APPLICATION OF EMERGING BIOREMEDIATION TECHNOLOGIES AS A TECHNIQUE FOR CONTROLLING/TREATMENT OF OIL CONTAMINATED SOIL

Rakiya Zubairu[1], Sadiya .S. Umar[2], Habiba. I. Abdulsalam[2], Jibrin. Y. Dabogi[3] and **Talatu .S. Bosso[4].**

Dept. of Biological Sciences, Niger State Polytechnic, Zungeru, Nigeria.
School of Preliminary Studies, Niger State Polytechnic, Zungeru, Nigeria.
Dept. of Sci. Lab. Tech, School of Technology, Kano State Polytechnic, Nigeria.
Email: Zubairurakiya50@gmail.com, sadiyassumar@gmail.com, habibsalam141@gmail.com

ABSTRACT

As environmental pollution continue to be a global concern towards health and well-being of the populace, most especially dwellers of oil drilling nations, efforts are constantly been made to minimise its damaging effect not only to the human populace but to safe guard the natural order of the environment as well. As such, this overview aims at addressing the effect(s) of oil spillage incidences in both local (Nigeria) and global context as well as its effect(s) on both human and the environment. Furthermore, pollution control measures including conventional remediation and bioremediation methods will be effusively deliberated. As emerging bioremediation technologies that involve the utilisation of biological systems to minimise or treat pollutants is receiving renewed interest, this overview will further ponder on the mechanism behind such processes. Interestingly, bioremediation techniques utilises the natural way to effect its process, however, scientific modification via biotechnology process aids to speed up the progression of the method involved. As such, possible oil contamination clean-up procedures/methods via bioremediation will be identified for future reference.

Keywords: Bioremediation, Biotechnology, Microbial Biodegradation, Oil spillage, Niger Delta.

Introduction

Crude Oil Composition and Global Spillage History:

Crude oil or fossil fuels are naturally occurring unrefined and non- renewable petroleum products formed from the remains of dead organisms accumulated within the earth's crust, over millions of years of decay (Speight, 2014). Crude oil is composed of volatile hydrocarbons (hydrogen and carbon) including aliphatic hydrocarbons such as the saturated paraffins and their cyclic counterparts, the naphthenes. While the unsaturated benzene- based aromatics are mostly hydrocarbons, they do possess a sub- class of non- hydrocarbon compounds including asphaltenes and resins that contain nitrogen, oxygen and sulphur (Subiranaand Sheu, 2013: Reddy *et al.*, 2014) as presented in table 1 & Figure 1. According to Tissot*et al.* (2013); Waples, (2013), crude oil exploitation is the world's leading economy, however, several environmental damages due to oil exploration including oil spills, gas flares, effluents and waste discharge pose a great challenge to public health and biodiversity of the producing areas concerned. Carls *et al.,* (2016) reported that global oil spillage onto the environment due to human activities ranges from 1.7- 5.4 million tons per year. Taking for instance the Exxon Valdez oil spill in USA in 1989 and Macondo Deepwater spill in Gulf of Mexico in 2010 that led to the release of over 10.6 million tons and 4.9 million barrels worth of oil products to the environment respectively (Lindstrom *et al.*, 1991: Rico- Martinez *et al.*, 2013). Furthermore, Wang *et al.*, (2016) reported that subsequent sample analysis after the spills revealed the presence of 1×10^{11}g of C_1- C_5 compounds released to the atmosphere and 7800µgL^{-1} of toxic aromatic compounds including benzene dissolved in ground water.

Hydrocarbons	Weight (%)	Elements	Weight (%)
Paraffins (Alkanes)	30	Carbon	83- 87
Naphthenes (Cycloalkanes)	49	Hydrogen	10-14
Aromatics (Benzene or 6-C ring derivatives)	15	Nitrogen	0.1-2
Asphaltenes/Resins	6	Oxygen	0.1-1.5
		Sulphur	0.5-6
		Metals	<0.1

Table 1: Crude Oil Composition. Source: (Subrina et al., 2012).

