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Bioremediation and phytoremediation of oil spill in Niger Delta – A case study of Eriemu in Delta State

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ABSTRACT: Bioremediation of oil spill was investigated to determine the degradation of petroleum hydrocarbons released into soil and water. The impacted area was divided into two blocks, A and B represented heavily and moderately polluted areas respectively, Block C, an unimpacted area represented control block. The total petroleum hydrocarbon (TPH) and the microbes content at different depth were determined for each block. The result of initial profile study was used as a guide to divide the soil horizon into four depth intervals. Excavation was carried out on each block to 2m depth and the excavated materials from each interval were laid on PVC sheets as biopiles 1, 2, 3 and 4. Seeded microbes were applied according to nutrient formulation needed to degrade the level of TPH in each pile. Water hyacinth trained and genetically modified was used in aqua cells to treat pumped groundwater before re-injection into the soil. Continuous monitoring of bioremediation carried out on biopiles and groundwater shows that the TPH reduced to less than 100pmm, and 0ppm respectively within 8 weeks. The pH of the soil piopiles and groundwater was maintained the natural range (6-8) over the same period. Heavy metal concentration in the impacted soil blocks showed no significant differences and they existed and concentration levels far below 2500pmm at which microbial physiological activity can be affected. The effect of solar energy, though not investigated, but could not be ruled out under this circumstance.

Key Words: Bioremediation; Phytoremediation; Oil spillage; Environmental pollution; Niger Delta; Nigeria.

Introduction

Oil spillage is a common phenomenon in the oil producing states especially in the Niger delta area of Nigeria. The environmental consequences of this problem are a point of concern and every means are being employed to tackle the problems. Anytime oil spillage accident occurs, several thousands of hectares before any action could be take to stop it. The ecology of the area that received oil spill usually suffers as forest, wildlife, aquatic life and groundwater are affected. In most cases, natural drainage conveys the oil spilled as run-off away into water bodies of the Niger Delta. Economically, several hectares of farmland and plantation (rice, rubber and oil palm) are lost while fishing is also affected. A high proportion of spilled crude percolate into the ground to pollute groundwater, therefore, the soil matrix and groundwater retain large quantity of the hydrocarbon released. The nature of crude oil is composed of different grades of complex hydrocarbons and trace metals. Many of the pollution problems today result from new

chemicals and the products derived from them (McEdownet *et al*., 1993). Prior to the advent of industry, enzymes had evolved over thousands of years in parallel with natural occurring organic compounds. Consequently, microorganisms were capable of degrading almost all-organic compounds. The introduction of many structurally novel compounds into the environment over a relatively short time span has not allowed organisms sufficient time to develop appropriate degradative mechanisms for these compounds. As a result, many new compounds are resistant to microbial breakdown in the environment, resulting in pollution of watercourses, ultimately entering food chain and threatening the health of all organisms.

Concern about environmental pollution caused by oil industry has led to significant changes in government legislation. The Ministry of Environment (MOE) and Ministry of Petroleum Resources through their implementation agency, Federal Environmental Protection Agency (FEPA) and Department of Petroleum (DPR) in Nigeria have set up integrated guidelines to provide population control measures and have resulted in strict control of oil spill and remediation programme. The petroleum business concerns especially the Shell Petroleum Development Corporation (SPDC) is being made to comply with stipulated guidelines by undertaking monitoring programmes. The operations covered the land, swamp (fresh and brackish water) and shallow offshore with facilities like flow stations, compressor stations, gas plants, sewage treatment plant, Jetties, Terminals and power plant. Private consultants are being employed by SPDC to carry out the exercises of monitoring the effect of aqueous discharge on the receiving environment and to take immediate action when significant fluxes are observed.

