OIL CONTAMINATION OF LAND IN THE NIGER DELTA REGION OF NIGERIA AND THE ASSESSMENT OF BIOREMEDIATION AS AN EFFECTIVE REMEDIAL SOLUTION

[1*]Chidimma L. Enwere, [2]Aaen Bjorn, [2]Hytiris Nick, [3]Onyiliofor O. Ebube and **[4]Gideon I. Ogu**

[1]Department of Environment and Bioconversion, National Biotechnology Development Agency, Abuja, Nigeria.

[2]Department of Energy and Environmental Management, Glasgow Caledonian University, Glasgow, Scotland.

[3]Department of Project and Operations, Cloudlog Nigeria Limited.

[4]Department of Biological Sciences, Novena University, Ogume, Delta State, Nigeria.

*****Corresponding author's e-mail: chidimmaenwere@yahoo.co.uk

ABSTRACT

Oil contamination is a serious environmental problem and has become unacceptable for the whole world as awareness of its effects on the environment has increased. Unfortunately, it is not possible to substitute all the industrial processes causing environmental pollution with clean alternatives. Therefore, treatment both at source and after release, whether accidental or not, must be considered as alternatives in many cases. This paper evaluates different bioremediation processes to restore land ravaged by oil contaminants. Bioremediation exploits the ability of microorganisms to degrade and /or detoxify organic contamination by carrying out the mineralization of organic chemicals, which results ultimately to the formation of CO_2, H_2O and biomass which are usually harmless by-products. This technique has been long applied as a treatment technology for the decontamination of hydrocarbon-contaminated soils. This is due to its simplicity, higher efficiency, cost-effectiveness and environmental friendly treatment when compared to other technologies. The aim of this paper is to illustrate the use of bioremediation as a sustainable technique for treatment of land contaminated by oil and or its products in Niger Delta of Nigeria.

Keywords: Oil contamination, Oil spill, Environmental Degradation, Bioremediation, Micro Organisms.

1.0 INTRODUCTION

Oil contamination is a major environmental problem which is caused as result of oil operations. Activities of oil companies constitute environmental problems; with substantial implications for economic development and human health. As a result of its impacts some individuals live as aliens in their own communities, where they are unable to actualize their interest or aspirations. This is the problem of the people of Niger Delta in Nigeria which contains the bulk of Nigeria's proven oil and gas reserves. The region is ridden with environmental problems, ranging from devastation of land and water (crippling income generation through farming and fishing), through death of thousands of domestic animals, disastrous fire out-breaks, various illnesses to deaths. These have led, to political unrest, with the people of the area feeling exploited and calling for reparations. Despite several indications of the environmental degradation and health effects caused by oil contamination of land in the Niger Delta region, little attention has been paid to investigating the effectiveness of the use of bioremediation in this region. Undertaking an evaluation of a selection of case studies could provide better insight if bioremediation is the appropriate solution to oil contaminated land in the region.

2.0 JUSTIFICATION OF THE STUDY; OVERVIEW OF THE DAMAGE IN THE NIGER DELTA

Oil and gas activities as well as enormous oil installations deployed in the Niger Delta explains her vulnerability to oil contamination. The social and environmental costs of oil contamination have been extensive. These include destruction of wildlife and biodiversity, loss of fertile soil, pollution of air and drinking water, degradation of farmland and damage to aquatic ecosystems, all of which have caused serious health problems for the inhabitants. Oil spills in the Niger Delta have reduce nutrient value of the soil, induce land fragmentation and sets communities on fire. For example, a spill at Osima creek in Agbakabiriyai, near Nembe on February 28th 1998, led to eight days of fire, which razed down the entire community. This resulted to the destruction of about 400 houses, and the displacement of about 130,000 inhabitants (Olukoya, 2002). Also a spill that occurred on 7th December, 2008 in Ikarama community terribly caught fire on 1st of March 2009. The fire caused more damage to the environment (www.eration.org/index.php?). Given these challenges, land as an economic power resource base becomes critical for the Niger Delta region.

