Bioremediation of Hydrocarbon Polluted Soil in the Barrier Island Forest Ecosystem in the Niger Delta through Enhanced Natural Attenuation Process (ENAP)

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Abstract. Environmental damages resulting from oil exploration and production activities has been witnessed over the years in the Niger Delta region. Soil productivity in the Island Forest Ecological Zone was investigated to establish the impacts of oil spills on this ecological zone and remedial actions to help the zone recover. Remediation by Enhanced Natural Attenuation Process (ENAP), was found to be most environmentally friendly and cost effective technology to handle the pollutions in this ecological zone of the Niger Delta region. This technology facilitated the program of microorganisms to biodegrade the hydrocarbon impacted soil. The study focused on the bio-physicochemical parameters of the oil spill polluted soil with particular reference to areas of oil production of the Island Forest Ecological Systems with those of the unaffected soil as well as their response to bioremediation interventions using ENAP. The outcomes showed clearly significant decrease in the values of the key indicator parameters, such as the Total Petroleum Hydrocarbons (TPH). But for the unenhanced process, the outcome showed low level of reduction of TPH values for the polluted soils. A degradation trend was shown with time leading to significant TPH reductions and improved key soil productivity indices. The outcome showed that the level of the nutrient status of soil in the region can be improved through the natural attenuation methods.

Key Words: bioremediation, hydrocarbon, soil, Island, ecosystem, natural, attenuation

Introduction

The release of oil into the environment constitutes serious soil damage in the Niger Delta. The area is devastated and currently faces series of ecosystem depletion as most soil flora and fauna are destroyed and extinct. Oil spills from the activities in the oil industry in the region affect the environment in the operational areas where the oil facilities are situated, right of ways (ROW) and third party areas. These are caused from equipment failures, leaks from corroded equipment and vandalisation (sabotage) etc. The spilled crude oil from the source, through a meandering transportation mechanism and exposure pathway, gets to the receptors which are - soil, vegetation, surface and ground water, marine environment, animals and humans - and pollute the environmental media. Soil productivity, measured by physical, chemical and biological parameters, is adversely affected.

The impacts include loss in the productive capacity of soil, with implications on living organisms and economically on the people in the polluted area, and consequently high poverty rate and unemployment among the people. This study focused on the application of enhanced natural attenuation methods in the remediation of oil polluted soil in the Island Forest Ecosystem in the Niger Delta. It examined the effect of oil pollution on soil productivity in the region, examined the relationship between soil temperature and oil pollutants in the polluted soil in the study area, determined the effect of enhanced natural process of bioremediation on soil fertility improvement and compared the differences between the enhanced and unenhanced remediation in the study sites.

Literature Review

Several works have been done on hydrocarbon polluted soil studies. The studies include the effects of oil spillage on soil; Abii and Nwosu (2009) and Aghalino (2000) on the negative impact of oil activities on wild life, soil, air, water and the ecosystem of communities.

The oil pollution effects include brownish vegetation and soil erosion, diminishing resources of the natural ecosystem, fertile land turned barren and adverse effect on the life, health and economy of the people. In Amadi and Ue Bari (1992) study in the rainforest ecosystem in Nigeria, soil and microbiological properties were evaluated 17 years after oil spillage to assess the effects of oil and interrelationship between the hydrocarbon utilizing and nitrifying micro-organisms. The study showed that organic carbon, total nitrogen, carbon/nitrogen ratio, available phosphate and exchangeable potassium were high at moderate and high impacted zones. Also the distribution of aerobic petroleum hydrocarbon utilizing fungi and bacteria showed a lesser condition at the moderately impacted zone than at the highly impacted zones.

The effect of crude oil pollution on soil productivity and the growth of plants and uptake of nutrients were investigated by Agbogidi, Eruotor and Akparabi (2007) by growing corn on a soil polluted by crude oil. The soil was analyzed for organic carbon, total and available nitrogen, extractable phosphate, and exchangeable potassium, calcium, iron and manganese after each cropping. It was observed that germination and yields were drastically reduced as the level of pollution increased. At 4.2 percent crude oil pollution level, the average reductions were 50 percent in germination and 92 percent in yield. The amount of organic carbon, total nitrogen, extractable phosphate, and exchangeable potassium, iron and manganese increased in the soil with level of crude oil addition, while extractable phosphate and exchangeable calcium were reduced. The poor growth was attributed to suffocation of plants caused by exclusion of air by oil and exhaustion of oxygen by increased microbial activity, interference with plant-soil-water relationships and toxicity from sulfides and excess manganese produced during the decomposition of the hydrocarbons.

