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Evaluation of the Efficacy of Soil Remediation by Enhanced Recovery and Aeration Technique in Ogale Community in Eleme Local Government Area, in Rivers State

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Abstract: Study evaluated soil remediation by enhanced natural attenuation as option to improve soil nutrients in oil impacted communities in Eleme local government area of Rivers state. Experimental method was deployed for the study and sources of data were both primary and secondary. The study was anchored on environmental quality theory.Some of the objectives of the study includes; Evaluation of the efficacy of the soil remediation technique on soil quality in the study area; Determine the extent of variation in soil physicochemical properties in the study area, Identification of the presence of heavy metals in the study area and outlining of interaction existing between remediated soil through enhanced natural attenuation and impacted soil in the study area. Study analysed the variations in soil physiochemical properties, heavy metals, micro- bacteria count and TPH at 50cm, 150cm and 250 cm depths across the impacted soil sample KH1, treated soil sample KH2 and unimpacted soil KH3 (control). Descriptive statistical technique was deployed for analysis via SPSS23.0 version. Results showed that amongst others, that the highest recorded $_{P}$H value of 6.99 was at 250cm distance of unimpacted soil in KH13 and a decrease in Total Nitrogen content from unimpacted soil by 0.017mg/kg. Studyrecommends adoption of enhanced natural attenuation as an option to improve on soil impacted by oil pollution in the study area. Study also recommends full implementation of environmental laws and regulations by responsible agencies in order to achieve the full potentials of bioremediation of oil impacted soil in the study area.

Keywords: Evaluation, Efficacy, Soil, Remediation, Natural, Attenuation.

1. Introduction

In recent years, concerns about remediation by enhanced natural attenuation as an option to improved soil impacted by hydrocarbon have increased interests in environment studies, biogeography, soil science and GIS mapping because of its attendant problem in food security, health risks, soil fertility reduction, fauna, flora and benthos displacement and extinction. Oku, (2003) noted that almost 11million gallons of oil per year through bunkering leak into the Niger Delta marshlands and rivers without consummate bioremediation. Petroleum was discovered in Ogoni in 1958 and since then an estimated 100billion dollars' worth of oil and gas has been carted away from Ogoniland. Between 1976 and 1991, over two million barrels of oil polluted Ogoniland in 2,976 separate oil spills. While oil production has ceased, pipelines operated by Shell still traverse the land, creeks and waterways. Studies have shown that exploration activities in Ogale Community Eleme Local Government Area over the past years have not employed best available technological practices in bioremediation to clean up oil pollution that occurs through transportation, bunkering, vandalism, pipeline leaks and rupture (Chinweze et al., 2019) etc. Bioremediation is the removal of pollution or contaminants from environmental media such as soil, groundwater sediment, or surface water (Kadafa, 2012).Studies have shown that bioremediation uses microorganisms to degrade organic contaminants in soil, groundwater, sludge, and solids, while the microorganisms break down contaminants by using them as an energy source or metabolizing them with an energy source. In Ogale Community Eleme Local Government Area, oil exploration activities without comprehensive bioremediation strategies plan which would have protected its natural resources have not been of much help to the local communities, it has rather been a course of pain and suffering (Odoemene, 2018).The effect of oil pollution has been persistent over the years in Ogale Community Eleme Local Government Area, vegetation alteration and pollution, wildlife species depletion, air, soil, streams, rivers and wetlands that serves as sink for ecological balance has been affected (Anyanwu, 2018). Many of the oil facilities and operations are located within sensitive habitats including vital areas to fish breeding, sea Tuttle nesting, mangroves and rainforest. These areas have been severally damaged by oil pollution emanating from bunkering activities and have contributed to increased biodiversity loss, pollution of water and land resource, deforestation

which has ushered in high level of poverty as a result of the loss of their means of livelihood. One fallout of oil pollution in the Ogale Community Eleme Local Government Area is the destruction of the traditional local economic support system of fishing and farming. The combination of the effects of oil spill and acid rain resulting from gas flaring has caused soil degradation which affects crop yield and harvest. Also,drinking water sources are polluted alluding to portable water becoming very scarce (NNPC,2016). Today, most of the youths and women have become jobless since their local economic support system is no longer sustainable.Soil polluted with hydrocarbon becomes water logged; inducing several stresses on the plant and microbial community; ranging from changes in structure and configuration of enzymes. Polluted soil could also become unsuitable due to increase in the toxic levels of elements and heavy metals. Soil polluted with hydrocarbon heavy metals becomes water logged; inducing several stresses on the plant and microbial community; ranging from changes in structure and configuration of enzymes. Polluted soil could also become unsuitable due to increase in the toxic levels of elements and heavy metals.Majority of the studies concentrated on the impacts of hydrocarbon on soil, water and the ecosystem, while some concentrated on the effect of oil bunkering one human health and vegetation. Little or no work has been done on remediation by enhanced natural attenuation as an option to improve soil impacted areas in Ogale Community Eleme Local Government Area, Rivers State, South- South Nigeria (NNPC, 2018). Against this background, the research focused on remediation by enhanced natural attenuation as an option to improve soil impacted areas in Ogale Community, Eleme Local Government Area, Rivers State. The research also underlines the need to ascertain and identify advantages of enhanced natural attenuation methods in the remediation of hydrocarbon polluted soil. The research also suggests the need to integrate the findings of the study into the Government policy on environment sustainability.

