Environmental technologies for remediation of contaminated lands in the Niger Delta region of Nigeria: Opportunities for ecosystem services to host communities.

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Abstract:
Several remediation technologies have been tried in the Niger Delta region of Nigeria to address the persistent hydrocarbon contamination with little or no success as they are either inappropriate for the environment and thus complete remediation is not achieved or they negatively impacted the environment which consequently leads to air pollution. The removal of hydrocarbons from contaminated soil is an essential practice because of its attendant environmental and public health concerns. The efficiency of the available remediation methods is dependent on the amount of oil spilled, the oil penetration depth into the soil, soil type, the age and level of contamination. This work has considered a gamut of remediation technologies available and concluded that not minding the limitations and advantages, the bioremediation is a suitable and sustainable technology for the treatment of crude oil impacted lands that comes with additional benefits of ecosystem services implementation. This paper presents the applications and multiple benefits of bioremediation technologies in remediation of contaminated soils and crude oil polluted lands in Nigeria's Niger Delta in a sustainable way to return the lands to original state and support ecosystem services inherent in natural habitats to the communities.

Keywords: bioremediation, contamination, crude oil production, ecosystem services, Niger-Delta.

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1.0 INRODUCTION

The Niger Delta is the region that sits directly on the Gulf of Guinea on the Atlantic Ocean in Nigeria. It is located within the nine coastal Nigerian states of Abia, Akwa Ibom, Bayelsa, Cross River, Delta, Edo, Imo, Ondo and Rivers. The region extends over an area of about 112,000 square Km and makes up about 12.0 percent of Nigeria's land mass. With a population of about 31 million people in about 3000 communities *(NDDC, 2014),* the region is one of the most densely populated regions of Africa *(Steiner, 2010).* Nigeria has the largest oil and gas reserves in Africa, and most of these reserves are found in the Niger Delta and the continental shelf of the country. The Niger Delta's massive oil deposits have been extracted since commercial production started in 1956 and petroleum production has since then formed the backbone of Nigeria's economy, accounting for over 90% of the country's total foreign exchange revenue *(NDDC., 2014).*

Nigeria with a population of about 198 million (2018 estimate) has a proven reserve of 36.97 billion barrels and currently produces about 2.10 million barrels of crude oil per day. It is the largest crude oil producer in Africa, the eleventh largest producer of petroleum, the eighth largest exporter of crude oil and has the tenth largest proven reserve of crude oil in the world *(Zabby et al., 2017)*. Since the first commercial oil well was drilled and produced in Oloibiri in 1956, oil exploration and production activities have been concentrated in the Niger Delta region which has over 1,000 oil wells and about 47,000 km of oil and gas flowlines *(Ngobiri et al., 2007)*. The production of crude oil has been beneficial to the economy of Nigeria: production companies have provided high paying jobs to the citizens, paid taxes and royalties to government, provided infrastructure around their areas of operation and awarded scholarships to citizens *(Ngene et al., 2016)*. Notwithstanding, oil extraction and processing activities has resulted in massive land contamination in Nigeria especially in the Niger Delta region of the country *(Sam et al., 2016; UNEP, 2011)*.

Several technologies have been employed for the remediation of crude oil contaminated land in the Niger Delta, but these efforts have yielded little or no success as they are either inappropriate for the environment and thus complete remediation is not achieved *(Gaidom, 2015)* or they negatively impacted the environment (e.g open dump burning) and consequently led to pollution. This work has looked through the successes achieved by the bioremediation technology bearing in mind the challenges of the Niger Delta terrain and has considered it the best technology for the remediation of crude oil impacted lands in the Niger Delta region of Nigeria. The result of this work is very important as it will provide technical guide for the Hydrocarbon Pollution Remediation Project (HYPREP) through which the Federal Government of Nigeria plans to clean up crude contaminated lands in Ogoni and other Niger Delta communities.

2.0 LITERATURE REVIEW

There are multitude of resources and processes that are supplied to man by natural ecosystems. These benefits are collectively referred to as ***ecosystem services*** and include products like clean drinking water and processes such as the decomposition of wastes. The ecosystem services could be grouped into four broad categories: *provisioning*, such as the provision of food and water; *regulating*, such as the control of climate and disease; *supporting*, such as nutrient cycles and crop pollination; and *cultural*, such as spiritual and recreational benefits *(MA, 2005)*.