Without fertile soil and good water, indigenous communities in the region lose their mode of survival and are faced with the crisis of food shortages. Due to oil spillage, many water ways, land and marine systems in the region have been badly polluted and residents have been badly affected by environmental damage. Fishing, a mainstay of the region economy has been reduced in both fresh water and marine ecosystems. Forests and agricultural land have been damaged by chronic spills and atmospheric pollution leading to low agricultural productivity. In Oloibiri, farming and fishing which used to be the mainstay of the community's economy has been paralyzed, as farmlands have been destroyed, fishing activities grounded and aquatic life almost castrated by many years of oil prospection and exploration (Opukri and Ibaba, 2008).

Borrow pits in the Agbada field and contaminated soil in the Elelenwa field caused loss of soil fertility in these areas. The people are giving up their traditional occupation due to the destruction of the river and land by oil spillage. The immediate effect is the destruction of crops and plants and in the long run it reduces the nutrient value of the soil. The people in the region are exposed to number of health hazards. Researchers stated that oil spillage in the oil rich Niger Delta region of Nigeria has been linked to greater risk of developing different types of cancer due to exposure to oil pollutants (The Guardian, 2009). The researchers further demonstrated that other associated health effects include headache, light-headedness, loss of appetite, poor coordination, damaged kidneys, increased blood pressure and irritation of the eyes and skin. Also, persons with respiratory problems such as asthma are more susceptible to illness from oil exposure.

3.0 SOLUTION TO THE PROBLEM

Oil contamination is complex and heterogeneous in its distribution and its volume is often hard to estimate thereby constitute a difficult problem. Indeed, oil intoxicates the soil ecosystem; pollute the groundwater and foul walls of nearby buildings. Solutions to the problems require a multi-disciplinary approach during investigation, risk assessment and consideration of remedial actions. Remediation of oil contaminated land is widely acknowledged as a complex and major challenge for modern society. In this era, any remedial action must focus on sustainable solutions, which will restore the usability and economic value of the land. The solution must guarantee that the land is suitable for its use and is sustainable from an environmental and socio-economic point of view.

3.1.0 Bioremediation

In order to provide a sustainable solution, a technique has been proposed, by which a remediation may be carried out more directly by fostering the growth of macro organism capable of degrading targeted oil contaminant. Bioremediation is the use of biological treatments, to treat a wide range of contaminants, including petrols, oils, tars, etc.Thus microorganisms can by their biodegradative activities convert the hydrocarbons completely to CO_2, H_2O and biomass. They may be indigenous to the contaminated land or introduced to carry out the bioremediation.

3.1.1 Case studies of bioremediation

3.1.1.1 Case study 1 (Natural Attenuation)

Natural Attenuation is under the right circumstances, a more cost effective and ecologically sound to leave oil-contaminated sites to recover naturally than attempt to intervene. It relies on natural processes to achieve site-specific remedial objectives. A farmland settlement contaminated with crude oil located in Rumuekpe, Rivers State, Nigeria, was used to investigate the applicability and effectiveness of natural attenuation processes in the removal of crude oil hydrocarbon pollutants in the Niger Delta environment (Ehuebi et al., 2005). The soil sample was sandy soil and various operations were employed and these include:

Spiking of the soils with water uniformly to soften the soil and to allow the water penetrate the soil matrix. After that, the soil was tilled uniformly to distribute the petroleum contaminants and break up the soil lumps to fine particles thereby increasing the surface area.

Also, windrows were constructed and levelled after 3-4 weeks. These were constructed to achieve better aeration and optimize the efficiency of the attenuated processes, this exposes the microorganisms to oxygen, and aids in the biodegradation process of the petroleum hydrocarbon (Onifade et al., 2007). Water and fertilizer were added to the sandy soil to enhance the biodegradation of the petroleum hydrocarbons by the microorganisms when it penetrates the soil.