2. Aim and Objectives of the Study

The aim of study was to evaluate of the efficacy of soil remediation by trench enhanced recovery and aeration technique in Ogale Community in Eleme Local Government Area, in Rivers State.

The objectives includes to:

1. Evaluate the efficacy of the soil remediation technique on soil quality in the study area.
2. Determine the extent of variation in soil physicochemical properties in the study area
3. Identify the presence of heavy metals in the study area
4. Outline interaction existing between remediated soil through enhanced natural attenuationand impacted soil in the study area.

3. Method of Study

The study deployed the experimental research design to deal with the analysis of soil physicochemical properties on farm-land in Ogale Community Eleme local Government Area, which is a process of planning a study to meet specified objectives according to Montgomery (2007) and is best suited for hypothesis dealing with cause-and-effect relationship.

4. Study Location

Eleme is situated in Eleme local government area. Eleme community lies between Longitude 04 42’ to 04° 52’ and Latitude 006° 3’ E to 006° 10’ E about 15 km north-east of Port Harcourt, the capital of Rivers State. The study area has 23 communities which includes; Aabon, Agbela, Abgonchia, Agreta, Akpajo, Alejoh, Alese, Aleto, Ebubu, Aledo, Egalor, Ejama, Ekaara, Eteo, Eyaa, KKaalenbon, Nchia-Elleme Nonwakebera, Norkpo, Obolo, Ogale and Onne (Nwaichi & James, 2015).