Also Wokocha, Emeodu and Ihenko (2011) examined the impact of crude oil spillage on soil properties and food production in Ogba/Egbema/Ndoni Area in Rivers State, Nigeria. The results showed that the pH status of soil in heavily contaminated and moderately contaminated zones varied from acidic (pH 4.0) to neutral (pH 6.0). The chemical properties of soil indicated that percentage organic matter increased from 1.34 to 2.62, available phosphorus decreased from 15ppm in control to between 7.34 and 5.42 in soil polluted with high level of crude oil. The result was in line with Amadi and Ue Bari (1994), and Ogboghodo, Osemwota, Iruaga and Chikor (2000).

Andrade, Cavelo, Vega and Marcet (2004) in an experiment on the effect of prestige oil on salt marsh soils in the coast of Galicia (Northern Spain) revealed that oil pollution altered both physical and chemical soil properties, lowered porosity, and increased resistance to penetration and hydrophobicity. The crude oil spillage affected the physical, chemical and biological properties of soil, resulting in low food production by reducing the nutrients availability in the soils through increased soil acidity and toxicity of crude oil fractions. The experiment on the effect of poultry manure on maize planted on crude oil polluted soils showed that percentage growth rate in plant height and yield decreased with increase in crude oil contamination (Ogboghodo, 2004).

Crude oil spillage has effects by suppressing seed germination, regeneration and caused cellular and stomata abnormalities (Gill and Sandota, 1976). Ekundayo, Emede and Osayande (2001) confirmed that in crude oil polluted soils, possibility of grain yield is significantly reduced by 95 percent compared with the yield in the control. In a study of agricultural land in an oil producing area around Qua Iboe River in the Eastern Niger Delta, the fouled loamy soil samples polluted by crude oil were treated using chemical degreasers and detergents (Essien,

et al, 2010). The result of the treatments showed a significant effect on soil properties and crop growth parameters; however recovery level was significantly higher than the level of degradation, except in infiltration rate. Soil pH increased by 26% in fouled soil, attributed to bacterial biodegradation of crude oil under the anaerobic conditions present in the soil macro and micro-pores, and indicated the tendency of crude oil spills to buffer acidic soil to neutral. Hydraulic conductivity with 45 – 67% reduction from 82.24 cm/day in the control soil to 39.6 cm/day in polluted soil confirmed the blockage of polluted soils micropores by oil films. Crop growth, indicated by root elongation, diminished to 7.4 ± 0.64 cm in polluted soil compared to13.47 ± 6.40 cm in the control soil.

Daniel-Kalio et al (2006) worked on the effect of Bonny Light Crude oil pollution on soil and successive plantings in the same soil at 4 – week intervals on the growth of dayflower (Commelina benghalensis L.). The factorial sets of treatments were two levels of oil pollution (0 and 50 mg/g) and 5 successive plantings. Characteristics assessed were mean plant height, leaf area per plant and mean dry matter weight. At each of the 5 cropping, mean plant characters assessed were significantly higher at 0 mg/g oil pollution than at the 50 mg oil/g soil pollution level. The result of the investigation confirmed the effects of oil polluted soil on plant growth. Gill and Sandota (1976) examined the effect of crude oil on the growth and anatomical features of Chromolaena odorata. In the investigations the effects of Forcados Blend crude oil on crops, three concentrations (25.0 cm^3, 50.O cm^3 and 75 cm^3) applied to soil were found to suppress seed germination and regeneration; and caused cellular and stomatal abnormalities on the leaves of Chromolaena odorata. The result showed that oil pollution affected the rate of plant germination and growth.

Oil release into the environment, whether acute or chronic, has deleterious effects on agricultural lands and hence significant effects on plant growth (Agbogidi et al., 2005, 2006, 2007). Benka-Coker and Ekundayo (1995) reported that oil pollution tends to change the physical, biological and chemical properties of soil, thus affecting plant growth. Oil pollution has also been reported to create conditions in soils which make some essential mineral nutrients unavailable to plants and some non-essential minerals to appear and rise to a toxic level (Siddiqui & Adams, 2002).

Study Area

The study was carried out in the Bonny Oil Terminal Tank Farm Area of Shell Petroleum Development Company of Nigeria Limited. Bonny is a community with oil production and storage facilities, in the Barrier Island forest ecological zone of the Niger Delta. The soil in the study area was heavily polluted by hydrocarbon arising from leakages.