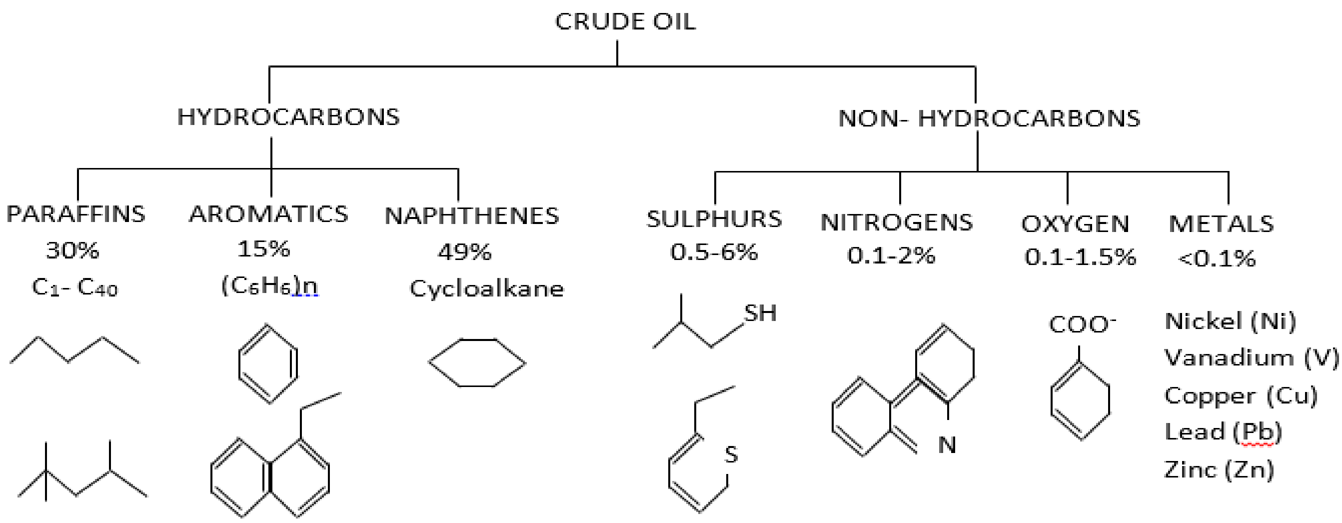


Figure 1: Schematic diagram of crude oil composition. Source: (Reddy et al., 2012).

Effect of oil spillage on human health:

Oil residues impact on public health and safety is basically through the accumulation of genotoxic hydrocarbon substances including poly-aromatic hydrocarbons (PAH) in air, soil, surface and ground water as illustrated in figure 2 (ITOPF, 2016). Osofsky *et al.*, (2014): Hansel *et al.,* (2015) reported that the accumulation of such toxic substances in ambient air and drinking water may cause direct health problems especially among the clean- up workers including dermatological (skin), respiratory, and gastrointestinal problems. While some may be indirect and take a longer period of manifestation including neurological, carcinogenic and mutagenic effects as well as reproductive problems such as stillbirths or abortion. Furthermore, another indirect effect is of food insecurity, as plants exposure to petroleum – contaminated soil may affect their photosynthetic abilities. In addition, oil contaminated water may cause sudden death in some food animal such as various aquatic animals and birds' species. While some larger food animals for instance cattle and goats may experience severe health problems including gastrointestinal and reproductive including decrease in milk production as well as growth problems. Thus, continuous consumption of such food animal might lead to subsequent accumulation or bio- magnification of such toxic substances within the human system (Akintunde *et al.,* 2015: Li *et al.,* 2016).