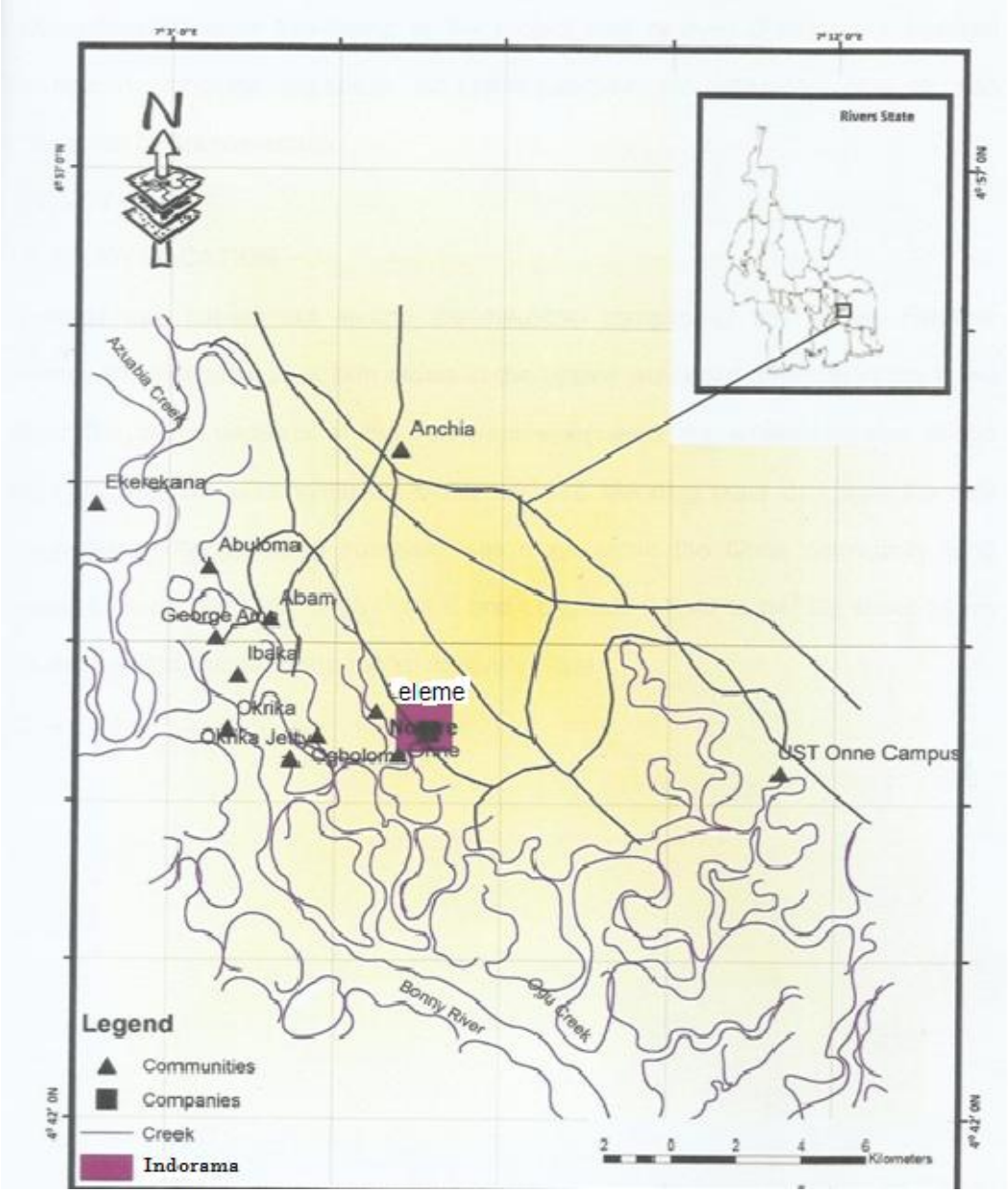

Figure 1: Showing study Location, Eleme LGA.

5. **Method of Data Collection**

The test soil that will be obtained is soil.

The preliminary process of bioremediation was fora period of 10weeks. The bioremediation processcomprised field experiment and laboratory simulation, with some physiochemical and microbial analyses. The concentration of total petroleum hydrocarbon (TPH) nitrogen and phosphorus wasdetermined, while the total heterotrophic bacteria (THB) and total hydrocarbon utilizing bacteria (THUB) was committed. These physiochemical parameters weremonitored once every two weeks for a period of 10weeks. 250ml glass jars and 400g plastic tub was be used for the samples and soil weight was more than 2kg, bulk enough in order for the laboratory to take a representative sub sample for testing. Each sample was taken in duplicate, and sample immediately put into a polythene bag to avoid aeration which was later transported to the laboratory. Samples were well labeled with masking tape so as to identify each farmland sample using the names of the communities in which they were collected (Laffon et al., 2016)

Remediation by Enhanced Natural Attenuation (RENA) Analysis: The following RENA techniques weredeployed to treat the contaminated farmland.

Spiking of Test Soils: The soils were spiked with water uniformly to soften the soil and to allow the water penetrate the soil matrix.

Initial Tilling: The soils were tilled in a week after they were spiked, that is mixing the soil and breaking the lumps. This wasbe done using shovel, composite samples were collected and sent to the laboratory for physiochemical and microbial evaluation.

Secondary Tilling: The soils were tilled and homogenized a week after the initial tilling. The lumps werebroken to very fine particles with shovel and rake. The essence of the tilling and homogenization was to uniformly distribute the petroleum contaminants and break up the soil lumps into fine particles thereby increasing the surface area. The composite samples were taken for analysis.

Windrow Construction: Windrows/ridges were constructed after the secondary tilling of the test site. The ridges weremeasured about 2feet high and 4feet wide. The windrows wasmade to achieve better aeration and optimize the efficiency of the attenuated processes in action, which exposes the microorganisms to oxygen, and aids in the biodegradation process of the petroleum hydrocarbon. Soil samples weretaken for analysis

Breaking down of Windrows: The windows were broken down after standing for between 3 and 4 weeks, after construction. Soil samples were taken for analysis.

Addition of Water: Water was added to the sandy soil to enhance the biodegradation of the petroleum hydrocarbons by the microorganisms when it penetrates the soil.

Addition of Fertilizer: Fertilizer application was done manually by sprinkling the fertilizer over the contaminated area. The process enhances the biodegradation of the petroleum hydrocarbon

Soil Sampling and Analysis: The topsoil samples of the farmland were taken at intervals of two weeks from 0.3metres deep. They weretaken using an auger machine into polypropylene bags, free from hydrocarbon contamination. This process was called augering. The soil samples were taken for immediate physico-chemical and microbial analysis.

Physico-Chemical and Microbial Analysis: Total phosphorous, total nitrogen and total petroleum hydrocarbon contents in the soil samples weredetermined by the method of American Association of Analytical Chemists (1990).

Microbial Analysis Total Heterotrophic Bacteria (THB) Count: The total heterotrophic bacterial count wasperformed on nutrient agar (Oxoide), using the spread place method (Gradi et al., 2017). Total viable counts of culturable aerobic heterotrophic bacteria wasobtained by preparing serial dilutions of gram wet saline (0.89% w/v NaCl) and surface plating on to sterile nutrient agar in triplicate. Culture plates wereincubated at room temperature (28 + 2OC for 48h. Plates yielding counts of 30 – 300 colonies werechosen and the counts obtained wasmultiplied by the dilution factor to obtain the number of bacteria per gramme of soil

Total hydrocarbon Utilization Bacteria (THUB) Count: Vapour-phase transfer method was adopted to estimate the population of THUB. A modified mineral salt medium of Mills et al., (2009), wasinoculated with suspension of test soil sample. Mixing 1g of wet soil with 10ml of sterile saline made suspension. Sterile filter paper (Whatman No. 1) saturated with crude oil wasplaced on the inside cover of each petri-dish kept in an inverted position. These filter papers will supply the hydrocarbons by vapour phase transfer to inverted inoculums. Plates werecounted after incubation at room temperature for 7days. The percentage of hydrocarbon utilizers within the heterotrophic bacteria population weredetermined (Mohamed, 2006).