Bioremediation involves the use of microorganisms and their biodegrative capacity to remove pollutants. The by-products of effective biodegradation of complex hydrocarbons, such as water and carbon dioixide are non-toxic and can be accommodated without harm to the living organisms and the environment. It is a very cheap alternative to several methods that are considered extra ordinary expensive. Biodegradation is the most significant natural attenuation process for petroleum hydrocarbons and is also being heavily employed and studied for chlorinated solvents for degreasing and dry cleaning, are commonly found as groundwater contaminants in urban areas (Masters, 2000). Phytomediation is a new technology for treating contaminated groundwater and soils. The uptake and detoxification of contamination by plant species has been used successfully in land treatment of sewage. The exotic plants, called hyperaccumulators such as water hyacinth have found their use in bioremediation of polluted water. Particularly isolated species are genetically engineered to assume high capacity to biodegrade various forms of pollutants found in water. They have the capacity of absorbing dissolved toxic subtonics from water and deposit them around roots cell vacuoles. But, the success of bioremediation can be limited since the availability of adequate amount of nutrients (nitrogen, phosphorus and oxygen) holds the key to quick growth and multiplication of microbes and water hyacinth.

Study Area

The study site is along Eriemu-UQSS 40mm trunk line spill site, about 3km from Ekuigbo town and about 5km from UQSS station in Igwemaro community. It is located approximately on latitude 5°31'N and longitude 5°45'E (Fig. 1). The climate of Eriemu is hot and humid. The annual rainfall ranges between 2500mm and 3500mm bimodal with peaks occurring in the month of July and September. The wet season over a period of ten months (February to November), while the dry season occurs between December and January. The highest temperature is recorded during the dry season as against the lowest in the rainy season. The vegetation around Eriemu is majorly a secondary forest dominated by shrub, hedges and grasses. Some primary forests, maintained as forest reserves and rubber plantations with a few oil palm trees dotted the terrain. Other form of vegetation present is the fresh water swamp forest. The geological formation of the area is generally classified as part of Warri deltaic plain.

The oil spillage occurred on 13th November 1996 as a result of underground leakage on a 400mm-pipe delivery line from Eriemu flow station to UQSS. An estimated volume of 350 barrels (700,000 litres) was recovered during initial cleanup. The area covered by the spill was about 1050m^2 and the soil profile was saturated with crude oil up to average depth of 4m. The seasonal rise and fall in shallow water table ranges between less than 1 metre during the wet season and about 4m to 12m at dry season.

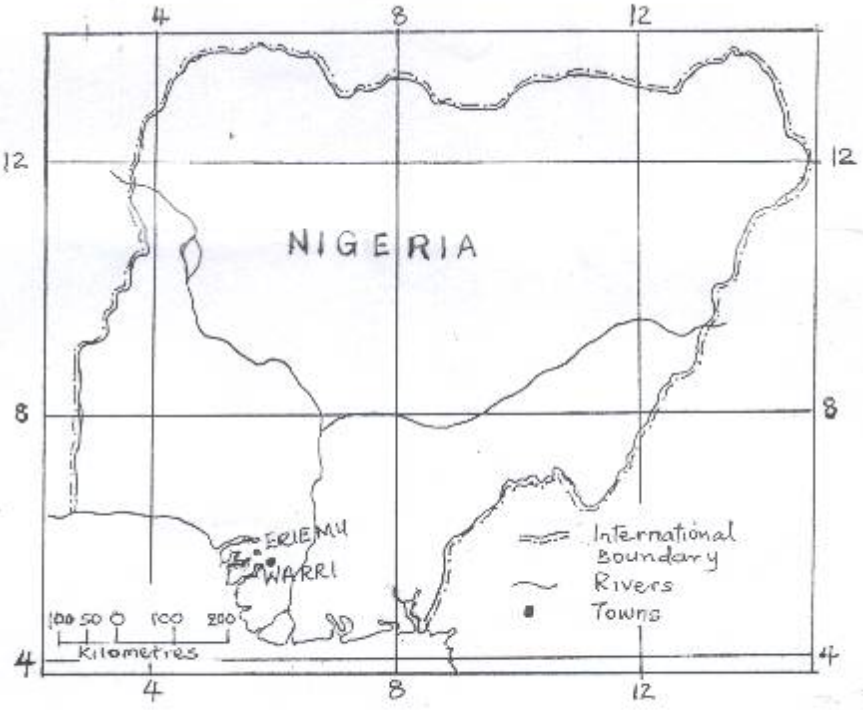


Figure 1: Approximate location of Eriemu, Nigeria.