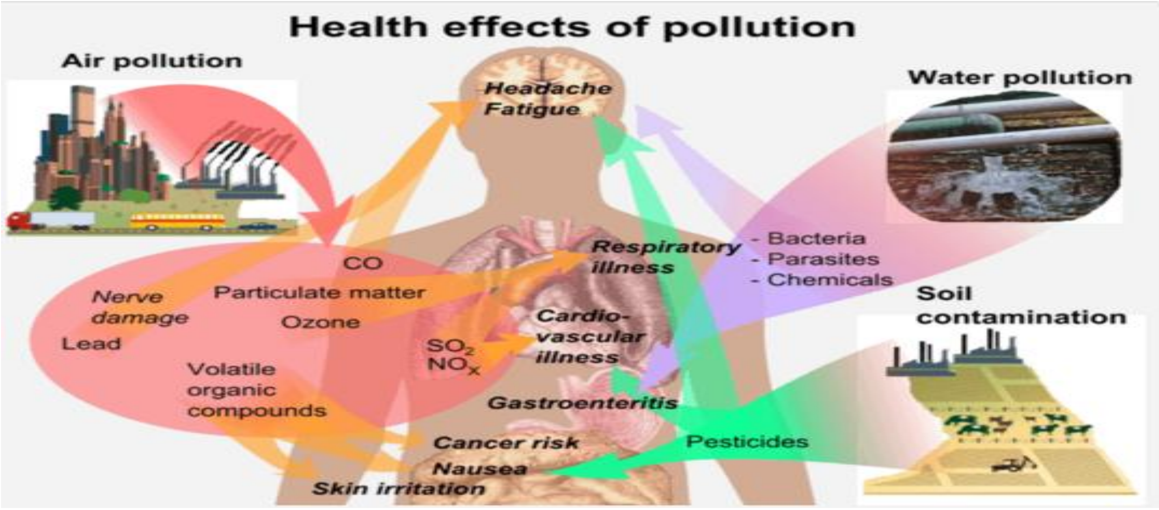
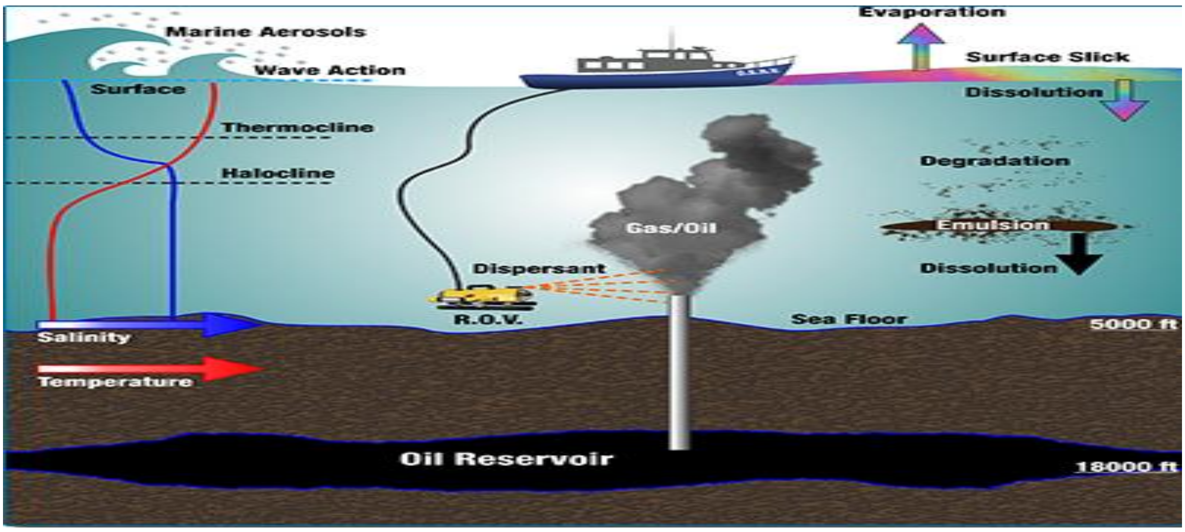


***Figure 2: Effect of environmental pollution (oil spillage) on human health. Source: (ITOPF, 2016*).**

Environmental fate of Crude oil products:

Crude oil released into the environment undergoes several weathering processes including "dispersion" which involves slick layer formation. While some portion of the dispersed oil undergo "volatilisation" due to low molecular weight, some portion might be subjected to "photolytic" or UV- light absorption to form soluble oxygenated (peroxide) active compounds of higher toxicity (Bacosa *et al.,* 2015: Lee *et al.,* 2014). The resultant non-volatile heavy weight hydrocarbons such as the aromatics and poly-aromatic compounds (PAHs) either get absorbed to form "sediments" with other biota or become "dissolved" (water- soluble) in groundwater as described in fig. 3 (Almeda *et al.,* 2014: Nelson *et al.,* 2016).

Figure 3: Biotic and Abiotic factors involved in oil disappearance after spillage. Source:



(Nelson et al., 2016).

Crude Oil exploration and exploitation history in Nigeria:

According to Akinlo (2012), the history of oil exploration in Nigeria dates back to 1907 when Nigerian Bitumen Corporation conducted exploratory work in the country; however, the firm left the country at the onset of World War I. Thereafter, license was given to succession oil firms such as D'Arcy Exploration Company and Whitehall Petroleum in 1923. However, oil of commercial value was not discovered until 1956 in Oloibiri, Owerri state of the Niger Delta region, when Shell D'arcy Petroleum Development Company of Nigeria which was a consortium of Shell and British Petroleum (then known as Anglo-Iranian) began exploratory/drilling activities in 1937 (Akpan, 2010). Other important oil wells discovered during the period were Afam and Bomu in Ogoni territory. Hence, commercial production of crude oil began in 1957 and in 1960, and total of 847,000 barrels of crude oil per day was exported. However, towards the end of the 1950s, non-British firms were also granted license to further explore for oil including Mobil in 1955, Tenneco in 1960, Gulf Oil and later Chevron in 1961, Agip in 1962, and Elf in 1962 (Baghebo and Atima, 2013). As a result, Kadafa, (2012) reported that subsequent crude oil discovery in eight states of the Niger Delta region had led to the "Oil Boom" era of Nigeria as the availability of 606 offshore and on-shore oil fields, 1,481 oil wells as well as the production of 2.2 million barrel of crude oil per day facilitates the construction of 4 refineries within the country. Prior to oil discovery, Nigeria (like many other African countries) strongly relied on agricultural exports to other countries to supply their economy; however, after commercial exploration began in 1958, Nigeria was placed as the largest oil producer in Africa and 6th largest producer in the world. These provide 85% of budget revenue and 95% of foreign exchange earnings of the country (Adeyemo, 2002).

The Niger Delta region:

The Niger Delta region, which is synonymous with the Niger Delta province in location and the contemporary heart of the petroleum industry, is a zone of dense cultural diversity and is currently inhabited by over 20 million people and roughly 40 ethnic groups speaking an estimated 250 dialects (Worgu, 2000). Some of the more relevant ethnic groups in the western part of the Niger Delta region including the Ijaw, Itsekiri, and Ogoni are mostly known for their fishing activities as their main source of income. The Niger Delta covers 20,000 km² within wetlands of 70,000 km² formed primarily by sediment deposition and this floodplain makes up 7.5% of Nigeria's total land mass (Oguine, 1999). It is the largest wetland and maintains the third-largest drainage basin in Africa. The Niger Delta's environment can be broken down into four ecological zones: coastal barrier islands, mangrove swamp forests, freshwater swamps, and lowland rainforests (Kuruk, 2004). Furthermore, this incredibly well-endowed ecosystem contains one of the highest concentrations of biodiversity on the planet, in addition to supporting abundant flora and fauna, arable terrain that can sustain a wide variety of crops, lumber or agricultural trees, and more species of freshwater fish than any ecosystem in West Africa (Nenibarini, 2004).