Crude oil production activities have happened in the Niger Delta region for over six decades. During this period, several spills have been recorded over the land which were either partially or not remediated leading to social, economic, ecological, environmental and public health impacts. As at 2008, oil related activities in the region have resulted in the contamination of an estimated 2000 sites *(Ite et al., 2013)*, and these are capable of having multitude of impacts (such as cancer, birth defects, genetic mutation and reproductive defects) on the human population *(Heubeck et al., 2003)*, and the ecology, e.g. damage to mangrove forests and wetlands; water pollution *(Inam et al., 2015; Zabbey and Uyi, 2014)*. An estimated 10m to 13 m tons of hydrocarbons have been reportedly spilled into the Niger Delta over the last 50 years *(Nwilo et al., 2006; Kadafa, 2012)*. During this period over 77% of spilled hydrocarbons were not recovered *(Nwilo et al., 2006; Kadafa, 2012)*. The volume of spilled hydrocarbon and the percentage that has been left unrecovered either due to negligence or use of ineffective remediation method has hampered the provision of ecosystem services to the host communities.

2.1 Some contaminated sites in the Niger Delta:

Several oil contaminated sites in the Niger Delta have remained sources of environmental and health hazards years after the crude oil spill was not cleaned-up properly. These crude oil spills have altered the ecosystem around the sites and rendered them unavailable for development and aesthetics. Some of these popular spills are:

a. The Ejama-Ebubu Spill: This happened in Eleme in 1969 during the Nigerian civil war and burnt for several months, impacting over 255 hectares of farmland in the area. It is yet to be fully remediated and still impacting on biodiversity *(UNEP, 2011; Giadom, 2015)*. The local population has continued to be exposed to petroleum hydrocarbon hazards.
b. The Jesse Pipeline Spill: This led to fire outbreak which claimed lives of over 1000 people including children and women in the region *(Chinweze et al., 2012)*. The region is currently plagued with diverse environmental, socioeconomic and public health issues. Public health issues such as birth defects, cancer, various illnesses and death have been linked to the petroleum hydrocarbon spill *(Amaize, 2016)*.
c. The Nsisioken Community in Ogoniland due to several non-remediated spills has continued to consume water heavily contaminated by benzene *(UNEP., 2011)*. Ecologically, the area has been adversely impacted; the mangrove forest and fresh water wetlands have been degraded by oil spills which has consequently rendered the ecosystem unsuitable for wildlife and biodiversity *(Chinweze et al., 2012)*.
d. The Funiwa-5 oil well blowout: This happened in 1980; killed a total of 836 acres of mangroves and defoliated un-estimated mangrove seedlings *(Raji and Abejide, 2013)*. It further affected the coastal mangroves which formed breeding ground for fishes and other aquatic organisms *(Kadafa et al., 2012)*. Consequently, fishery resources are in decline in the region *(UNEP., 2011)*.

2.2 Effects of crude oil contaminated lands on ecosystem services

Ecosystem services are very important to the wellbeing and survival of people. The society depends on the continuous provision of ecosystem services for the livelihoods of many people especially the poor communities like in the Niger Delta.

The increasing dependence of the Nigerian economy on hydrocarbon exploration and extraction has led to severe pressures on the environmental components and other receptive systems *(Ite et al., 2013)* resulting to accidental and incidental discharges of hydrocarbon and its products into the environment. Soil contamination in the Niger Delta has affected fisher men and farmers whose economic wellbeing is dependent on the rivers and the fertile soils respectively *(Eregha and Irugbe., 2009)*.

In the Niger Delta region, the level of land contamination continues to surge with associated socio-economic and environmental impacts. While soil quality, surface and ground water has been adversely affected thus impacting drinking water quality *(UNEP, 2011; Ahiarakwem et al., 2012; Davies and Abolude, 2016)*, many aquatic fauna and flora have reportedly gone into extinction *(Luiselli et al., 2015)*. For example, the mangrove ecosystem in the Niger Delta region is fast degrading *(UNEP, 2011)*. These effects on the health, environment and economy of the Niger Delta people has led to decades of public protest and outrage demanding urgent remediation in the region to reduce risk to human health and restore environmental ecosystem and therefore restore livelihood support structures *(UNEP, 2011)*.

