30	CASBCon3 K	10,123	8500	4000
31	CASBCon4 G1	22,764	10,200	9300
32	CASBCon4 G2	22,902	8900	6600
33	CASBCon4 G3	22,648	8300	6500
34	CASBCon5 E1	12,266	4500	1700
35	CASBCon5 E2	12,426	2100	1900
36	CASBCon5 E3	15,001	2600	1900
37	CASBCon6 E1	12,402	7000	3900
38	CASBCon6 E2	12,351	5900	3800

39	CASBCon6E3	14,983	6900	4000
40	CASBCon7E1	12,245	2200	1600
41	CASBCon7E2	12,359	5200	1700
42	CASBCon7E3	12,489	4800	2300

Table 3:TPH for Category B, Scenario A soil samples (Comparison of initial, monitoring, and close out analysis)

	Sample ID	TPH (mg/kg)		
		Initial analysis	Monitoring analysis	Close out analysis
43	CBSACon1E1	5796	2300	2100
44	CBSACon1E2	5896	2800	2400
45	CBSACon1K	5131	2000	1700
46	CBSACon2E	5964	1000	800
47	CBSACon2K1	5179	2500	600
48	CBSACon2K2	5207	700	600
49	CBSACon3E1	5887	1200	900
50	CBSACon3E2	5864	900	800
51	CBSACon3K	5174	1900	800

Table 4:TPH for Category B, Scenario B soil samples (Comparison of initial, monitoring, and close out analysis)

	Sample ID	TPH (mg/kg)		
		Initial analysis	Monitoring analysis	Close out analysis
52	CBSBCon1E1	12,357	4700	2100
53	CBSBCon1E2	12,379	6000	2400
54	CBSBCon1K	10,126	7900	1700
55	CBSBCon2E	12,334	7000	800
56	CBSBCon2K1	10,015	1300	600
57	CBSBCon2K2	10,103	5900	600
58	CBSBCon3E1	12,389	7000	900
59	CBSBCon3E2	12,295	6200	800
60	CBSBCon3K	10,157	7000	800

Table 5:TPH for Category C soil samples (Comparison of initial, monitoring, and close out analysis)

	SampleID	TPH (mg/kg)		
		Initial analysis	Monitoring analysis	Close out analysis
61	CCG1	11,200	11,000	10,800
62	CCG2	11,100	11,100	10,900
63	CCG3	11,150	11,000	10,800

Table 6:TPH for Control, Group 1 soil samples (Comparison of initial, monitoring, and close out analysis)

	Sample ID	TPH (mg/kg)		
		Initial analysis	Monitoring analysis	Close out analysis
64	ConSAGp1G	11,251	6000	4300
65	ConSAGp1E	5963	3100	1800
66	ConSAGp1K	5248	3200	1700
67	ConSBGp1G	22,809	19,500	16,200
68	ConSBGp1E	12,378	10,700	8600
69	ConSBGp1K	10,108	8700	6800

Table 7:TPH for Control, Group 2 soil samples (Comparison of initial, monitoring, and close out analysis)

	Sample ID	TPH (mg/kg)		
		Initial analysis	Monitoring analysis	Close out analysis
70	ConSAGp2G	11,193	10,100	8900
71	ConSAGp2E	5958	5600	4900
72	ConSAGp2K	5214	4800	4300
73	ConSBGp2G	22,868	21,700	19,600
74	ConSBGp2E	12,407	11,800	10,900
75	ConSBGp2K	10,113	9700	8900

Performance against applied remediation approach and impact levels based on TPH analysis following TPH reduction monitoring

Table 8: Category A, Scenario A soil samples (Performance against applied remediation approach and impact levels based on TPH reduction monitoring)

Set up	Sample ID	Remediation approach	Starting mean TPH (mg/kg)	Mean TPH at monitoring (mg/kg)	% TPH Degraded	% TPH Remaining
Container 1 set ups	CASACon1E1 CASACon1E2 CASACon1K	Phytoremediation utilizing Maize	5684	1500	73.6	26.4
Container 2 set ups	CASACon2E CASACon2K1 CASACon2K2	Phytoremediation utilizing Cowpea	5405	2133	60.5	39.5
Container 3 set ups	CASACon3E1 CASACon3E2 CASACon3K	Phytoremediation utilizing Maize plus Cowpea	5661	1700	70.0	30.0
Container 4 set ups	CASACon4G1 CASACon4G2 CASACon4G3	Biostimulation	11,145	4066	63.5	36.5
Container 5 set ups	CASACon5G1 CASACon5G2 CASACon5G3	Biostimulation plus phytoremediation utilizing Maize	11,174	1366	87.8	12.2
Container 6 set ups	CASACon6G1 CASACon6G2 CASACon6G3	Biostimulation plus phytoremediation utilizing Cowpea	11,132	2066	81.4	18.6
Container 7 set ups	CASACon7G1 CASACon7G2 CASACon7G3	Biostimulation plus phytoremediation utilizing Maize and Cowpea	11,065	1100	90.1	9.9