The farmland which initially has the concentration of 1.10×10^4 mg/kg of the total petroleum hydrocarbon was reduced to 282 mg/kg after 10 weeks. No significant degradation was observed after the 10^{th} week. This could be that the nitrogen and phosphorous concentration could no longer support the biodegradation.

In general, it is limited to the treatment of superficial 10 - 35cm of soil. The process reduces monitoring, clean-up liability and maintenance costs, although the cost of remediation is not stated. However, this technique often takes a long time to complete because of population size of the indigenous degrading microorganisms is low (Olaniran et al., 2006). Although it takes time, Abu and Dike (2008) argued that depending on location and sensitivity, it is more cost effective and ecologically sound to leave oil-contaminated sites to recover naturally than attempt to intervene. This technique relies on natural conditions and behaviour of soil microorganisms that are indigenous to soil.

3.1.1.2 Case study 2 (biostimulation)

This field pilot was undertaken in 2005 at a crude-oil polluted agricultural site in Port Harcourt, Nigeria and the experiment was carried out for the period of six weeks (Ayotamuno et al., 2006a). The oil contaminated soil from the site was divided into six soil sample cells. These cells inhibited excess runoffs of the crude-oil contaminant: as such run-offs were inevitable since the remediation treatment took place during the rainy season (June – August). The surface area of the soil within the cells was exposed so that the soil temperature, nutrient concentration, moisture content and oxygen availability could be controlled. The soil is normally moisture laden due to the high annual rainfall in the area. Different amounts of fertilizer as nutrient and equal rates of tilling were applied to soil. The following quantities of fertilizer 100g, 150g, 200g, 300g and 400g were applied to A, B, C, D, E respectively and the control O with no fertilizer. The various soil cells were tilled twice a week.

After the six weeks of total remediation, the results indicate that the application of nutrients (fertilizers) lead to high rates of biodegradation of petroleum-polluted agricultural soils.

There was a distinct decrease in the percentage of the Total Hydrocarbon Content (THC) in all the soil samples in the cells except in the control cell, for which the THC increased. The percentage THC reductions for the treatment cells were 95%, 93%, 92%, 63% and 50% for cells A, B, C, D and E, respectively. The results indicate that applied fertilizer increased hydrocarbon degradation since hydrocarbon content of the control cell, which did not received fertilizer treatment, was on increase. The cost of remediation is not stated.

3.1.1.3 Case study 3 (A combination of bioaugumentation and biostimulation)

Another crude oil contaminated site located along the New Calabar River in Rivers State in the Niger Delta Nigeria was remediated using bioremediation for a period of 20 weeks described that site is a tidal plain, dominated by mangrove swamp and composed of organic soil which are moist and saline (Odokuma and Dickson, 2003). The field experiments are as follows;

A combination of bioaugumentation (addition of external indigenous microbial populations) with hydrocarbon utilizing indigenous bacteria and biostimulation (addition of appropriate microbial nutrients) with agricultural fertilizer and tilling were employed as remedial options in a crude oil polluted tidal plain dominated by mangrove vegetation.

Six soil samples designated C_1, C_2, E, A, B and D were employed and these include; A (biostimulation, bioaugumentation and tilling), B (bioaugumentation and tilling) and D (biostimulation and tilling), C_1 (uncontaminated soil from a different location), C_2 (contaminated soil from the same location without remediation treatment) and E (tilling alone). Agricultural fertilizer NPK 15:15:15 was applied to the cells and these provide them with nitrogen, phosphorous and potassium nutrients. These soil cells were tilled daily to provide maximum aeration and adequate mixing of nutrients and microbes. Thus there was an increase in the hydrocarbon utilizing bacterial counts for all treatment options throughout the remediation period. After the period of 20 weeks of remediation process, the recorded percentage hydrocarbon reduction for the various treatment options were 36, 63, 65,76,82 and 84 for $C_{1,}$ E, C_2 , B, D and A, respectively. This increase was greater in option A, B and D. Option A (84%) and option D (82%) recorded higher levels of hydrocarbon loss than the other four options B (76%), C_1 (36%), C_2 (65%) and E (63%). The cost of remediation is not stated.