2.3 Remediation Technologies

Remediation is the process of returning soil, water or air functionality that existed prior to a contamination. Variety of techniques exist for remediation depending on the media (e.g air, water, soil) and the contaminant (e.g heavy metal, PCB) *(Gomes et al., 2013)*. Soil remediation methods can be divided into three parts: biological, physical and chemical *(Khan et al., 2004; Yao et al; 2012; Lim et al., 2016)* which can be done ex situ or in situ depending on the method employed *(Gomes et al., 2013)*.

The remediation by enhance natural attenuation (RENA) also known as “the do-nothing technique” which has been traditionally used for contaminated land clean-up in the Niger Delta by regulators and operators has been found to be inappropriate for the Niger Delta environment *(Sam et al., 2016; UNEP, 2011)*. RENA is unsuitable for majority of the sites in the Niger Delta region as the spilled oil has percolated into the soil beyond 5m depth and contaminated groundwater aquifer in different locations *(Orji et al., 2012)*.

2.3.1 Physical Remediation Method:

The physical remediation method involves either soil replacement or thermal desorption. The method is labour intensive, expensive and suitable for small contaminated sites *(Khan et al., 2004)*. The capping method, in which a contaminated sediment bed is isolated with a clean layer or “cap” commonly consisting of sand, gravel, silt or crushed rock debris, is also a physical remediation method. The passive cap made of unreactive materials mainly rely on containment rather than treatment. The cap cut down bio availability of contaminants by physically separating sediments from the aquatic environment, confining bioturbation to the top clean layer and limiting the possibility of re-suspension of contaminated sediments *(Agarwal et al., 2007)*. This method and other physical remediation methods, on stand-alone basis, are therefore not suitable for the large-scale contamination in the Niger Delta.

2.3.2 Chemical Remediation Method:

Chemical remediation method involves the washing of contaminated soils using clean water, reagents, and solvents that can leach the contaminants from the soil *(Yao et al., 2012; Lim et al., 2016)*. This method could be achieved through chemical leaching, chemical fixation, electrokinetic remediation, vitrify technology, chemical immobilization, oxidation, chemical fluid extraction and photo degrading among others. The method is expensive and has the potential to contaminate other environmental media including air and water bodies through the introduction of solvent and reagents during remediation *(Yao et al., 2012).* The approach is fast in clean-up but the harmful wastes generated in the process which includes carbon dioxide and other greenhouse gases are emitted to the surrounding environment.

2.3.3 Biological Remediation Methods:

The biological methods (e.g. bioremediation and phytoremediation) have become of great research interest in the last decade due to their various advantages. Bioremediation is using micro-organism to reduce or break down hazardous organic material to harmless compounds, such as CO_2 and water. Plants and their interactions with micro-organisms (e.g. bacteria, fungi etc) can also help degradation or dissipation of organic pollutants in contaminated environments. Usually, the biological methods are environmentally friendly and retain the quality of environments (soil or water) during the remediation process. Besides, these methods are cheaper than physical and chemical techniques used for remediation.

2.3.4 Phytoremediation:

Phytoremediation involves the use of living green plants or their roots to fix or absorb contaminants from soil. This approach uses enzymes present in plant roots to aid degradation of contaminants. It reduces the concentration of contaminant in soil and consequently reduces risk posed by such contaminants to the environment and human health. Phytoremediation has five approaches which include phyto-stabilisation, phyto-volatilisation, phyto-extraction, phytodegradation and rhizodegradation *(2011; Lim et al., 2016)*. Phyto-stabilisation is the use of plant roots to absorb and precipitate contaminants thereby fixing them to a point and reducing their bioavailability and migration to other ecological systems such as food chain and underground water *(Yao et al., 2012)*. Phyto-volatilisation is the transfer of contaminants (e.g. mercury) to a gaseous state using special matters secreted by plant roots *(Watanabe, 1997)*. Phyto-extraction on the other hand involves the use of tolerant and accumulating plants to absorb contaminants from soil, which are transferred and stored in over-ground parts *(Yao et al., 2012)*. The breakdown of contaminants through the metabolic processes of the plant is described as phyto-degradation. Rhizodegradation entails the degradation of contaminants through enhanced microbial activity in the rhizosphere zone (1–5 mm) of the soil. Generally, the different approaches of phytoremediation have peculiar characteristics that make them appropriate for different soil contaminants.