Materials and Methods

Sampling

Prior to sampling, the site was divided into three blocks labelled A, B and C (Fig. 2).

Block A represents heavily polluted area (50m by 15m)
Block B represents moderately polluted area (50m by15m)
Block C represents control area (50m by 15m).

Graduated stainless steel anger was used to collect soil samples at different profile depths on each block. Samples obtained were bulked, homogenized, kept in glass bottles, labelled and transported to the laboratory under stabilized conditions (preserved and refrigerated). The results of analyses were used as a guide for excavating block A and B and the materials excavated were laid out on PVC sheets in heaps labelled as biopiles 1, 2, 3 and 4 for the depth intervals 0-50cm, 50-100cm, 100-150cm and 150-200cm respectively. Samples were obtained from each biopile and sent to the laboratory for analysis. 'Seeded' microbes and nutrients (NPK 20:10:0 fertilizer) were applied to each biopile in the pre-determined quantities, then windowed and properly aerated. Then each pile was covered with PVC sheets.

Fourteen probes were inserted into the aquifer at depths varying from 3m to 11m, well distributed around the three block areas. Contaminated groundwater was pumped out into aquacell tanks and aerated using oxychrome air compressor and oil that rises to the water surface was continuously skimmed off. There was a set of aquacell of 15,000 litres each, arranged parallel and connected in series with operating values. The last tank is the outlet used for reinjection of treated water into the soil (Fig. 3). Water hyacinth plants, trained and genetically modified to withstand highly toxic conditions with developed capacity for accelerated uptake of hydrocarbons and heavy metals were used as bioreactors in the aquacell to treat the contaminated groundwater continuously pumped into the aquacell. Indigenous strains of heterotrophic bactteria and nutrients were introduced into groundwater through excavated test pits. Water samples were taken from outlets into aquacell I and correctly labelled against the depth and block area of extraction. The water samples were collected inside clean containers, labelled, preserved and transported to the laboratory under refrigeration. Both water and soil samples were analysed to determine the total petroleum hydrocarbon (TPH) and some physiochemical parameters present in them.

Results and Discussions

Oxygen is a major limiting factor in the treatment of soil and groundwater contaminated with crude oil, as microbes responsible for hydrocarbon degradation are microbial growth in oil contaminated soil and groundwater, adequate aeration to supply oxygen as an electron acceptor is required for the breakdown of hydrocarbons. Both nitrates and sulphates also act as electron acceptor but not suitable because, excess nitrate contaminate surface and groundwater. The oxygen is required by aerobic oil degraders as terminal electron acceptor in the complex metabolic activity to convert carbon and hydrogen found in hydrocarbons into carbon dioxide, water and biomass production as shown in this hypothetical equation:

$$(CH_2) + O_2 \xrightarrow[\text{nutrients}]{\text{Aerobic bacteria}} CO_2 + H_2O + \text{biomass}$$

The micro organisms that drive the above reaction are self-adjusting and self-regulating in utilizing the carbon in petroleum for energy to maintain their metabolic processes and production of biomass depending on prevailing environmental factors and availability of nutrients.

The results of analysis carried out on core samples obtained from the site are shown on Table 1. Heavy metals deposited in the soil progressively decreased from the surface to 90cm depth, beyond which the values are noted to be increasing. This gives an indication of the accumulation of heavy metals as may be retained periodic static level of ground water table as it fluctuates among seasons. The values obtained from impacted and non-impacted (control) blocks appears very insignificant, but this is still subject to further investigation as well reference to other studies on the Niger Delta ecology.