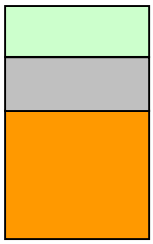
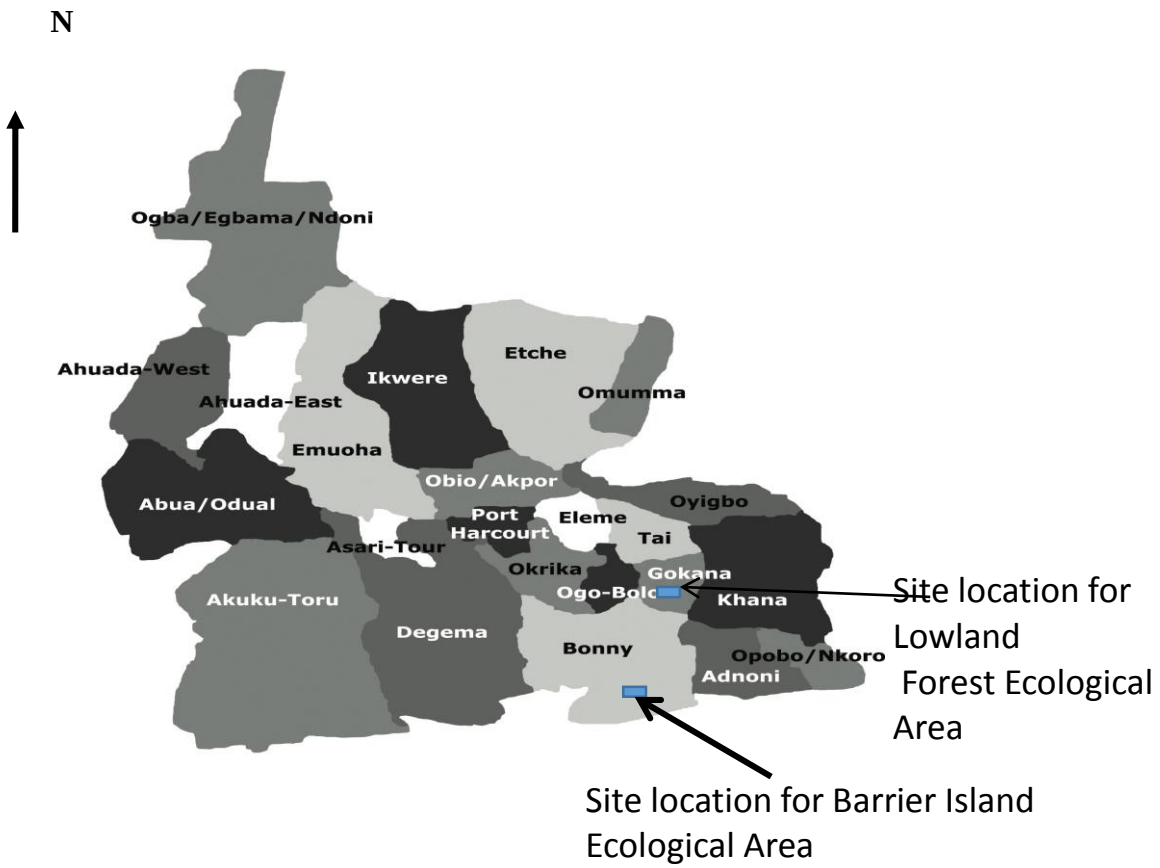


Figure 1. Site lithology
Source: Field Investigation

The distribution of soil in the area below 2m is sandy clay. Bonny Island is approximately 40 km South of Port Harcourt, Nigeria. Bonny Island lies between 4°52′N to 5°02′N and longitudes 6°56′E to 7°04′E within the Beach ridges onshore geomorphic sub-environment of the Niger Delta (Figure 2).



Scale: 1cm = 13km

Figure 2. Map of rivers state showing the study areas

Source: Rivers State Ministry of Urban Planning (2010)

Methodology

Source of data is mainly primary source. Soil sample was collected from some selected sites in the study area. Secondary data were obtained from literatures from University of Nigeria Enugu Campus (UNEC) library, University of Port Harcourt library, Shell Petroleum Development Company, Agip Oil Company, Rivers State University of Science and Technology, Port Harcourt.

Sample Frame and Sample Size

The study area was also delineated into heavily polluted and medium polluted sections. Five composite samples were obtained from each section at random at depth of 0-15 cm (topsoil) and at depth 15-30 cm (sub-soil) respectively. Again the five samples were bulked up and a representative sample of the soil mixture obtained for laboratory analysis.

Sample Collection Procedure/Strategy

The sampling area for the Barrier Island Ecological area was $20x10m^2$ which was further divided into 25 grid plots, each measuring $2 \times 4m^2$. The same area was measured out for the Lowland Forest Ecological area and the control section.