6. Results

Table 1.1: GPS Coordinates for Longitude and Latitude of Sampled Locations

Location	Longitude	Latitude
KHI	$05^0$37’38.423’’E	$05^0$1’22.067’’N
KH2	$05^0$37’50.022’’E	05^{02}’30.607’’N
KH3	$05^0$37’26.824’’E	$05^0$0’16.69’’N

Source: Researcher’s Computation (2024)

Table1,1: showed Longitude and latitude of sample locations in the study area. Sampled point 1 (KH1) has longitude and Latitude of $05^0$37’38.423’’E and $05^0$1’22.067’’N, Sampled Point 2 (KH2) has longitude $05^0$37’50.022’’E and Latitude of 05^{02}’30.607’’N, Sampled Point 3 (KH3) as Longitude and Latitude of $05^0$37’26.824’’E and $05^0$0’16.69’’N, which is the control respectively. The assertion was in line with Abii, &Nwosu (2019) who stated that GPS locational mapping of longitude and latitude aids in soil samples collection for experimental purposes.

Research Question 1. What is the impact of bioremediation on soil quality in the study area?

Table 1.2: Impact of Bioremediation on Soil Quality in the Study Area.

Sampled ID	Impacted Soil KH1			Treated Soil KH2			Unimpacted soil KH3 (Control)			HYPREP Soil Intervention Target	SPDC Target
Unit/Depth	50cm	150cm	250cm	50cm	150cm	250cm	50cm	150cm	250cm	1000mg/kg	3000mg/kg
Mg/kg	487.92	3,488	3,204	213.69	363.49	432.9	32.23	76.07	75.14	Acceptable	Acceptable
Mg/kg	476.86	3,677	3,342	286.54	354.88	493.8	33.34	86.09	88.66	Acceptable	Acceptable
Mg/kg	497.94	3,573	3,214	223.76	374.68	442.6	32.44	77.64	75.14	Acceptable	Acceptable

Source: Researcher's Computation (2024)

Impact of Bioremediation on Soil Quality in the Study

Analysis on the impact of Bioremediation on Soil Quality in the study Area in Table1.2 above shows the soil quality at 50cm depth in KH1 was 487.92mg/kg, 3488 mg/kg at 150cm, 3204 mg/kg at 250cm respectively. However, when the soil was treated, it showed a value of 213.69 mg/kg at 50cm depth, 363.49 mg/kg at 150cm and 432.9 mg/kg, while the control (un-impacted) 50cm depth had 32.2349 mg/kg, 86.09mg/kg and 88.66mg/kg at the depths of 50cm. 150cm and 250cm respectively. More so, the soil quality at 50cm depth in KH2 was 476.86mg/kg at 50cm, 3677mg/kg at 150cm, 3342mg/kg at 250cm respectively. When the soil was treated, it showed a value of 286.54 mg/kg at 50cm depth, 354.88mg/kg, 86.09mg/kg and 88.66mg/kg at the depts of 50cm, 150cm and 250cm respectively. Finally, soil quality at 50cm depth in KH3 was 497.94mg/kg, 3573mg/kg at 150cm, 3214mg/kg at 250cm respectively. When the soil was treated, it showed a value of 223.76mg/kg at 50cm depth, 374.68mg/kg at 150cm and 442.6mg/kg, while the control (un-impacted) 50cm depth as 32.44mg/kg, 77.64mg/kg and75.14mg/kg at the depths of 50cm, 150cm and 250cm respectively. This is in conformity to HYPREP Soil Intervention and SPDC Target of 1000mg//kg and 3000mg/kg on soil quality index respectively. Thus, the impact of bioremediation on soil quality in the study area was acceptable, this also was in line with Abha, & Singh, (2014), that bioremediation was vital in soil quality restoration and management. It also corroborates with Agarry & Latinwo(2015) biodegradation of Diesel oil in Soil and its enhancement by application of bioventing and amendment with brewery waste effluent as biostimulation-bioaugmentation agents.

Research Question 2: What is the extent of variation in soil physicochemical properties in the study area?