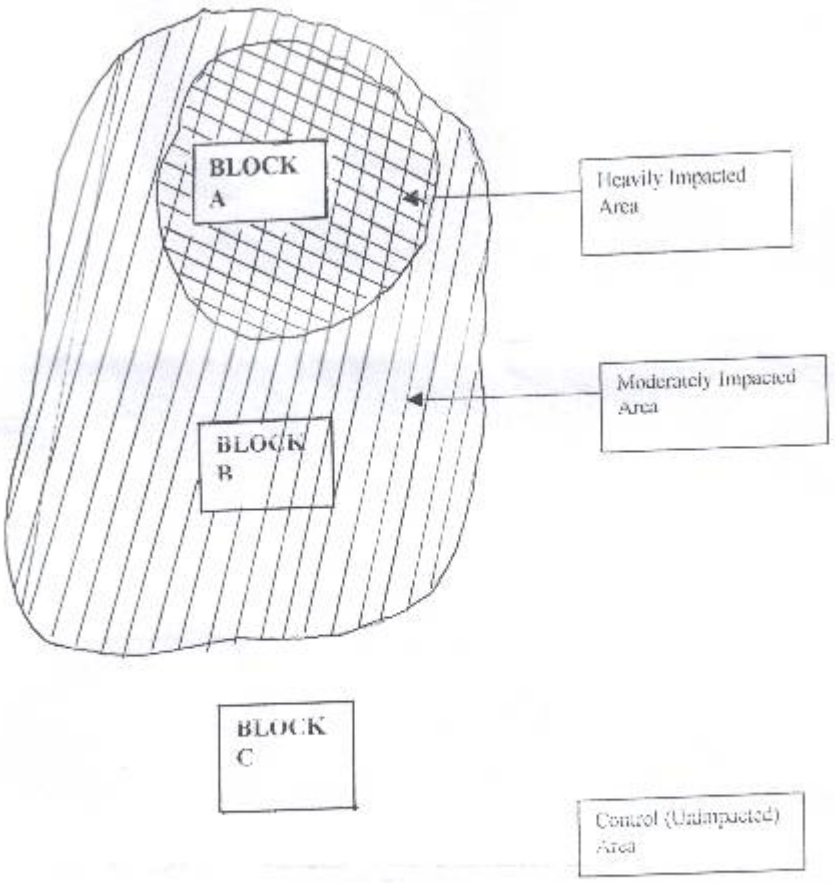
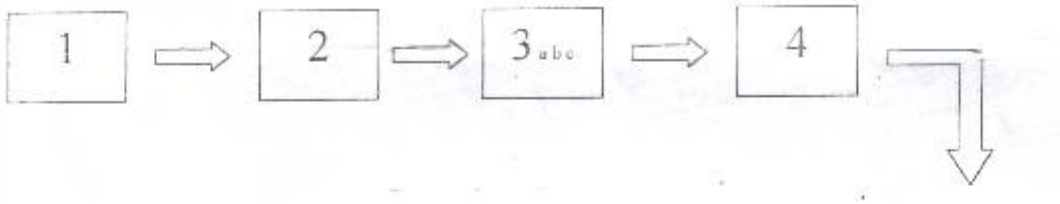


Figure 2. Block Areas as Designed for Sampling



1 - Contaminated raw water
2 - Physical screening
3 - Biological treatment
  (a) Fertilizer application
  (b) Planting of water hyacinth
  (c) Seeding isolates of oil degraders
4 - Certified treated water
5 - Re-injection of treated water into the ground

Figure 3. Flow diagram of Phytoremediation in the aquacells

Table 1: Mean values of heavy metals in core samples.

Location	Depth	Fe	Mn	Zn	Cu	Cd	Cr	Ni	V	Pb	Hg
High core	0-30	11.26	2.44	6.47	6.27	4.79	0.40	6.24	0.03	0.65	0.005
impacted area	30-60	22.51	3.05	1.10	9.41	3.51	1.98	5.72	0.05	0.06	0.009
	60-90	19.31	1.93	0.97	5.11	2.52	1.31	4.31	0.02	0.06	0.005
	90-120	20.96	1.72	0.86	4.39	1.87	1.05	3.79	0.04	0.04	0.004
Secondary	0-30	16.42	1.78	5.44	3.92	1.75	0.99	5.38	0.04	0.06	0.007
impacted area	30-60	15.01	1.80	0.68	4.07	1.62	0.78	3.19	0.05	0.39	0.007
	60-90	17.03	0.93	0.43	3.79	1.51	0.89	2.79	0.05	0.28	0.004
	90-120	14.96	1.03	0.73	2.99	1.68	0.68	3.11	0.04	0.18	0.005
Unimpacted	0-30	23.45	2.50	0.84	6.27	4.86	4.16	4.39	0.05	0.03	0.010
area	30-60	19.14	1.83	0.53	4.70	3.05	1.29	4.15	0.06	0.72	0.023
	60-90	21.07	1.94	0.51	4.23	2.91	2.03	3.89	0.06	0.65	0.024
	90-120	18.25	1.74	0.67	4.31	2.67	1.20	3.23	0.07	0.54	0.008