Table 9: Category A, Scenario B soil samples (Performance against applied remediation approach and impact levels based on TPH reduction monitoring)

Set up	Sample ID	Remediation approach	Starting mean TPH (mg/kg)	Mean TPH at monitoring (mg/kg)	% TPH Degraded	% TPH Remaining
Container 1 set ups	CASBCon1E1	Phytoremediation utilizing Maize	11,608	5000	56.9	43.1
	CASBCon1E2					
	CASBCon1K					
Container 2 set ups	CASBCon2E	Phytoremediation utilizing Cowpea	10,811	5733	47.0	53.0
	CASBCon2K1					
	CASBCon2K2					
Container 3 set ups	CASBCon3E1	Phytoremediation utilizing Maize plus Cowpea	11,632	6833	41.3	58.7
	CASBCon3E2					
	CASBCon3K					
Container 4 set ups	CASBCon4G1	Biostimulation	22,771	9133	59.9	40.1
	CASBCon4G2					
	CASBCon4G3					
Container 5 set ups	CASBCon5E1	Biostimulation plus phytoremediation utilizing Maize	13,231	3066	76.8	23.2
	CASBCon5E2					
	CASBCon5E3					
Container 6 set ups	CASBCon6E1	Biostimulation plus phytoremediation utilizing Cowpea	13,245	6600	50.2	49.8
	CASBCon6E2					
	CASBCon6E3					
Container 7 set ups	CASBCon7E1	Biostimulation plus phytoremediation utilizing Maize and Cowpea	12,364	4066	67.1	32.9
	CASBCon7E2					
	CASBCon7E3					

Table10: Category B, Scenario A soil samples (Performance against applied remediation approach and impact levels)

Set up	Sample ID	Remediation approach	Starting mean TPH (mg/kg)	Mean TPH at monitoring (mg/kg)	% TPH Degraded	% TPH Remaining
Container 1 set ups	CBSACon1E1	Phytoremediation utilizing Maize	5607	2366	57.8	42.2
	CBSACon1E2					
	CBSACon1K					
Container 2 set ups	CBSACon2E	Phytoremediation utilizing Cowpea	5450	1400	74.3	25.7
	CBSACon2K1					
	CBSACon2K2					
Container 3 set ups	CBSACon3E1	Phytoremediation utilizing Maize plus Cowpea	5641	4000	29.1	70.9
	CBSACon3E2					
	CBSACon3K					

Table 11: Category B, Scenario B soil samples (Performance against applied remediation approach and impact levels based on TPH reduction monitoring)

Set up	Sample ID	Remediation approach	Starting mean TPH (mg/kg)	Mean TPH at monitoring (mg/kg)	% TPH Degraded	% TPH Remaining
Container 1 set ups	CBSBCon1E1	Phytoremediation utilizing Maize	11,620	6200	46.6	53.4
	CBSBCon1E2					
	CBSBCon1K					
Container 2 set ups	CBSBCon2E	Phytoremediation utilizing Cowpea	10,817	4733	56.3	43.8
	CBSBCon2K1					
	CBSBCon2K2					
Container 3 set ups	CBSBCon3E1	Phytoremediation utilizing Maize plus Cowpea	11,613	6966	40.0	60.0
	CBSBCon3E2					
	CBSBCon3K					

Table 12: Category C soil samples (Performance against applied remediation approach and impact levels based on TPH reduction monitoring)

Sample ID	Remediation approach	Starting mean TPH (mg/kg)	Mean TPH at monitoring (mg/kg)	% TPH Degraded	% TPH Remaining
CCG1	NA	11,150	11.033	1.1	99.9
CCG2					
CCG3					