Despite the benefits of phytoremediation in contaminated land clean-up, there remain a gamut of challenges which have led to continuous search for more sustainable approaches *(Susarla et al., 2002; Sas-Nowosielska et al., 2004)*. For example, specific phytoremediation prescription could not be applicable to diverse site conditions, as concentration levels could be toxic to the intervention plants *(Susarla et al., 2002)*. Phytoremediation is a slow remediation strategy and could only be considered for long-term clean-up. In addition, the approach is affected by external parameters which include type and concentration of contaminants, water content, soil chemical properties and plant resistance to phototoxic effects *(Lim et al., 2016)*, and prevailing ecological and climatic conditions. The primary challenge is to identify and select plant species which could withstand the toxicity of the contaminants *(Peng et al., 2009; Lim et al., 2016)*. This is followed by the bioaccumulation of hydrocarbon in plants. More importantly, plant tissues (e.g. roots) responsible for contaminant uptake must be able to access contaminants in soil; thus, where contaminants have percolated into soil layers out of reach of plant root system the approach might be unviable. Also, safe disposal of used plants is a challenge yet to be resolved in many regions *(Sas-Nowosielska et al., 2004)*.

3.0 BIOREMEDIATION:

Bioremediation is an approach that facilitates the natural biodegradation process of hydrocarbons through the provision of nutrients and oxygen required by microbes. Bioremediation technologies are cost-effective and resource conservative approaches *(Susarla et al., 2002; Lim et al., 2016)*. Three distinctive approaches are adopted in the context of bioremediation, namely, bioaugmentation, biostimulation and bioventilation.

Bioaugmentation is used to enhance the performance of the microbial population through the addition of bacterial with specific catabolic activities, strains or enrichment consortia to increase the rate of contaminant degradation *(Lim et al., 2016)*. One challenge of this approach is that there is no single strain of bacteria that has the requisite metabolic capacity to degrade all oil components. Thus, studies recommend diverse types of bacteria strains and fungi for the remediation of hydrocarbon contaminants *(Lim et al., 2016)*.

The adjustment of environmental parameters such as nutrient introduction, biopolymers and biosurfactants is described as biostimulation *(Jiang et al., 2016)*. The adjustment of these parameters could stimulate the growth of oil degrading microbes and thus the rate of responsive degradation by the microbes. The influence of nutrient amendments had been demonstrated *(Chaîneau et al., 2005)*.

Bioventilation on the other hand involves the addition of oxygen to the soil voids to stimulate the growth of microbes. Oxygen is a necessity and often the limiting factor in the process of biodegradation as it enhances microbial metabolism of organic matter and generate more energy *(Lim et al., 2016)*.

3.1 Bioremediation in Crude Oil Contamination:

Crude oil is a composite mixture of thousands of different chemical compounds. As the composition of each type of oil is unique, there are different ways to deal with them through microbes and flora. Bioremediation of crude oil contaminants can occur naturally or can be encouraged with addition of microbes and fertilizers. The constituents of oil differ distinctly in volatility, volubility, and susceptibility to biodegradation. Some compounds are easily degraded, some resist degradation and some are non-biodegradable *(Mukred et al., 2008)*. The biodegradation of different petroleum compounds occurs simultaneously but at different rates because different species of microbes preferentially attack different compounds. The following have been found to determine bioremediation success of crude oil contaminated sites:

3.1.1 Bacteria

Although, many microorganisms can degrade the crude oil present in the soil, it has been found beneficial to employ mix culture opposed to pure cultures in bioremediation as it shows the synergistic interactions *(Bhakta, 2017)*. Bacteria that can degrade petroleum products include *Pseudomonas, Aeromonas, Moraxella, Beijerinckia, Flavobacteria, Chrobacteria, Nocardia ,Corynebacteria, Atinetobacter, Mycobactena, Modococci, Streptomyces, Bacilli, Arthrobacter, Aeromonas, Cyanobacteria etc(Bhakta, 2017).*

3.1.2 Nutrients:

Microorganisms are present in contaminated soil but not in the numbers required for bioremediation of the site. Their growth and activity must be stimulated. Carbon is the most basic form of nutrient required for living organism. In addition to this, the bacteria also need macronutrient like nitrogen and phosphorous to ensure effective degradation of the oil.

3.1.3 Oxygen:

Although oxygen is not the rate limiting factor, it is one of the most essential elements of microbial degradation of hydrocarbons. Oxygen is necessary for the initial breakdown of hydrocarbons and succeeding reaction may require it. In presence of oxygen complete degradation of oil takes place.

3.1.4 Detergents:

Oils are hydrophobic in nature, their availability to bacteria are limited which leads to the slow degradation. Adding detergent to the oil contaminated soil help in desorbing the hydrocarbon and hence boost up the bioremediation process. Generally, microbiologically produced detergents called rhamnolipids are used.

3.1.5 Environmental Requirements:

Optimum environmental condition for degradation of crude oil contaminants is shown in the Table 1 below:

Table 1: Environmental conditions affecting degradation

Parameters	**Condition required for microbial activity**	**Optimum value for an oil degradation**
Soil moisture	25–28% of water holding capacity	30–90%
Soil pH	5.5–8.8	6.5–8.0

Oxygen content	Aerobic, minimum air-filled pore space of 10%	10–40%
Nutrient content	N and p for microbial growth	C:N:P = 100:10:1
Temperature (°C)	15–45	20–30
Contaminants	Not too toxic	Hydrocarbon 5–10% of dry weight of soil
Heavy metals	Total content 2000 ppm	700 ppm
Type of soil	Low clay or silt content	

Source: *Vidali., 2001*

3.2 Application of Bioremediation on Crude Oil Contaminated Sites:

Bioremediation has been applied in many known crude oil contaminated sites. The effect of bioremediation on these sites are discussed below:

1. *Amoco Cadiz*: This spill happened in March 1978 and contaminated large stretches of the Brittany shoreline in France. Study showed that natural biodegradation occurred rapidly as the microbial population in the region proved that low-molecular weight hydrocarbon degradation could be as fast or faster than chemical evaporation and dissolution. Until that spill, it had been accepted that biodegradation occurred only after a significant lag period, typically of the order of 2-4 weeks, and that chemical and physical weathering of the oil always preceded biological weathering *(Atlas, 1995).*

2. *Exxon Valdez:* The *Exxon Valdez* oil spillage in March 1989 created the largest spill ever with more than 2,000 km of oiled shoreline (*Sugai et al., 1997*). In Prince William Sound, both remediation techniques: seeding with microbial cultures and environmental modification were considered. The seeding with microbial culture technique had challenges in selection of products and natural biodegradation started after a 3-5 day lag period. However, the enhancement of biodegradation through the addition of nitrogen and phosphorus in the form of: Inipol EAP22™, an oleophilic fertilizer formulation, and Customblen™, a granular slow-release fertilizer showed great success *(Pritchard et al., 1992).*

3. *Mega Borg:* This spill occurred off the coast of Texas in June 1990. Application of seed culture produced by Alpha Corporation was reported to be effective in removal of significant amount of oil by the Texas General Land Office although no systematic or independent monitoring was used.