The samples were mainly soil samples collected randomly at depth of 0-15 cm (topsoil) and at depth 15-30 cm (sub-soil) respectively.

Sampling Techniques

The planned sample protocol was such that, samples were collected to reflect the heavily polluted areas and the medium polluted areas. All the necessary quality control measures were observed in the collection process.

The main sample type was soil samples. It was ensured that after sampling a particular section, the hand auger used for sampling was washed thoroughly using clean water, to free it from contaminants, before sampling other sections.

Five samples were collected randomly from each sampling grid plot of each ecological system, from each depth of 0-15 cm (topsoil) and at depth 15-30 cm (sub-soil) respectively. The samples were then bulked up to obtain a representative sample from the range 0 to 30cm. The samples were carried in aluminum foil containers, placed in a cold cooler for transport to the laboratory for analysis. Time interval between sample collection and transport to the laboratory, was within 2 to 4 hours to preserve the samples integrity.

Treatment

The same area was measured out for the control. In each treatment plot, the soil was tilled and nutrient amendment, sodium-phosphate-potassium organic fertilizer application was done manually by sprinkling. The soils were further tilled by harrowing and then spiked with water uniformly to soften them and allow the water penetrate the soil matrix. They were tilled in a week after they were spiked. Composite samples were collected and sent to the laboratory for physiochemical and microbial evaluation. The soils were tilled again and homogenized a week after the initial tilling to uniformly distribute the petroleum contaminants and break up the soil lumps to fine particles thereby increasing the surface area. Windrows/ridges were constructed after the secondary tilling of the test site.

The ridges measured about 2 feet high and 4 feet wide. The windrows were made 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. The windrows were broken down after standing for between 3 and 4 weeks, after construction. Water was added to the sandy soil to enhance the biodegradation of the petroleum hydrocarbons by the microorganisms when it penetrates the soil.

The samples were analyzed, for the parameters of concern - temperature, Total Petroleum Hydrocarbon (TPH), Electrical Conductivity (EC), Heterotrophic Bacterial Count, Hydrocarbon Utilising Bacteria, pH, and soil Nutrients parameters(nitrate and phosphate). The parameters were engineered and monitored in a way to create a favourable and enabling environment for the microbes to multiply and biodegrade the hydrocarbon impacted soil naturally. The process involved a stepwise monitoring and controlling of the parameters for a period of 24 weeks.

Soil temperature was measured in situ at the site with the use of a thermometer. The pH was measured in situ at site with the use of a pH meter. The nitrate content was determined using titrimetric method; while Phosphate was determined by Vanodomolybdo Phosphoric acid Colorimetric method. Total Petroleum Hydrocarbon (TPH) was measured using Gas Chromatographic (GC) Analysis. Electrical Conductivity was determined electrometrically with a calibrated electrical conductivity meter. Total Heterotrophic Bacterial (THB) Count was determined using pour plate method and Total Hydrocarbon Utilising Bacteria (THUB) was determined using spread plate method. Multiple Linear Regression (MLR) was used for data analysis and test of hypothesis. MLR was used to test the relationship between temperature and soil fertility parameters.

Data Analysis and Discussion

The heavily contaminated waste treatment medium for the enhanced process had temperature values in the range of 26^0C-32^0C with an average of 27.95^0C. Variation in temperature was minimal; however temperature increased gradually from Week 4 (28^0C) to (29^0C) in Week 12. Thereafter, there was a slight decline in temperature to 27^0C before increasing to a maximum of 32^0C. The percentage difference in temperature at the end of the study was 18.75% while the mean value was 27.95±2.38 (Figure 3a). For the unenhanced process, the temperature varied from 29^0C to 32^0C with an average value of 28.95^0C and percentage difference of 9.38%. The mean value was 28.95±2.09 (Figure 3b).