Oil Spillages history as key environmental issue in the Niger Delta region:

Despite the lucrative advantages of decades of oil exploration and exploitation in the Niger Delta region, negligence of the oil industry as well as oil Sabotage/bunkering/vandalisation of oil products and facilities within the region have led to disastrous bearings on the environment, livelihood as well as health of the populace inhabiting that region (Nwilo and Badejo, 2005a). As studies have shown that over 6,817 of oil spill incidents have occur within the last 50 years which is 50 times that of Exxon Valdez oil spill incident in the USA (10.6 million tons), which also amounts to 9- 13 million barrels of oil loss to the environment (Kadafa, 2012). Nwilo and Badejo, (2005b) reported that poor management by oil companies is responsible for many fire well outbreaks, gas explosions as well as oil spillage records and their associated effects in Nigeria. Taking for instance the major Texaco oil spill in 1980 which was estimated to be about 8.4 million US oil gallons alongside well fire outbreak that claim 180 lives and rendered many sick due to drinking polluted water (Onuaho, 2008). This precipitated social unrest between the communities and the oil industries, which was perhaps captured in a 1983 report issued by the NNPC (Nenibiri, 2004). Other oil spill incidents include GOCON's Escravos oil spill in 1978 which was estimated to be about 580,000 barrels and the most recent and perhaps the major oil spill incident in Nigeria in Ogoniland by shell in 2008 (fig 4 & 5) which was estimated to be around 670,000 barrel of oil loss to the environment, although the World Bank argues that the true quantity of petroleum spilled into the environment could be as much as ten times the officially claimed amount (Odeyemi and Ogunseitan, 1985). These caused damage to over 340 million hectares of mangrove, as sample analysis indicated the presence of 7,420µg/L of dissolved hydrocarbon in the area, 0.155- 48.2µg/L of benzene in air samples as well as > 3µg/L of hydrocarbons in water samples collected from 28 wells within the community (Powell et al., 1985). Hence, this can be the major contributor to disease burden in the area as toxic gases are inhaled and petroleum contaminated drinking water is consumed on daily basis, in addition to contaminating the estuarine zone animals such as fish and crab which may not only kill them but also make them unfit for human consumption (Nenibarini, 2004).

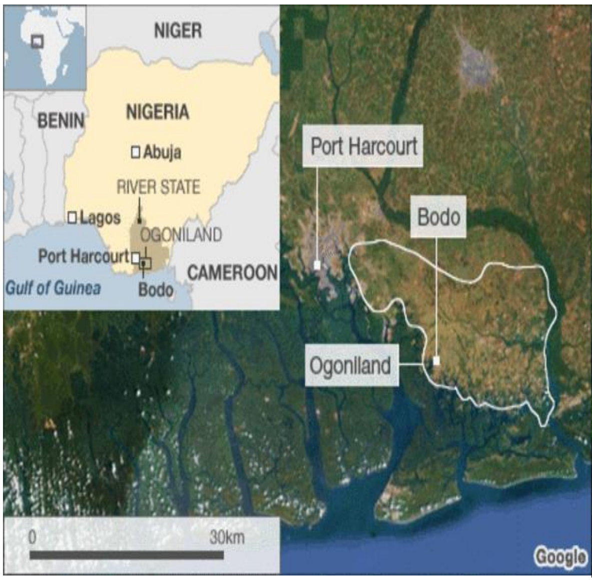


Fig 4: Map of Ogoniland in Nigeria **Fig 5: Ogoniland (Nigeria) oil spill 2008**

Major Causes of oil spill in the Niger Delta region:

Half of all spills occur due to pipeline and tanker accidents (50%), other causes include sabotage (28%) and oil production operations (21%), with 1% of the spills being accounted for by inadequate or non-functional production equipment. Corrosion of pipelines and tankers is the rupturing or leaking of old production infrastructures that often do not receive inspection and maintenance (Oviasuyi and Uwadiae, 2010). A reason that corrosion accounts for such a high percentage of all spills is that, as a result of the small size of oilfields in the Niger Delta, there is an extensive network of pipelines between the fields, as well as numerous small networks of flow-lines: the narrow diameter pipes that carry oil from wellheads to flow stations, allowing many openings for leaks (Osuntokun, 2000). However minimal incidences are associated with on- shore facilities/areas as most pipelines and flow-lines are visibly laid above the ground level (Osobo, 1996). Furthermore, oil pipelines are estimated with a life span of about fifteen years, however, most pipelines in question are as old as fifty to fifty-five years and in agreement, Shell admits that most of the facilities were constructed between the 1960s and early 1980s to the then prevailing standards (SPDC, 1995). Sabotage is another main cause of oil pollution or spillage within the region which is often performed primarily through what is known as "bunkering", whereby the saboteur(s) attempts to tap the pipeline. In the process of extraction, sometimes the pipeline is damaged or destroyed and oil extracted in this manner is sold (Tolulope, 2004). Sabotage and theft through oil siphoning has become a major issue in the Niger Delta states contributing to further environmental degradation due to oil spillages as evident in the oil spill data illustrated in fig 6 & 7. Damaged lines may go unnoticed for days, and repair of the damaged pipes takes even longer. Oil siphoning has become a big business, with the stolen oil quickly making its way onto the black market (UNEP, 2013).

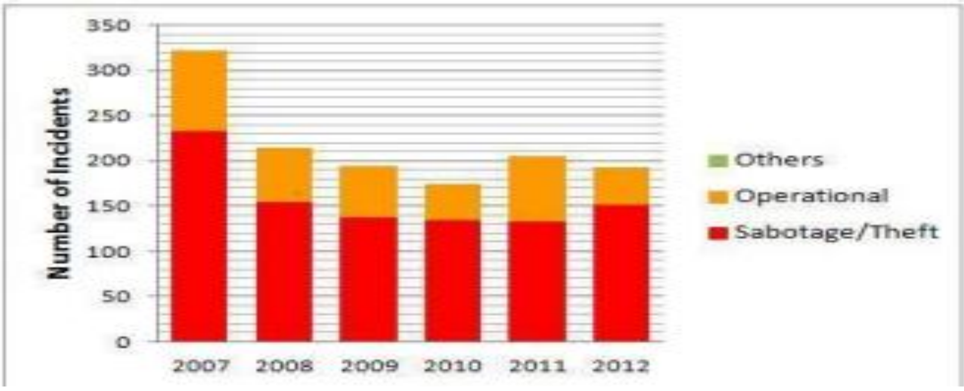


Fig 6: Number of oil spill incident/year. Source: UNEP, 2013.

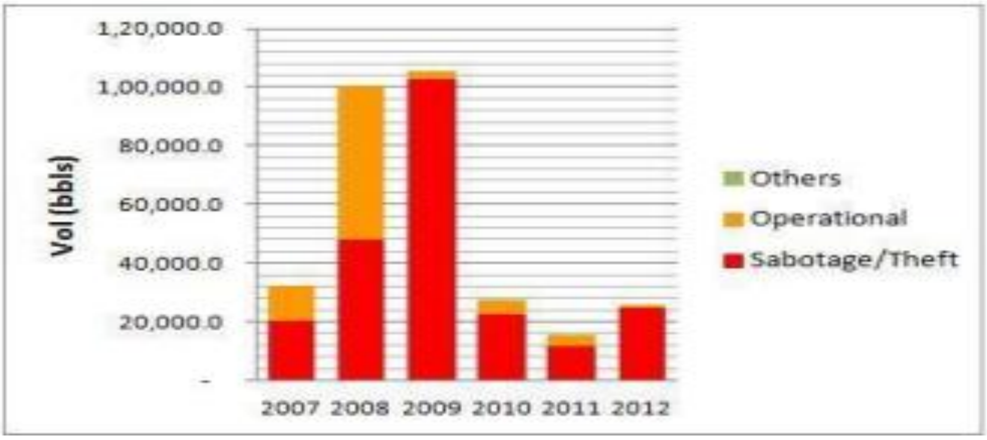


Fig 7: Volume of oil in barrel(s) per year. Source: UNEP, 2013.