3.1.1.4 Case study 4 (phytoremediation)

The field experiment was undertaken at a petroleum site in Port Harcourt Rivers State in 2005. The field pilot was carried out to assess the potential of phytoremediation to degrade petroleum hydrocarbons in the Niger Delta region of Nigeria. Z. Mays (corn) and P. purpureum (elephant) which are common tropical plants were utilized for phytoremediation treatment in the area (Ayotamuno, 2006b).

They further described that the field plots involved six field plots that were made into beds. These beds control the exposed surface area of the soil, the nutrient concentration, as well as temperature and oxygen availability. They also served to prevent excessive runoff of the contaminant, which is a common trend in the locality sequel to the large volume of rainfall and the nature of the soil. The six field plots designated A, B, C, D, E, and O. Where Plot O is the control site (with no treatment), plots B and E received elephant grass treatment, plots C and D received corn treatment, while plot A had a mixture of corn and elephant grass growing on it.

These plots were tilled to allow for easy penetration of plant roots and infiltration of the crude oil contaminant. Thereafter NPK fertilizer was applied to the treatment plots in order to provide nitrogen, which is a major limiting nutrient in the growth of soil biota. The environmental parameters, moisture content, pH and electrical conductivity were fairly stable.

After six weeks of the remediation process (June to August), recorded percentage of Total Hydrocarbon Content (THC) reduction were 67.5, 55 and 74% for corn, elephant grass and combination of corn and elephant grass treatments respectively. The trend of the results suggests that if the experiment continued for a longer period, more of the contaminant would have been degraded. The cost of remediation is not stated.

3.2 Comparison analysis for bioremediation methods

To determine the effectiveness of different bioremediation processes described in the case studies, a comparison analysis of the different bioremediation processes as described in the case studies is used. Eight criteria stated below were used to evaluate these processes (Rushton et al., 2007).

Table 1 Evaluation criteria for bioremediation processes

Criteria	Definition	Score
Efficiency	95-99% removal warrants 20	20
Time	Removescontaminants within weeks	15
Cost	Relatively inexpensive	15
Maintenance	Easy to maintain	10
Simplicity	Easy to operate	10
Practical applicability	Used under various situations with no or little modification	10
Cleanliness	Pollutants are not transferred to other locations	10
Control	Need for pH, temperature or moisture control	10
Score		100

Table 2 Assessment processes as indicated by case studies

Criteria	Biostimulation	Natural attenuation	Phytoremediation	Mycoremediation	Combination of bioremediation processes	Bioaugmentation
Efficiency	18	12	15	13	20	18
Time	15	12	12	10	15	15
Cost	-	-	-	15	-	-
Maintenance	8	10	10	7	10	8
Simplicity	10	10	10	8	8	7
Practical Applicability	10	8	8	7	10	8
Cleanliness	10	8	8	7	10	10
Control	10	10	10	10	10	10
Scores	**81***	**70***	**73***	**77**	**83***	**76***

Source: Author

Note: *Score does not include for cost

The advantages and disadvantages of the various bioremediation processes used on different oil contaminated sites as described in the case study form basis for the comparative analysis performed on bioremediation processes. Eight criteria as illustrated in table 1 above by Rushton et. al. (2007) were used to evaluate these processes. Table 1 shows the definition and scores assigned to these criteria. The final results of the comparative analysis are shown in Table 2 and all except one of the processes were evaluated without cost as this was not available. But even without cost most of the processes showed above 70% effectiveness. Among the bioremediation processes evaluated, the biostimulation and combination of processes showed the highest score.

3.3 DISCUSSION OF THE CASE STUDIES

The biodegradation of oil contaminants is not a new concept as it has been intensively studied in controlled conditions and in open field pilot experiments. The technique has acquired a new significance as an increasingly effective and cheap cleanup technology with the success it recorded in the cleanup of the Exxon Valdezoil spill of 1989 in Prince William Sound and the Gulf of Alaska. Since then, the technique has also been successfully applied in various places as highlighted in the case studies discussed above.