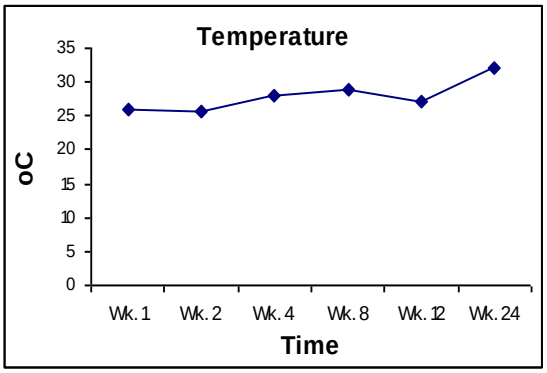


Figure 3a. Temporal variation in temperature in heavily-polluted soil in barrier island ecosystem (enhanced process)

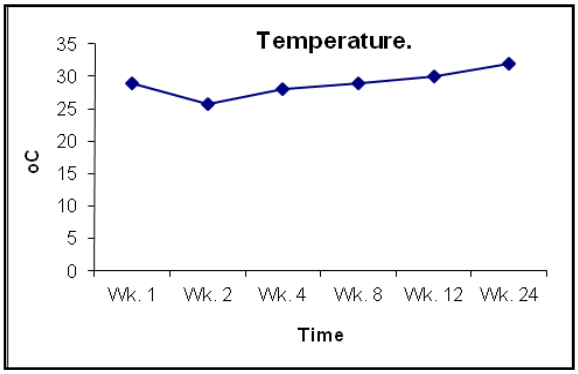


Figure 3b. Temporal variation in temperature in heavily-polluted soil in barrier island ecosystem (unenhanced process)

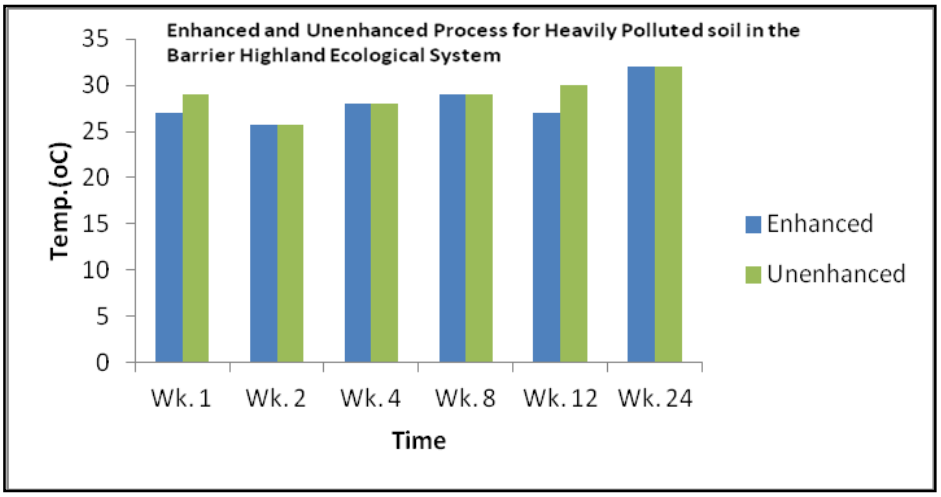


Figure 3c. Comparative variations in temperature in heavily-polluted soil in barrier island ecosystem between the enhanced and the unenhanced process

pH values for the heavily contaminated soil treatment medium in the enhanced process increased gradually, from slightly acidic (6.59) in Week 1 to basic (8.81) in Week 8. Thereafter, there was a sharp decrease from basic to slightly acidic (6.98) in Week 12. At the end of the study in Week 24, the pH value was 6.89. Percentage increase in pH was 25.2% and the mean 7.46±0.79 (Figure 4a). Comparatively, in the unenhanced process, the pH ranged from 4.18 to 5.69 with the average value 4.87 and percentage difference of 26.54% while the mean value was 4.87±0.28 (Figure 4b).

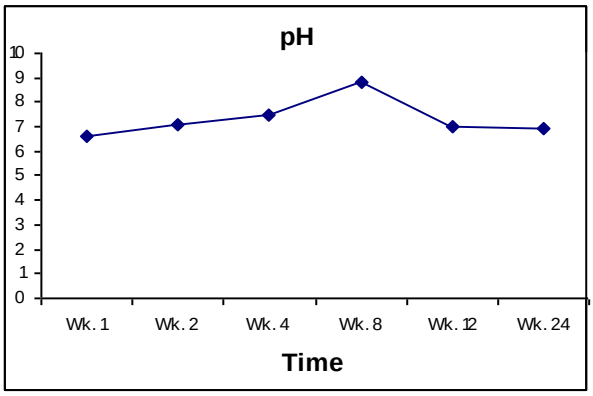


Figure 4a. Temporal variation in pH in heavily-polluted soil in barrier island ecosystem (enhanced process)