4. *Apex* Barges: Application of seed culture treatment from Alpha Corporation to this spill accident at Galveston Bay in Texas in July 1990 was also reported successful by Texas General Land Office. Independent observation, however, indicated that although the treated oil changed in physical appearance, chemical analysis failed to prove that the product enhanced petroleum biodegradation *(Atlas, 1995; Swannell et al., 1996).*

5. Arabian Gulf War: In the Arabian Gulf, the results have shown that the addition of nutrients and bacteria to oil has enhanced the biodegradation of the *n*-alkane fraction of the oil. Another study concludes that bioremediation could best be carried out by the indigenous microorganisms if they are properly managed, that means that dry habitats have to be watered if necessary *(Radwan et al., 1997).*

6. Goi Community in Ogoniland: Samples of soil from crude oil contaminated area in this Niger Delta community was subjected to application of nitrogen-phosphorous-potassium fertilizer at proper aeration and watering. The result showed that addition of nutrients in form of fertilizer to indigenous micro-organisms has proved to be effective in enhancing biodegradation and environmentally safe. It was also observed that microbes with the capacity to degrade oil are present in lowland environments and environmental parameters besides nutrients affect degradation rates in the field *(Akpan et al., 2013).*

7. Ajoki Community in Ikpoba Okha: The remediation process was done using denitrifying bacteria for 27 days at 7 days intervals. The results show that the remediation method adopted yielded a positive result which, however, reduced the soil organic content, total nitrogen, nitrate and phosphorus (*Imasuen et al., 2014*).

4.0 RESEARCH METHODS

The methods employed in this study are;

i. Comparative study of existing technologies used in remediation of crude oil contaminated soils
ii. Comprehensive literature review showing the impact of crude oil contaminated soil on the ecosystem services in the Niger Delta communities
iii. Appraisal of the studies on bioremediation and its impact on application at both international crude oil spills sites and those in the Niger Delta

5.0 RESULTS AND DISCUSSION

The observed rapid natural biodegradation on Brittany shoreline in France following the Amoco Cadiz spill in 1978 gave an insight into the probability of expedited microbial degradation of some components of hydrocarbon while leaving other components to degrade at slower rate. It revealed that there may not be a lag time before biodegradation starts if the right microorganisms and conditions are present.

During the application of bioremediation on the Exxon Valdez spill of 1989, the technique of seeding with microbial culture was unsuccessful as choice of products was a challenge. However, the enhanced biodegradation through the addition of fertilizers showed great success and therefore validated a new approach to the bioremediation process.

The study on Apex Barges spill showed that bioremediation process could affect the physical appearance of the treated oil without degrading the hydrocarbon. Therefore, clearly designed experiments with appropriate controls are required to evaluate the success of any application of bioremediation.

Studies carried out around the Arabian Gulf showed that addition of nutrients and bacteria to oil contaminants enhanced the bioremediation process. One of the studies showed that indigenous microorganisms if properly manged produced the best results.

The application of bioremediation in Goi and Ajoki communities in the Niger Delta showed that aeration, hydration, nutrients, bacteria and environmental parameters are precursors to the success of bioremediation process. These studies also showed that bioremediation depletes the soil of organic matter, nitrogen, nitrate and phosphorous.

The studies show that bioremediation is a very effective remediation technique for crude oil contaminated soils but could however require use of some class of microorganisms, nutrients, aeration, hydration and in some case application of detergents to obtain the best results.

6.0 CONCLUSION AND RECOMMENDATIONS

Contamination of land with crude oil affects the ecosystem services which nature renders to man and his environment. Several remediation technologies are available for treatment of these lands to return them to original state. However, trial of many of these technologies in the Niger Delta has yielded little or no success due to reasons ranging from soil type to the consequences of use of the technology on the environment. While the remediation by enhance natural attenuation (RENA) method has been unsuccessful due to percolation of crude oil through the mid-soil, the physical remediation methods are labour intensive, expensive and not suitable for large scale contamination as in Niger Delta region and the chemical remediations methods are expensive and could lead to contamination of other environmental media like air and water through the introduction of solvents and reagents during remediation.

Field trials involving bioremediation has yielded positive results. The results from studies and researches taking into consideration the limitations and advantages indicate that bioremediation is the most suitable technology for the clean-up of the Niger Delta crude oil contaminated sites to provide the communities opportunities for ecosystem service once more. This is considered because of the cost of remediation, acceptability, environment friendliness of the technology and the peculiarity of the Niger Delta environment. It is noteworthy however that bioremediation is a site-specific technology therefore treatability studies are highly recommended before full-scale remediation is considered.

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