The concentration of total petroleum hydrocarbon in the soil profile is reflected from the result of average values of TPH in core samples obtained from oil impacted blocks. The TPH concentration reduces with depth and this may be attributed to the high cation exchange capacity and nature of the topsoil layer with high affinity for retention of crude oil in soil colloids.

The TPH in reconditioned contaminated soil maintained as soil biopiles were monitored weekly for two months. In a period of six weeks, the results of conditioned soil pH monitored is shown on Table 3 Many conditions decidedly affect the growth of bacteria and ultimately, on the rate of hydrocarbon degradation in soil contaminated with crude oil, in this case, a soil with low pH. The re-conditioned soil pH of the biopiles average around 6.0 (5.9 – 6.32) which is within the natural range (6-8) that effectively support normal bacterial physiological activity. The TPH of reconditioned soil in the biopiles were less than 100 ppm after eight weeks (Table 4). The high rates of TPH depletion in re-conditioned soil were mainly due to the attainment of optimum soil nutrients biologically neutral pH regime, optimum soil nutrients and high loads of heterotrophic hydrocarbon bacteria. However, the total percentage depletion may not be solely due to microbes as the low molecular weight fraction of some hydrocarbons are readily volatized by the solar energy.

Table 2: Mean values of total petroleum hydrocarbon (TPH) in core samples obtained from oil impacted blocks profile.

Horizon	Depth (cm)	TPH
A	0-50	72,319.66
B	50-100	66,971.56
C	100-150	53,938.33
D	150-200	30,607.60

Table 3: Adjusted pH of conditioned soil sampled at 7 days interval.

	1	2	3	4	5	6
Biopile 1	6.02	6.03	6.12	6.01	6.18	6.13
Biopile 2	6.01	6.12	6.04	6.15	6.32	6.24
Biopile 3	5.89	5.96	6.00	5.97	5.98	6.01
Biopile 4	5.92	5.94	5.98	6.02	6.11	6.08

Table 4: TPH concentration (ppm) of conditioned soil at seven days interval.

Time (week)	Initial	1	2	3	4	5	6	7
Biopile 1	17,803	14,242	9.969	5,393	2.393	959	478	96
Biopile 2	18,113	14,128	10,030	5,517	2,482	869	313	97
Biopile 3	18,912	14,373	8,911	4,723	2,125	744	283	98
Biopile 4	19,031	14,464	9,112	4,374	1,881	677	257	98
Biopile 5	17,943	13,098	8,514	3,831	1,742	621	192	98

Table 5: Volume of groundwater extracted, treated and re-injected into the ground per month.

Volume of groundwater	Aug. 1999	Sept. 1999	Oct. 1999	Nov. 1999	Dec. 1999	Total
Extracted (m^3)	174	972	765	413	336	2657
Treated (m^3)	162	826	696	326	247	2257
Re-injected (m^3)	158	768	668	313	227	2134

The physical screening and aeration of pumped groundwater into the aquacell containing trained water hyacinth proved effective in the treatment of groundwater as only water that meets the minimum standard of 0ppm was re-injected into the ground. The end product of groundwater treatment that achieved 0ppm of TPH (which is non-toxic to the environment) shows that, there is excellent symbiotic association between the microbes and the trained water hyacinth. The products i.e. carbon dioxide in the aerobic catabolic activity on complex hydrocarbon by microbes is used by the water hyacinth in anabolic activity to produce oxygen which is used up by the microbes. The water hyacinth also provides nutrients to microbes by the decaying spongy root. The contaminated water gets “purer” and “purer” as it moves from one aquacell to the other till about 90-95% reduction is achieved at the final aquacell tank. Re-injection is only from the base of the final aquacell tank leaving traces of crude oil film on the water surface. The batch treatment process is continuous, and the volume of water extracted, treated and re-injected were recorded (Table 4).