Table 1. 3: Variations in soil physiochemical properties in the study area

Sample Depth	Impacted Soil Sample (K1)			Treated Soil Sample (KH2)			Unimpacted Soil Sample (Control KH3)		
	50cm	150cm	250cm	50cm	150cm	250cm	50cm	150cm	250cm
Ph	5.82	5.49	5.41	5.33	5.07	5.24	5.5	5.32	4.99
Total Nitrogen	0.018	0.017	0.018	0.018	0.016	0.017	0.022	0.022	0.017
Magnesium	3.905	2.196	3.196	3.07	3.272	2.96	3.976	3.704	3.905
Potassium	0.387	0.442	0.688	0.579	0.606	0.62	0.715	2.31	0.921
Salinity	40	40	40	49.98	34.99	44.99	49.98	34.99	34.99
Phosphorus	8.19	1.25	4.22	1.98	1.52	1.91	2.04	2.31	4.22
Alkalinity	0.20	0.21	0.21	0.21	0.20	0.20	0.20	0.19	0.21

Source: Researcher's Computation (2024)

Table 1.3 showed analysis on variation in soil physicochemical properties in the study area showed that pH at 50cm on impacted soil sample from KH1 was 5.82mg/kg, 5.49mg/kg and 5.41mg/kg accounted for 50cm, 150cm and 250cm respectively. At treated soil sample KH2, at 50cm was 5.33mg/kg, 5.07mg/kg and 5.24mg/kg accounted for 150cm and 250cm respectively. While un-impacted soil sample (Control) KH3 at 50cm, 150cm and 250cm amounted for 5.5mg/kg, 5.32mg/kg and 4.99mg/kg. This showed that the highest recorded pH value of 5.82 mg/kg was at 50cm impacted soil Sample in KH1. Total Nitrogen at 50cm on impacted soil sample from KHI is 0.018mg/kg, 0.017mg/kg and 0.018mg/kg accounted for 150cm and 250cm depth respectively. At treated soil sample K2, Total Nitrogen at 50cm was 0.018mg/kg, 0.018mg/kg and 0.016mg/kg accounted for 150cm and 250cm depth respectively. While un-impacted soil sample (Control)o K3 at 50cm, 150cm and 250cm Total Nitrogen accounted for 0.017mg/kg, 0.022mg/kg and 0.017mg/kg. This showed a decrease in total Nitrogen content from Un-impacted Soil Sample by 0.022mg/kg. Total Nitrogen at 50cm on impacted soil sample from KH1 is 0.018mg/kg, 0.017mg/kg and 0.018mg/kg accounted for 150cm and 250cm depths respectively. At treated soil sample KHH2, Total Nitrogen at 50cm was 0.018mg/kg, 0.018mg/kg and 0.016mg/kg accounted for 150cm and 250cm depth respectively. While un-impacted soil sample (control) KH3

at 50cm, 150cm and 250cm Total Nitrogen content from un-impacted soil sample by 0.022mg/kg and 0.017mg/kg. This showed a decrease in Total Nitrogen content from un-impacted soil sample by 0.022mg/kg. Magnesium at 50cm on impacted soil sample from KH1 was 3.905mg/kg, 2.196mg/kg and 3.196mg/kg accounted for 150cm and 250cm depths respectively. At treated soil sample KH2, Magnesium at 50cm was 3.07mg/kg, 3.272mg/kg and 2.96mg/kg accounted for 150cm and 250cm depth respectively. While Magnesium at unimpacted soil sample (Control) KH3 at 50cm, 150cm and 250cm accounted for 3.976mg/kg, 3.704mg/kg and 3.905mg/kg. Potassium at 50cm on impacted soil sample from KHI was 0.387mg/kg, 0.442mg/kg and 0.688mg/kg accounted for 150cm and 250cm depths respectively at treated soil sample KH2, Potassium at 50cm is 0.579mg/kg, 0.606mg/kg and 0.62mg/kg accounted for 1150cm and 250cm depth respectively. While Potassium at unimpacted soil sample (Control) KH3 at 50cm, 150cm and 250cm accounted for 0.715mg/kg, 2.31mg/kg and 0.921mg/kg respectively. Salinity content at 50cm on impacted soil sample from KH1 was 40 mg/kg, 40 mg/kg and 40 mg/kg accounted for 150cm and 250cm depth in KH1 respectively. At treated soil sample KH2, Salinity content at 50cm was 49.98mg/kg, 34.99mg/kg and 44.99mg/kg accounted for 150cm and 250cm depth respectively. While salinity content at unimpacted soil sample (Control) KH3 at 50cm, 150cm and 250cm accounted for 49.99mg/kg, 34.99mg/kg and 34.99mg/kg respectively. Phosphorus content at 50cm on impacted soil sample from KH1 was 8.19mg/kg, 1.25mg/kg and 4.22mg/kg accounted for 150cm and 250cm depth in KH1 respectively. At treated soil sample KH2, phosphorus content at 50cm was 1.98mg/kg. 1.52mg/kg and 1.914mg/kg accounted for 150cm and 250cm depth respectively. While salinity content at un-impacted soil sample (Control) KH3 at 50cm, 150cm and 250cm accounted for 2.04mg/kg, 2.31mg/kg and 4.22mg/kg respectively. From the analysis, there was very high content of phosphorus at 50cm on impacted soil sample from KH1. This also agrees with A1-Wasify & Hamed (2019) who stated that there was always high concentration level of Phosphorus due to loss of soluble P in surface runoff, draining tile, and groundwater at a shallow depth; and a potential for leaching of P in sandy and organic soils. Finally, Alkalinity content at 50cm was 0.20mg/kg, 0.21mg/kg and 0.214mg/kg accounted for 150cm and 250cm depth respectively. 0.21mg/kg, 20mg/kg and 20mg/kg for 50cm, 150cm, 250cm depths of KH2 while KH3 had at 50cm, 150cm and 250cm 0.20mg/kg, 0.19mg/kg and 0.21mg/kg respectively.