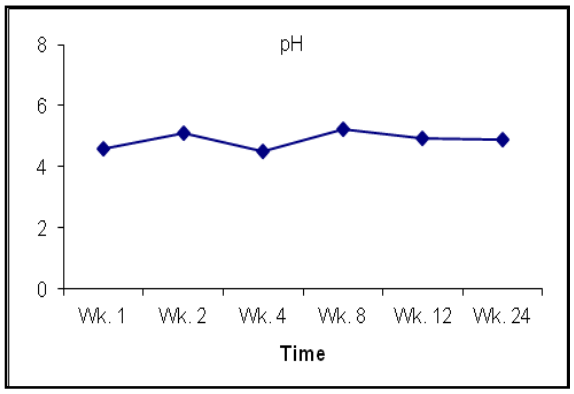


Figure 4b. Temporal variation in pH in heavily-polluted soil in barrier island ecosystem (unenhanced process)

Carbon dioxide that was released contributed to the alkalinity in the treatment medium. From the correlation analysis, changes in pH in the polluted soil were highly significant with a correlation variable score of 0.956. While the oil may have had some direct impact in lowering the pH, it is also possible that microbial actions through metabolic process contributed to changes in pH (Manahan, 1994).

Electrical Conductivity for the heavily Polluted treatment medium in the enhanced process was 455μS/cm in Week 1. There was a sharp increase to 1,368μS/cm in Week 2, this was probably due to ionic exchanges as a result of the treatment process. This was followed by a sudden decrease in Week 4, then an exponential increase to 165.7μS/cm in Week 24. The maximum value of Electrical Conductivity was 1,368 μS/cm and the minimum value 7.50 μS/cm. Mean value was 340.2±577.59 μS/cm. The percentage reduction was 99.5%. However for the unenhanced process, the variation was between 543μS/cm and 165.7μS/cm with the mean value of 372.6±130.28μS/cm and percentage variation of 69.48%.

It was obvious that the process of tilling the soil, creation of aeration and moisturing helped in the release of dissolved solutes and hence increase in EC at start of treatment. Previous studies on EC revealed that bulk EC of sediments during microbial mineralization of diesel or crude oil (investigated in a mesoscale laboratory experiment consisting of biotic contaminated and uncontaminated columns) demonstrated variance with level of contamination (Atekwana, et al., 2004a). The numbers of degrading microorganisms increased with a clear pattern of depth zonation within the polluted column. Microbial community structure determined from ribosomal DNA intergenic spacer analysis showed a highly specialized microbial community in the unpolluted column. The polluted column showed temporal increases in bulk conductivity, dissolved inorganic carbon and calcium, suggesting that the high bulk conductivity was due to enhanced mineral weathering from microbial activity. The greatest change in bulk conductivity occurred in sediments above the water table saturated with crude oil. Variations in EC magnitude and microbial populations and their depth distribution in the polluted column are similar to field observations (Atekwana, et al., 2004b).

Nutrients were in high demand from start to end of treatment because it is a buster of the microbes which in turns eats up the hydrocarbon at a speedy rate. Nitrate concentration at start of treatment in Week 1 for the enhanced process was 83.67mg/l. This was the peak value which decreased sharply from week 2 to Week 4 (19.92mg/l). There was a slight increase to 44.7mg/l in Week 8. And between Week 12 and 24, there was no significant increase. Mean value was 33.73±16.0mg/l and percentage reduction was 76.2%. In the unenhanced process, variation

was between 24.7mg/l and 83.67mg/l with a mean value of 52.05±22.24mg/l and the percentage difference was 70.48%.

In the enhanced process, Phosphate depletion fluctuated between 0.83mg/l to 3.6mg/l as the minimum and maximum values respectively. From Week 1 to Week 2, there was a slight increase in concentration (2.63mg/l), which decreased in Week 4. Between Week 4 and Week 12, there was another slight increase (3.6mg/l), which finally decreased to 0.86mg/l in Week 24. The mean value was 1.984±1.19mg/l. Percentage reduction in phosphate concentration was 76.94% (Figure 5a). While in the unenhanced process the highest value was 3.0mg/l and the lowest 0.76mg/l with the mean value of 1.74±0.91mg/l and percentage variation 74.67%. (Figure 5b).