However, the successful application of bioremediation depends on appropriate hydrocarbon-degrading microorganisms and environmental conditions of the site.

The results of *case study* 1 and *C2 in case study 3 (*natural attenuation*)* indicate that remediation of an oil polluted soil can be achieved through natural processes of biodegradation without external interference. These revealed that there is higher Hydrocarbon Utilizing Bacteria (HUB) in crude oil polluted soil. This could be as a result of high moisture content in the Niger Delta of Nigeria which favours the microorganisms since favourable moisture is required for their growth and function. Ijah and Abioye (2003) in a similar observation pointed out that high HUB may be due to the presence of residual crude oil in the polluted soil which boosts the carbon supply in the soil and favours the growth of the hydrocarbon utilizing bacteria.

The high rate of hydrocarbon loss may possibly be attributed to favourable conditions of temperature, pH and sufficient metabolic nutrients. According to United States Environmental Protection Agency (EPA) (2006), optimal biodegradation of hydrocarbon occur at pH 7 although acceptable range is 6-8. The Agency further stated most bacteria in the soil that degrade hydrocarbon are mesophiles which have an optimum temperature between the range of 25°C to 34°C.

The comparison analysis shows that this process account for over 70% hydrocarbon loss without cost being evaluated. Therefore, natural attenuation could be viewed as a viable treatment option in sensitive environments when time is not a constraint and no imminent danger to the receiving environment or valuable natural resource such as water sources.

In some sites where natural communities of degrading microorganisms were present in low numbers or even absent, bioaugmentation, i.e., the addition of contaminant-degrading organisms, was employed to speed up the degradation process. Like in *case study 3 option B,* the process recorded approximately 76% of the hydrocarbon loss. This suggests that the process has been effective in the Niger Delta region. The high efficiency of bioaugmentation in this field experiment could be as a result of the adding pre-selected hydrocarbon degrader and favourable environmental condition. These increased the microbial activity and consequently, give high hydrocarbon loss as shown by the result of the case study. These microorganisms like bacteria, saprophytes, etc. have efficient ability to utilize the residual crude oil as their source of carbon and energy (Ijah and Antai, 2003).

However, there have been some arguments that in the field, bioaugmentation of contaminated soil has been less effective. Selecting and culturing organisms directly from the local site have shown to give the best results (Bento et. al., 2005). Indigenous microorganisms are well adjusted to their own environment and that the immediate increase in the population density of these microbes ensures rapid degradation of the pollutant (Gallego et. al., 2001). With increased inspecific microbial community and nutrient addition, this approach significantly reduces cleanup time.

From the case study, we would suggest that the best bioaugmentation performance can be achieved by the use of microorganisms that are already present in the soil.

The results of the case studies suggest that biostimulation has been successfully used in remediating the contaminated soil in the Niger Delta. The result of *case study 2* shows that it accounts for over 80% rate of degradation. Adequate supply of nutrients is essential for increased activity of microorganisms since nitrogen, sulphur, and carbon are essential elements for cellular metabolism in microbial life. These nutrients provide microorganisms with a favourable environment in which they can effectively degrade contaminants. Lack of these nutrients limits growth and activity of microorganisms as well as the rate of degradation. The results demonstrate that application of nutrients like fertilizer enhances the growth of hydrocarbon degrading organisms and as a result cause rapid remediation process. Some of these like ammonium nitrate is used as agricultural fertilizer and are readily available in large quantities. It is very cheap to buy and easy to apply.