Research Question 3: Are there presence of heavy metals in soil in the study area?

Table1.4. Presence of Heavy Metals in Soil in the Study Area

S/N	Parameters/ Depth	Impacted Soil Sample (KH 1)			Treated Soil Sample (KH 2)			Unimpacted Soil Sample (Control KH 3)		
	Heavy Metal (mg/kg)	50cm	150cm	250cm	50cm	150cm	250cm	50cm	150cm	250cm
1	Arsenic	<0.001	<0.001	<0.001	5.33	5.07	5.24	5.5	5.32	4.99
2	Barium	0.02	0.016	0.019	0.016	0.021	0.023	0.022	0.021	0.024
3	Chromium (Cr)	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
4	Cadmium	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	2664	2189	2092
5	Iron	2664	2189	2092	2081	2460	2891	2747.3	2508.7	3232.2
6	Lead	<0.002	<0.002	<0.002	<0.002	<0.002	<0.002	<0.002	<0.002	<0.002
7	Mercury	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
8	Nickel	<0.008	<0.008	<0.008	<0.008	<0.008	<0.008	<0.008	<0.008	<0.008

Table 1.4 showed the presence of heavy metals in soil in the study area. From the analysis itshows that Arsenic at 50cm on impacted soil sample from KH1 was <0.001mg/kg. <0.001mg/kg and<0.001mg/kg, for 150cm and 250cm respectively. At treated soil sample KH2, Arsenic at 50cm was 5.33mg/kg, 5.07mg/kg and 5.24mg/kg accounted for 150cm and 250cm respectively. While unimpacted soil sample (Control) KH3 at 50cm, 150cm and 250cm accounted for 5.5mg/kg, 5.32mg/kg and 4.99mg/kg. Presences of Barium heavy metals in soil in the study area at 50cm on impacted soil sample from KH1 was 0.02mg/kg, 0.016mg/kg and 0.019mg/kg for 150cm and 250cm respectively. At treated soil sample KH2, Barium at 50cm was 0.016mg/kg, 0.021mg/kg and 0.21mg/kg accounted for 150cm and 250cm respectively. While unimpacted soil sample (Control) KH3 at 50cm, 150cm accounted for 0.022mg/kg, 0.021 mg/kg and 0.024mg/kg. Presence of Chromium (Cr) heavy metals in the soil in the study area at 50cm on impacted soil sample from KH1 was <0.001mg/kg, <0.001mg/kg and <0.001mg/kg for 150cm and 250 respectively. At treated soil sample KH 2 Cr at 50cm was <0.001mg/kg and was <0.001mg/kg accounted for 150 and 250 respectively. While unimpacted soil sample (Control) KH3 50cm and 150 and 250 accounted for was <0.001mg/kg, <0.001mg/kg, and <0.001mg/kg. Presence of Cadmium heavy metals in soil in the study area at 50cm , 150 and 250 recorded, 0.001mg/kg, <0.001mg/kg and <0.001mg/kg respectively for KH1. At treated soil sample KH2, Cadmium at 50cm <0.001mg/kg, <0.001mg/kg and <0.001mg/kg accounted for 150cm and 250cm respectively. While Unimpacted soil sample (Control) KH3 at 50cm is 2664mg/kg, 2189mg/kg and 2092mg/kg for 150cm and