Conclusions and Recommendations

The risk of contamination in groundwater is too great to rely on natural attenuation alone, especially in densely populated urban areas. It is therefore being suggested that ‘air spagging’ or the injection of air into biopiles or directly into aquifers, is carried out as well. The bacteria being used in the remediation process

will have enough oxygen at its disposal to transform the contaminants and/or volatiles organic contaminants for removal or venting to the atmosphere. This will enable faster and economical clean up.

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References

1. API (1969). Manual on Disposal of Refinery Waters, Chap. 8, American Petroleum Institute, New York.
2. Stainer, J.L. *et al*. (1978). Air flotation treatment of Refinery Wastewater Chem. Engng. Prog. 74, 39 – 45.
3. Gonzalez-Marlinez and Duque-Luciano, J. (1992). Aerobic submerged Biofilm Reactors for Wastewater Treatment. Journal of Water Research, Vol. 26, No. 6, pp. 825 – 833.
4. Choi, E. and Burkhead, C.E. (1982). The hydrodynamic evaluation of fixed media biological process. Proceedings of First International Conference on fixed-film Biological Processes. Kings Island, Ohio.
5. Loehr, R.C.; Martin Jr. J.H. and Neuhauser, E.F. (1992). Land treatment of an aged oily sludge – organic loss and change in characteristics. Journal of Water Research, vol. 26, No. 6, pp. 805 – 815.
6. Brown, K.W. and Donnelly, K.C. (1983). Influence of soil environment on biodegradation of refinery and petroleum sludge. Envir. Pollute (Ser. B) 6, 119 – 132.
7. Bouwer, E.J. and Zehnder, A.J.B. (1993). Bioremediation of organic-compounds – putting microbial metabolism to work. Trends in Biotechnology II, 360 – 367.
8. Bull, A.T. (1992). Degradation of harzadous wastes. In: The Treatment and Handling of Wastes (Bradshaw, A.D.; Southwood, Sir. R. and Wemer Sir F., Eds.). The Royal Society by Chapman and Hall, London, UK.
9. Chaudry, G.R. and Chapala Madugu, S. (1991). Biodegradation of halogenated organic compounds. Microbial Reviews 55(1), 59 – 79.
10. Alexander, M. (1981). Biodegradation of chemicals of environment concern science 211, 132 – 138.
11. Mara, D.D. (1974). Bacteriology for Sanitary Engineers, Churchill Livingstone, Edinburgh, U.K.
12. McEldowney, S.; Hardman, D. and Waite, S. (1993). Pollution, Ecology and Biotreatment. John Wiley and Sons, New York, USA.
13. Nurmalalihandan, N. et. Al., (1994). The toxicity of mixtures of organic chemicals to microorganisms. Journal of Water Research, vol. 28, pp. 543 – 551.
14. Kovalick, W. (1999). The Perspectives for Clean Up. Paper presented at EPA Innovative Clean-Up Approaches Conference, Bloomingdale, Illinois, USA.
15. Nyer, E. and Gearthart, M.J. (1997). Treatment Technology: Plumes don't move. Groundwater Monitoring and Remediation 17, 1: pp. 52 – 55.
16. Rabideau, A.J. and Blayden, J.M. (1998). Analytical Model for Contaminant Mass. Removal by Air Spagging. Groundwater Monitoring and Remediation 18, 4pp., 120 – 130.
17. Barker, J.F. (1999). In-situ Reactive Barriers for Treating Groundwater Contaminated by Petroleum Hydrocarbons. In Proceedings of Petroleum Hydrocarbons and Organic Chemical in Groundwater: Prevention, Detection and Remediation. National Groundwater Association, Houston, Texas, USA.