However, excessive nutrient concentrations inhibit the biodegradation activity. For example, in case *study 2* where different quantities of 100g, 150g, 200g, 300g, 400g of fertilizer were added to different soil samples. The recorded percentage result of hydrocarbon losses were as follow 95%, 93%, 92.3%, 63% and 50% respectively. It is evident, from the result that different concentrations of fertilizer affect the rate of degradation. Soil sample that received the highest amount of fertilizer gave the least degradation rate. A similar behaviour in a field experiment was observed and reported that this could be due to the retardation of microbial activity resulting from the high concentration of ammonia gas released from the fertilizer (Dorn and Salanitro 2000). This consequently causes a drop in pH which results to low degradation. This implies that the higher the quantity, the lower the rate of degradation. This demonstrates that to achieve the optimal degradation rate, the right quantity of nutrient must be added. This also suggests that a trial test should be done in a small scale before carrying out the experiment in the field.

Care must be taken to avoid applying more nutrient than required by the degrading organisms for the degradation of the petroleum hydrocarbon. Research has shown that adding small amounts of nutrients continuously or at intervals to maintain an appropriate level would allow optimal conditions to be maintained. This will help to prevent leaching out to groundwater. The results of biostimulation process illustrate that it is cheap since the cost of nutrients is significantly less and no continuously operating equipment is required. The comparison analysis indicates that the process is effective since it accounts for over 80% hydrocarbon loss.

The result of the *case study 4* indicated that the use of phytoremediation in oil contamainted soil gave over 70% of hydrocarbon loss within six weeks. The result illustrates that phytoremediation treatments involving a combination of both plants thrive better than the ones involving one type of plant.

The use of phytoremediation on a spill site in Ogbogu and Port Harcourt imply that with selected plants that tolerate oil and whose roots are associated with oil degrading microorganisms, oil contaminated soil can be remediated. Research Studies have shown that hundreds of millions of oil-utilizing microorganisms are associated with roots. The microorganisms take up and metabolize hydrocarbons quickly and this helps detoxify and remediate the soil. To achieve optimal remediation environmental factors such as temperature, pH, moisture content and redox status must subject to conditions that are highly favourable for biological activity.

The field experiment results indicated that several methods like tilling, watering and addition of organic materials (straw, compost, etc.) could decrease the contamination level. These operations and conditions facilitate the oxidation of easily degradable petroleum components, as well as contribute an increase in microbial activity. For example in *case study 3***,** option E where only tilling was applied, recorded hydrocarbon degradation of 63%. For this to occur, certain conditions should apply, such as pH, moisture content and a tillage rate of between 2 and 5 times a week (Odokuma and Dickson, 2004). This suggested that only tillage of the hydrocarbon contaminated soil with controlled environmental condition accounts for over 60% degradation. This rate of degradation is acceptable and it implies that more than half of the oil contaminated soil has been treated and little quantity is sent to landfill.

The combination of biostimulation and bioaugmentation gave the highest microbial population within the period of 20 weeks of the remediation process. In most sites, the employment of a combination of bioremediation technique displays a higher rate of degradation. For example, results of *Case study 3* indicates that higher rate of oil degradation was obtained when different bioremediation processes are combined and this recorded over 80% of hydrocarbon loss. Thus, confirming the significant effectiveness of the combination of bioremediation processes in the degradation of hydrocarbon.

The results indicate that microorganisms and nutrients (combination of biostimulation and augmentation) are utilized under some specified conditions to ameliorate the negative effects in a cost-effective and environmentally friendly approach within an appreciable time-scale. Although there have been some arguments that bioremediation takes long time. *The case study 3* illustrated that addition of adequate supply of proper nutrients and microorganisms ensure rapid remediation.

From the results, it could be said that if the experiment had continued for a longer period, more of the contaminant would have been degraded.

The final results of the comparative analysis in *table 4* shows the scores of different bioremediation processes discussed above. The analysis gives an insight of the effectiveness of different bioremediation processes. Among these processes combination of bioremediation processes scored the highest (83%) followed by biostimulation (81%). Other processes like phytoremediation, bioaugmentation, mycostimulation scored 73%, 76%, 77% respectively. Thus, whatever process in bioremediation technology employed for remediation, it is an effective, cheap and environmental friendly alternative to conventional remediation methods. These processes are aesthically pleasing environmental pollutant removal as well as lesser financial commitment. While using these bioremediation processes, costly transport or processing of hydrocarbon contaminated soil is not encountered, since the treatment processes are accomplished on-site. Also the legal problems associated with transport of hazardous waste to hazardous waste processing site are avoided completely.