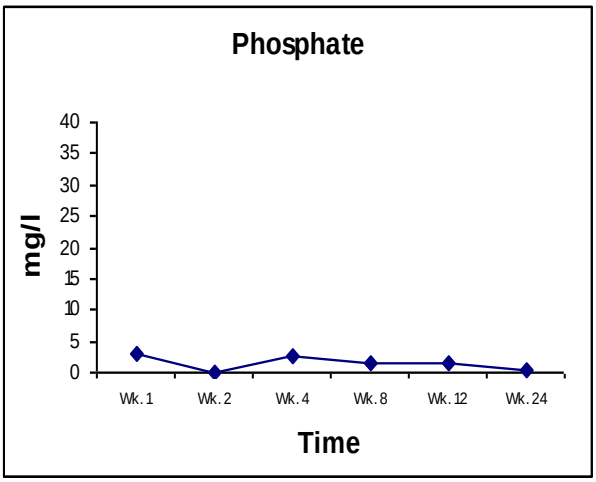


Figure 5a. temporal variation in phosphate heavily-polluted soil in barrier island ecosystem (enhanced process)

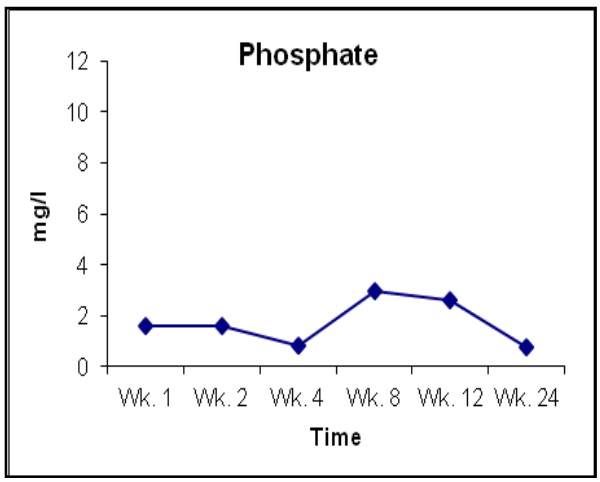


Figure 5b. temporal variation in phosphate in heavily-polluted soil in barrier island ecosystem (unenhanced process)

The highest TPH value for the heavily polluted soil in the enhanced process was 19,790 ppm as shown from the sampling result. This value responded to the treatment as it decreased to 3,059.06 ppm in Week 2. There was further slight reduction in TPH value to 938ppm in Week 4. Continued intervention resulted in further reduction in value in Week 8 (671.956ppm). By the last week (Week 24), the TPH value has decreased to 271.53ppm. The maximum TPH value was 19,700ppm and the minimum value was 271.35ppm. The mean value was 1,013.841±1,187.45ppm..The percentage reduction in TPH was 98.62% (Figure 6a).

For the unenhanced process, the highest TPH value was 19,790ppm with a very slow degradation to the minimum value of 16,276.5ppm. The slow degradation trend, however is attributed to by the non enhanced nature of the treatment process. The percentage reduction was 17.75% indicating poor degradation trend. The mean value was 18,668±1,402ppm (Figure 6b).

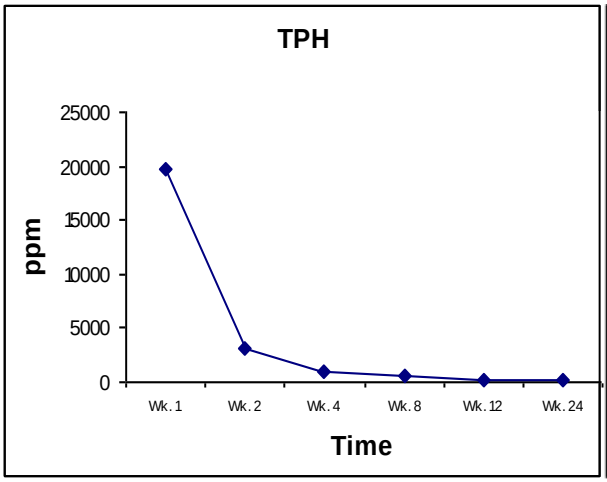


Figure 6a. Temporal variation in TPH in heavily-polluted soil in barrier island ecosystem (enhanced process)

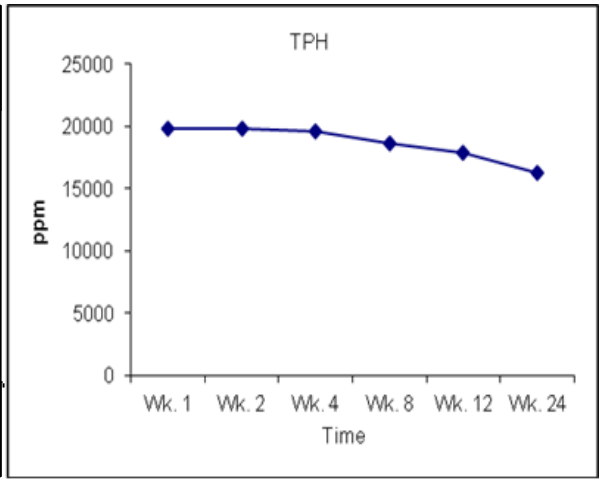


Figure 6b. Temporal variation in TPH in heavily-polluted soil in barrier island ecosystem (uenhanced process)