Table 13: Control, Group 1 soil samples (Performance against applied remediation approach and impact levels based on TPH reduction monitoring)

Sample ID	Remediation approach	Starting TPH (mg/kg)	TPH at monitoring (mg/kg)	% TPH Degraded	% TPH Remaining
ConSAGp 1G	Enhanced natural attenuation	11,251	6000	46.7	53.3
ConSAGp 1E	Enhanced natural attenuation	5963	3100	48.0	52.0
ConSAGp 1K	Enhanced natural attenuation	5248	3200	39.0	61.0
ConSBGp 1G	Enhanced natural attenuation	22,809	19500	14.5	85.5
ConSBGp 1E	Enhanced natural attenuation	12,378	10,700	13.6	88.4
ConSBGp 1K	Enhanced natural attenuation	10,108	8700	14.9	85.1

Table 14: Control, Group 2 soil samples (Performance against applied remediation approach and impact levels based on TPH reduction monitoring)

Sample ID	Remediation approach	Starting TPH (mg/kg)	TPH at monitoring (mg/kg)	% TPH Degraded	% TPH Remaining
ConSAGp 2G	Natural attenuation	11,193	10,100	9.8	90.2
ConSAGp 2E	Natural attenuation	5958	5600	6.0	94.0
ConSAGp 2K	Natural attenuation	5214	4800	7.9	92.1
ConSBGp 2G	Natural attenuation	22,868	21,700	5.1	94.9
ConSBGp 2E	Natural attenuation	12,407	11,800	4.9	95.1
ConSBGp 2K	Natural attenuation	10,113	9700	4.1	95.9

Performance against applied remediation approach and impact levels based on TPH analysis following close out analysis

Table 15: Category A, Scenario A soil samples (Performance against applied remediation approach and impact levels based on TPH of the close out analysis)

Set up	Sample ID	Remediation approach	Remaining mean TPH (mg/kg)	Mean TPH at close out (mg/kg)	% TPH Degraded	% TPH Remaining
Container 1 set ups	CASACon1E1 CASACon1E2 CASACon1K	Phytoremediation utilizing Maize	1500	1000	33.3	66.7
Container 2 set ups	CASACon2E CASACon2K1 CASACon2K2	Phytoremediation utilizing Cowpea	2133	1033	51.6	48.4
Container 3 set ups	CASACon3E1 CASACon3E2 CASACon3K	Phytoremediation utilizing Maize plus Cowpea	1700	833	51.0	49.0
Container 4 set ups	CASACon4G1 CASACon4G2 CASACon4G3	Biostimulation	4066	867	78.7	21.3
Container 5 set ups	CASACon5G1 CASACon5G2 CASACon5G3	Biostimulation plus phytoremediation utilizing Maize	1366	750	45.1	54.9
Container 6 set ups	CASACon6G1 CASACon6G2 CASACon6G3	Biostimulation plus phytoremediation utilizing Cowpea	2066	900	56.4	43.6
Container 7 set ups	CASACon7G1 CASACon7G2 CASACon7G3	Biostimulation plus phytoremediation utilizing Maize and Cowpea	1100	467	57.6	42.4

Table 16: Category A, Scenario B soil samples (Performance against applied remediation approach and impact levels based on TPH of the close out analysis)

Set up	Sample ID	Remediation approach	Remaining mean TPH (mg/kg)	Mean TPH at close out (mg/kg)	% TPH Degraded	% TPH Remaining
Container 1 set ups	CASBCon1E1 CASBCon1E2 CASBCon1K	Phytoremediation utilizing Maize	5000	3267	34.7	65.3
Container 2 set ups	CASBCon2E CASBCon2K1 CASBCon2K2	Phytoremediation utilizing Cowpea	5733	4150	27.6	72.4
Container 3 set ups	CASBCon3E1 CASBCon3E2 CASBCon3K	Phytoremediation utilizing Maize plus Cowpea	6833	3700	45.8	54.2
Container 4 set ups	CASBCon4G1 CASBCon4G2 CASBCon4G3	Biostimulation	9133	7467	18.2	81.8
Container 5 set ups	CASBCon5E1 CASBCon5E2 CASBCon5E3	Biostimulation plus phytoremediation utilizing Maize	3066	1833	40.2	59.8
Container 6 set ups	CASBCon6E1 CASBCon6E2 CASBCon6E3	Biostimulation plus phytoremediation utilizing Cowpea	6600	3900	40.9	59.1
Container 7 set ups	CASBCon7E1 CASBCon7E2 CASBCon7E3	Biostimulation plus phytoremediation utilizing Maize and Cowpea	4066	1867	54.1	45.9