It could be reasonable to say from analysis and case studies that all the bioremediation processes are effective in Niger Delta

To know the bioremediation process to employ, understanding exactly the hydrocarbon contaminant (fuel, diesel, etc.), the temperature and pH of the soil are very important as this will help to achieve a perfect remediation.

Although there have been secondary air pollution associated with this technique and this include dust and odour but these have been managed effectively by environmental experts..

For example, in remediation of former shell oil storage depot westerhill Road Bishopbriggs by Luddon construction Ltd as reported by IKM consulting Ltd. The site is close to commercial and residential development. Odour generated from the hydrocarbon contamination site was an issue and the wind blows it over the site on to these areas.

Luddon Company managed the odour with Odour Suppression Units on site which are portable and moved daily to suit wind direction. These units spray out a diluted fragrance to mask the odours.The company use odour suppression units which have an added benefit of water spraying thereby offering assistance in dust management. Also, the dust was controlled by use of Road Sweeper (Unpublished).

4.0 CONCLUSION

The main thrust of the study is to suggest bioremediation as an effective solution in the Niger Delta of Nigeria. The findings of the study showed that bioremediation is very effective in the region. Various soil remedial options are available and have been considered to restore oil contaminated soil in different sites in different parts of the world and in Nigeria.

Thus, the associated health and environmental effects of the physicochemical approach are currently directing greater attention to the exploitation of the biological alternatives. The main reasons for this are:

- The simplicity of biological configuration has made it a promising and effective technique. For example, if the use of bioremediation requires meeting a certain minimum rate, adjustment of conditions to improve biodegradation activity becomes essential and bioremediation configuration makes this control possible.

- Bioremediation processes do not involve the use of sophisticated equipment and the use of chemicals. They eliminate or transform the oil contaminant by use of biological processes to relatively harmless by-products such as water and CO_2. As a result of such factors and others, these bioremediation processes have received considerable attention and have demonstrated their effectiveness and sustainable abilities in remediating oil contaminated soils.

Considering the case studies, it was possible to stimulate the indigenous microbial population and sustain an active hydrocarbon degrading microbial count by supplementation of inorganic fertilizer, moisture content, and soil mixing for ensuring sufficient aeration. Under these controlled conditions, the results of case studies indicated that bioremediation has reduced oil contamination of soils by over 80%. As with any biochemical reaction, hydrocarbon biodegradation rates are heavily dependent on chemical and physical conditions such as pH, moisture content and temperature, as well as availability of microorganisms.

The result of the comparison analysis (table 2) indicates that all processes of bioremediation are effective under these controlled environmental conditions since each process accounted for over 70% hydrocarbon loss.

As previously discussed, there is an urgent need to implement the most appropriate remediation techniques on a large scale in the Niger Delta region of Nigeria.

Based on the success of the case studies on bioremediation recorded by the various studies which are highlighted above, it is of the authors' view that this technology should be encouraged and implemented in the Niger-Delta region of Nigeria.

It would be reasonable to state that bioremediation represents a cost effective and environmentally-friendly technology for hydrocarbon contaminated site restoration which can be applied over a wide variety of environmental setting. Also, it appears to be the most acceptable technology that can meet up with the regulations that govern clean up of oil-polluted sites. However, all aspects of bioremediation should be integrated with respect to the site in question for rapid and effective remediation and monitoring should be an integral aspect of any bioremediation project.

A prerequisite for this to be successfully achieved is the creation of favourable conditions within the soil environment, such as adequate nutrient supplementation and oxygen availability, for the proper development of soil microbes and plant utilization of the contaminant for their metabolism.

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