Total Heterotrophic Bacterial Count for the enhanced process in the heavily polluted treatment medium was 6.5 x 10^6 Cfu/g at the start of the experiment in Week 1. The value increased gradually to 9.1 x 10^6 Cfu/g due to substrate availability in Week 2. It gradually decreased to 7.5 x 10^6 Cfu/g in Week 24. Percentage decrease in value was 28.57%, and the mean 7.92±0.79 (Figure 7a). For the unenhanced process, the variation was between 6.5 x 10^6 Cfu/g to 2.5 x 10^6 Cfu/g with percentage difference of 61.54%and mean of 4.37±1.34 (Figure 7b).

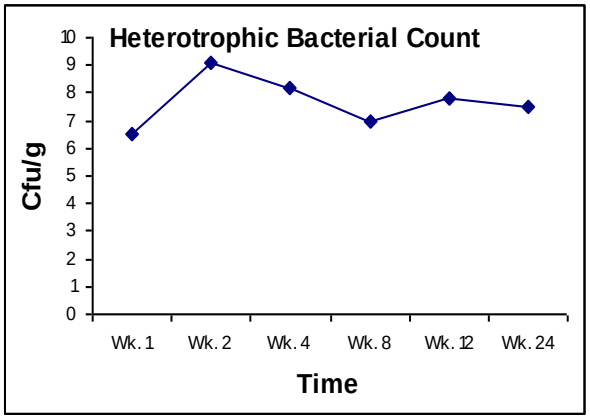


Figure 7a. Temporal variation in Heterotrophic bacteria count in heavily-polluted soil in barrier island ecosystem (enhanced process)

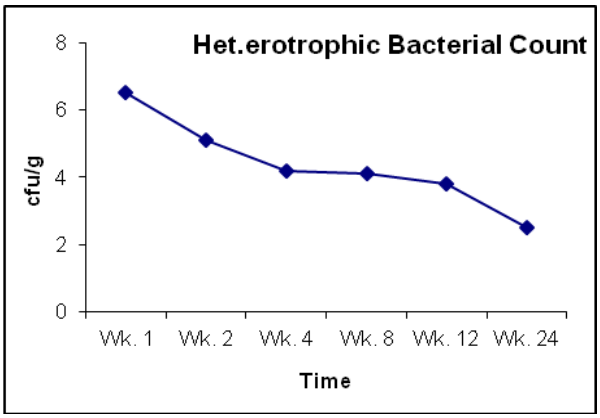


Figure 7b. Temporal variation in Heterotrophic bacteria count in heavily-polluted soil in barrier island ecosystem (unenhanced process)

There was also evidence of established decrease in the number of hydrocarbon utilising Bacteria (biomass) as a direct consequence of the bioutilization of the hydrocarbons polluting the soil. The hydrocarbon content reduced as the hydrocarbon utilising bacteria decreased in population. This agrees with Braddock et al. (1997).

Conclusion

This study demonstrated that oil pollution reduces soil fertility and productivity in the Barrier Island Ecosystem in the Niger Delta Region and that oil polluted sites could be

resuscitated by the process of ENAP. Consequently, the high TPH values at the start of the experiment were reduced to low and acceptable threshold values with improved nutrient concentrations and bioavailability.

As long as oil production is continuous in the Niger Delta Region oil spillages, pollutions due to equipment failures, maintenance, sabotage etc will also continue. These noteworthy results from bioremediation applications confirmed the theoretical information base established by previous studies. The 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 the environments and environmental parameters besides nutrients affect degradation rates in the field. Thus field applications of nutrients are still to some degree influenced by temperature, water runoff, substrate, and other environmental parameters that are neither fully understood nor easily quantified.

However, in the Barrier Island Ecosystem of the Niger Delta, environmental conditions are favourable to these parameters. The results further demonstrated that ENAP can assist in achieving the benefits of quick intervention. This study deviated a bit from previous studies and focused on the interrelationship and influence of temperature on bioremediation rates and soil fertility improvement using the enhancement process of bioaugmentation and biostimulation. Based on the findings, it is recommended that remediation of hydrocarbon-polluted soil by enhanced natural attenuation should be encouraged since it is cost-effective and environmentally friendly. Oil companies in the Niger Delta should encourage the use of this technique in remediating hydrocarbon-polluted environment as a way of demonstrating their corporate responsibility of protecting the environment. Further studies should be conducted on how to improve the efficiency of the technique.

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