Table 17: Category B, Scenario A soil samples (Performance against applied remediation approach and impact levels based on TPH of the close out analysis)

Set up	Sample ID	Remediation approach	Remaining mean TPH (mg/kg)	Mean TPH at close out (mg/kg)	% TPH Degraded	% TPH Remaining
Container 1 set ups	CBSACon1E1 CBSACon1E2 CBSACon1K	Phytoremediation utilizing Maize	2366	2067	12.6	87.4
Container	CBSACon2E	Phytoremediatio	1400	667	52.4	47.6

2 set ups	CBSACon2K1 CBSACon2K2	n utilizing Cowpea				
Container 3 set ups	CBSACon3E1 CBSACon3E2 CBSACon3K	Phytoremediation utilizing Maize plus Cowpea	4000	833	79.2	20.8

Table 18: Category B, Scenario B soil samples (Performance against applied remediation approach and impact levels based on TPH of the close out analysis)

Set up	Sample ID	Remediation approach	Remaining mean TPH (mg/kg)	Mean TPH at close out (mg/kg)	% TPH Degraded	% TPH Remaining
Container 1 set ups	CBSBCon1E1 CBSBCon1E2 CBSBCon1K	Phytoremediation utilizing Maize	6200	3267	47.3	52.7
Container 2 set ups	CBSBCon2E CBSBCon2K1 CBSBCon2K2	Phytoremediation utilizing Cowpea	4733	2967	37.3	62.7
Container 3 set ups	CBSBCon3E1 CBSBCon3E2 CBSBCon3K	Phytoremediation utilizing Maize plus Cowpea	6966	3500	49.8	50.2

Table 19: Category C soil samples (Performance against applied remediation approach and impact levels based on TPH of the close out analysis)

Sample ID	Remediation approach	Remaining mean TPH (mg/kg)	Mean TPH at close out (mg/kg)	% TPH Degraded	% TPH Remaining
CCG1 CCG2 CCG3	NA	11,033	10,833	1.8	98.2

Table 20: Control, Group 1 soil samples (Performance against applied remediation approach and impact levels based on TPH of the close out analysis)

Sample ID	Remediation approach	Remaining TPH (mg/kg)	TPH at close out (mg/kg)	% TPH Degraded	% TPH Remaining
ConSAGp 1G	Enhanced natural attenuation	6000	4300	31.7	68.3
ConSAGp	Enhanced natural	3100	1800	41.9	58.1

1E	attenuation				
ConSAGp 1K	Enhanced natural attenuation	3200	1700	46.9	53.1
ConSBGp 1G	Enhanced natural attenuation	19,500	16,200	16.9	83.1
ConSBGp 1E	Enhanced natural attenuation	10,700	8600	19.6	80.4
ConSBGp 1K	Enhanced natural attenuation	8700	6800	21.8	78.2

Table 21: Control, Group 2 soil samples (Performance against applied remediation approach and impact levels based on TPH of the close out analysis)

Sample ID	Remediation approach	Remaining mean TPH (mg/kg)	Mean TPH at close out (mg/kg)	% TPH Degraded	% TPH Remaining
ConSAGp 2G	Natural attenuation	10,100	8900	11.9	88.1
ConSAGp 2E	Natural attenuation	5600	4900	12.5	87.5
ConSAGp 2K	Natural attenuation	4800	4300	10.4	89.6
ConSBGp 2G	Natural attenuation	21,700	19,600	9.7	90.3
ConSBGp 2E	Natural attenuation	11,800	10,900	7.6	92.4
ConSBGp 2K	Natural attenuation	9700	8900	8.3	91.8

Based on the results (as presented in tables 1 to 21 above), eliminating the contribution of natural attenuation from the applied remediation approaches yielded mean TPH reduction of up to; 68% of the initial or starting TPH in low impacted soils and the remaining TPH after reduction monitoring was further reduced by 67% with a mean TPH reduction of up to 72% observed in the high impacted soils following TPH reduction monitoring which was further reduced by 47% at close out for all clayey silty sand soil set ups, 66% in low impacted soils and the remaining TPH after reduction monitoring was further reduced by 42% while a mean TPH reduction of up to 52% was observed in the high impacted soils following TPH reduction monitoring which was further reduced by 29% at close out for silty sand soil set ups; and 80% in the low impacted soils and the remaining TPH after reduction monitoring was further reduced by about 67% while a mean TPH reduction of up to 55% was observed in the high impacted soils following TPH reduction monitoring which was further reduced by 9% at close out for sand soil set ups.