250cm respectively. KH1 impacted soil, 50 cm 2664mg/kg, 150, 2189mg/kg and 259, 2092 mg/kg. At treated soil sample KH 2, Iron at 50cm 2081mg/kg, 2460mg/kg and 2891mg/kg accounted for 150cm and 250cm respectively. While Unimpacted soil sample (Control) KH3 at 50cm, 150cm and 250cm accounted for 2747.3mg/kg 2508.7mg/kg and 32332.2 mg/kg. Lead presences in soil in the study area at 50cm on impacted soil sample from KH was <0.002 mg/kg, <0.002 mg/kg and <0.002mg/kg for 150cm and 250cm respectively. At treated soil sample KH 2, Lead at 50cm was<0.002mg/kg and 0.002mg/kg accounted for 150cm and 250cm respectively. While unimpacted soil sample (Control) KH3 at, 50cm, 150cm and 250cm accounted for <0.002mg/kg, <0.002mg/kg and 0.002mg/kg. Mercury Presences in soil in the study area at 50cm on impacted soil sample from KH1 was<0.001mg/kg, <0.001mg/kg and <0.001mg/kg, <0.001mg/kg and <0.001mg/kg accounted for 150cm and 250cm respectively. At treated soil sample KH2, Mercury at 50cm was<0.001mg/kg, <0.001mg/kg and <0.001mg/kg accounted for 150cm and 250cm respectively. While unimpacted soil sample (Control) KH 3 at 50cm, 150cm and 250cm accounted for <0.001mg/kg, <0.001mg/kg and <0.001mg/kg. Nickel presence in soil in the study area at 50cm on impacted soil sample from KH1 was <0.008mg/kg and <0.008mg/kg for 150cm respectively. At treated soil sample KH2, Nickel at 50cm wass<0.008mg/kg and <0.008mg/kg accounted for 150cm and 250cm respectively. While unimpacted soil sample (Control) KH 3 at, 50cm, 150cm and 250cm accounted <0.008mg/kg, <0.008mg/kg, <0.008mg/kg. From the analysis, Nickel presences in soil in the study area does notvary across all the sampled depths of the soil in the study area.

Research Question 4. What are the Interactions Existing between Remediated Soil through enhanced natural attenuation and impacted soil in the study Area?

Table1.5: Interaction existing between remediated soil through enhanced natural attenuation and impacted soil in the study area

S/N	Parameters/ Depth	Impacted Soil Sample (KH 1)			Treated Soil Sample (KH 2)			Unimpacted Soil Sample (Control KH 3)		
	Micro-Bacteria Count ($X10^3$cfu/g)	50cm	150cm	250cm	50cm	150cm	250cm	50cm	150cm	250cm
1	Total Heterotrophic Bacteria (THB)	3.1	<0.01	0.8	1.1	1.7	1.8	8	6.7	8.1
2	Total Heterotrophic Fungi Count (THF)	0.7	<0.01	0.2	0.3	0.5	0.4	0.8	0.8	0.7
3	Hydrocarbon Utilizing Bacteria (HUB)	0.2	<0.01	<0.01	<0.01	0.1	0.1	0.1	0.1	0.2
4	Hydrocarbon utilizing Fungi (HUF)	<0.01	<0.01	<0.01	<0.01	<0.01	0.1	0.1	0.1	<0.01
	Organics mg/kg									
1.	TPH (mg/kg)	1121	2712	399.16	50.07	437.8	53.44	140.59	97.32	35..63
	PAH									
2.	Naphthalene	<0.01	0.16	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
3.	Acenaphthylene	<0.01	0.07	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
4.	Acenaphthene	<0.01	0.05	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
5.	Fluorine	<0.01	0.04	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
6.	Anthracene	<0.01	0.08	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
7.	Phenanthrene	<0.01	0.08	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01

Source: Researcher's Computation, (2024)

Table 1.5, analysis on interaction existing between remediated soil through enhanced natural attenuation and impacted soil in the study area shows Total Heterotrophic Bacteria (THB) count at Impacted Soil Sampled (KH1) at varying depths 50cm, 150cm and 250cm as 3.1mg/kg, <0.01mg/kg and 0.8mg/kg, KH2 at 50cm, 150cm and 250cm are 1.1mg/kg, 1.7mg/kg and 1.8mg/kg, KH3 at 50cm, 150cm and 250cm are 8mg/kg, 6.7mg/kg and 8.1mg/kg respectively. Total Heterotrophic Fungi Count (THF) count at Impact Soil Sampled (KHI) at varying depths 50cm, 150cm and 250cm as 0.7mg/kg, <0.01mg/kg and 0.2mg/kg, KH2 at 50cm, 150cm and 250cm are 0.3mg/kg, 0.5mg/kg and 0.4mg/kg. KH3 at 50cm, 150cm and 250cm are 0.8mg/kg, 0.8mg/kg and 0.7mg/kg respectively. Hydrocarbon Utilizing Bacteria (HUB) count at Impacted Soil Sampled (KH1) at varying depths 50cm, 150cm and 250cm as 0.2mg/kg, <0.01mg/kg and <0.01mg/kg, KH2 at 50cm, 150cm and 250cm are <0.01mg/kg, 0.1mg/kg and 0.1mg/kg. KH3 at 50cm, 150cm and 250cm are 0.1mg/kg, 0.1mg/kg and 0.2mg/kg respectively. Hydrocarbon utilizing Fungi (HUF) count at Impacted Soil Sampled (KH1) at varying depths 50cm, 150cm and 250cm as <0.01mg/kg, <0.01mg/kg and <0.01mg/kg, KH2 at 50cm, 150cm and 250cm are <0.01mg/kg, <0.01mg/kg and <0.01mg/kg, KH3 at 50cm, 150cm and 250cm are