4. CONCLUSION

This study has shown non-correlation of soil profile across previously remediated sites when geological sustainability is not in view. For avoidance of geological change except change that has geological explanation, geological sustainability needs to be flagged-off. Where applicable, non-excavation methods vsuch as biostimulation and phytoremediation should be deployed; the bench scale study indicated the effectiveness of both approaches in low as well as high crude oil impacted soils. Uzochukwu et al., (2023), gives detailed explanation of the deployment of biostimulation and phytoremediation in the treatment of contaminated soils and a measure of its effectiveness. Where non-excavation methods may not be applicable such as impacted sites with impacts at deeper depths, efforts should be made to ensure that consideration of geological sustainability is in view. Flagging off geological sustainability implies implementing measures to ensure that soil excavated for remediation are separated and remediated according to various soil layers encountered and are returned to their true subsurface position after remediation. This can be achieved by boring holes at designated locations in the crude oil impacted area to obtain the soil profile of the area noting the thickness of the various soil layers and their depth intervals. This will enable gathering of background data ahead of the excavation that will inform decision on number of lots to be prepared for separation of soil layers based on the number of soil layers obtained from the background data. Each lot containing each soil layer should be properly labelled to indicate soil type and the depth interval it was excavated from. After remediation of excavated soil, soil excavated from deeper depth should be backfilled before soil excavated from shallower depth. In other words, soil layers should be returned to the depth interval they were excavated from. This is necessary, not only to ensure correlation of soil profile across the site and to avoid human induced change in groundwater flow direction, but to ensure that soil that are already suited to environmental conditions prevailing at the depth interval where they were excavated from are returned to their subsurface position.

In a nutshell, this study re-directs the mind on the need to narrow down environmental sustainability to geological sustainability especially in the area of remediation of crude oil contaminated sites involving excavation and backfilling. In view of the aforementioned, this study calls on the geological society to flag off geological sustainability campaign and enforce measures geared towards maintenance of geological sustainability.

ACKNOWLEDGMENT

I am thankful to my supervisors (Associate Prof. S.E. Abrakasa, Prof. H.O. Nwankwoala and Prof. L.C. Osuji) who guided me in my PhD research with their helpful information, practical advice and ideas. I am also thankful to ACE-CEFOR for organizing series of progress report presentation that kept me on track with insightful comments and wholesome criticism that helped me in successfully carrying out the research. I express my sincere gratitude to Shell Petroleum Development Company of Nigeria Limited (SPDC) for accepting me into her graduate internship program and to the management of the Ogoni Restoration Project (ORP) team of SPDC for retaining me after the internship program. Working with the ORP team gave me the practical experience I needed to successfully complete my research.

REFERENCES

[1] Amanda, V.E., (2006). Phytoremediation of Petroleum Hydrocarbons. U. S. Environmental Protection Agency, Environmental Careers Organization, Washington, DC (2006). Retrieved from https://clu-in.org/download/studentpapers/A_Van_Epps-Final.pdf

[2] American Geosciences Institute (AGI). https://www.americangeosciences.org/geoscience-currents/geoscientists-petroleum-and-environment. Retrieved on 22nd July, 2022.

[3] United Nations Environment Programme, (2011). Environmental Assessment of Ogoniland. ISBN: 978-92-807-3130-9

[4] Uzochukwu, C., (2022). Remediation Amid Continuous Crude Oil Pollution: A Look

Ahead on the Use of Phytostabilizer as a Proactive Containment and Remediation tool, a case study of Bodo Creek in Ogoni, Niger Delta. International Journal of Scientific Research and Engineering Development, pg. 858 – 864, vol 5(6).

[5] Uzochukwu, C., Abrakasa, S.E., Nwankwoala, H.O., and Osuji, L.C., (2023). Evaluation of the Role of Limiting Factors of Bioremediation Based on a Bench Scale Study Utilizing Biostimulation and Phytoremediation Approach. International Journal of Scientific Research and Engineering Development, pg. 844 – 852, vol 6(3).