0.1mg/kg, 0.1mg/kg and <0.01mg/kg respectively. TPH count at Impacted Soil Sampled (KH1) at varying depths 50cm, 150cm and 250cm as 1121mg/kg, 2712mg/kg and 399.16mg/kg. KH2 at 50cm, 150cm and 250cm are 50.07mg/kg, 437.8mg/kg and 53.44mg/kg, KH3 at 50cm, 150cm and 250cm are 1140.59mg/kg, 97.32mg/kg and 35.63mg/kg respectively. Also, PAH Naphthalene in Impacted Soil Sampled (KH1) at varying depths 50cm, 150cm and 250cm as 1121mg/kg, 2712mg/kg and 399.16mg/kg, KH2 at 50cm, 150cm and 250cm are <0.01mg/kg, 0.1mg/kg and 0.1mg/kg, KH3 at 50cm, 150cm and 250cm are <0.01mg/kg, 0.1mg/kg and 0.1mg/kg respectively. Acenaphthylene in Impacted Soil Sampled (KH1) at vary depths 50cm, 150cm and 250cm are as 1121mg/kg, 2712mg/kg and 399.16mg/kg, KH2 at 50cm, 150cm and 250cm are <0.01mg/kg, 0.1mg/kg and 0.1mg/kg, KH3 at 50cm, 150cm and 250cm are <0.01mg/kg, 0.1mg/kg and 0.1mg/kg respectively. Acenaphthene in Impacted Soil Sampled (KH1) at varying depths 50cm, 150cm and 250cm as <0.01mg/kg, 0.07mg/kg and <0.01mg/kg, KH2 at 50cm, 150cm and 250cm are <0.01mg/kg, <0.01mg/kg and <0.01mg/kg. KH3 at 50cm, 150cm and 250cm are <0.01mg/kg, <0.01mg/kg and <0.01mg/kg respectively. Acenaphthene in Impacted Soil Sampled (KH1) at varying depths 50cm, 150cm and 250cm as <0.01mg/kg, 0.05mg/kg and <0.01mg/kg. KH2 at 50cm, 150cm and 250cm are <0.01mg/kg, 0.07mg/kg and <0.01mg/kg. KH3 at 50cm, 150cm and 250cm are <.01mg/kg, 0.07mg/kg and <0.01mg/kg respectively. Fluorine in Impacted Soil Sampled KH1 at varying depths 50cm, 150cm and 250cm as <0.01mg/kg, 0.04mg/kg and <0.01mg/kg. KH2 at 50cm, 150cm and 250cm are <0.01mg/kg, 0.07mg/kg and <0.01mg/kg. KH3 at 50cm, 150cm and 250cm are <0.01mg/kg, <0.01mg/kg and <0.01mg/kg respectively. Analysis of Anthracene in Impacted Soil Sampled KH1 at varying depths of 50cm, 150cm and 250cm as <0.01mg/kg, 0.08mg/kg and <0.01mg/kg. KH2 at 50cm, 150cm and 250cm are <0.01mg/kg, 0.07mg/kg and <0.0mg/kg. KH3 at 50cm, 150cm and 250cm are <0.01mg/kg, <0.01mg/kg and <0.01mg/kg respectively. Finally, Phenanthrene in Impacted Soil Sampled (KH1) at varying depths 50cm, 150cm and 250cm as <0.01mg/kg, 0.08mg/kg and <0.01mg/kg. KH2 at 50cm, 150cm and 250cm are <0.01mg/kg, 0.07mg/kg and <0.01mg/kg. KH3 at 50cm, 150cm and 250cm are <0.01mg/kg, <0.01mg/kg and <0.01mg/kg respectively.

Conclusion

Soil are often polluted by different agents, such as heavy metals from mining, agricultural, petrochemical and other industries, including radiological, nuclear and other anthropogenic pollutants. These agents negatively affect the soil, plants, organisms and humans, and have necessitated the need for remediation. Remediation by enhanced natural attenuation (RENA) is a type of remediation process used to control soil pollutants by turning the soil to promote microbial proliferation, aeration, nutrients, moisture and degradation, conversely the study ascertained that remediation by enhanced natural attenuation was an option to improve soil impacted areas in Khana Local Government Area, Rivers State, Nigeria as well as other areas in the Niger Delta region, Nigeria where oil spillages has impacted on the soil. There was evidence of enrichment through remediation by enhanced natural attenuation on the physicochemical properties, heavy metals control and an overall improvement in the soil quality of the polluted soils that was in agreement with HYPREP Soil Intervention Target and SPDC Target soil quality standardization in Ogoni Land Rivers State, Nigeria.

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