Health and Environmental Consequences of oil spills in the Niger Delta region:

While the popularity of selling stolen oil increases, so also health and environmental issues increase alongside increasing number of deaths due to oil related accidents. For instance, in late December 2006 more than 200 people were killed in the Lagos region of Nigeria in an oil line explosion (Orisakwe, 2012). Furthermore, Onosode (2000), reported that the major impact of oil spillage on the environment/ecosystem in the Niger Delta region is ecocide or loss of mangrove forest. An estimated 5 to 10% of Niger Delta mangrove ecosystems have been wiped out either by settlement or oil explorations. The rainforest which previously occupied some 7,400 km² of land has disappeared as well. Spills in populated areas often spread out over a wide area destroying marine and aquacultures that cause fish depletion through contamination of the marine systems (Orisakwe, 2011). The fishing industry is an integral part of Niger Delta sustainability because it provides much needed nutrients as well as source of livelihood for the people, but with the higher demand on fishing, fish populations are declining as they are being depleted faster due to pollution as well as overfishing than they are able to restore their number (Omoweh, 1995). In addition to habitat loss, climate change due to global warming caused by excessive combustion is another key issue that add pressure to the ecosystems. In agricultural communities, often a year's supply of food can be destroyed instantaneously due to pollution as evident during the 2008 Shell/Ogoniland oil spill that led to the destruction of 240,000 tons worth of food reserve (SPDC, 2013). The banks of the Niger River are desirable and ideal locations for people to settle. The river provides water for drinking, bathing, cleaning in addition to fishing. Thus, oil spillage within the Niger Delta region is among the chief causative agent of short term diseases such as breathing, skin lesions and gastrointestinal problems due to consumption of contaminated water or aquatic animals including fishes and crabs (Obasohan et al., 2010). While bio-magnification/bio-accumulation of toxic hydrocarbons within the system is responsible for long term carcinogenic or mutagenic effects such as neurological and reproductive (abortion or stillbirth) effects. Hence, many inhabitants of the Niger Delta region have lost basic human necessities such as access to conducive environment, good health, food, clean water, as well as ability to work/earn a living as fishing is one of the main sources of livelihood to the Niger Delta dwellers (Ikelegbe, 2005).

Remediation and Bioremediation

Remediation technologies are the techniques used in accelerating biotic and abiotic processes that aid in environmental clean- up of contaminated sites including physical/mechanical containment, thermal treatment as well as chemical methods (Prendergast, 2014). While bioremediation is a pollution management process that utilises biological systems such as naturally occurring or deliberately introduced microorganisms and their enzyme in order to consume or transform environmental pollutants including organic and inorganic waste into less toxic forms so as to reclaim environmental quality (Atlas, 1981: Malik, 2014: Kothe, 2015). Biodegradation is the primary mechanism used in the bioremediation of pollutants by using microorganism to mineralise pollutants to carbon dioxide (CO_2) and water (H_2O) through various metabolic pathways including glycolysis and TCA cycle (Atlas, 1995: Prince *et al.,* 2016). According to Kuppusamy *et al.,* (2016), bioremediation is generally classified as *in- situ* or *ex- situ*. *In- situ* bioremediation involves treatment at contamination site which include intrinsic or natural attenuation (physical, chemical, biological) as well as engineered bioremediation which include injection wells, bioventing and permeable reactive barriers to name a few (Xu *et al.,* 2016). While *ex- situ* involves treatment of contaminants in a separate facility by using composite, land farming, slurry- phase (bioreactors), bio- piles and vacuum systems (Tomei *et al.,* 2016). Herrero, (2015) describes bio- augmentation (seeding) as another bioremediation process that involves supplementing indigenous microbial consortia with competent or specific microbial strains of variable genetic diversity with the purpose of accelerating biodegradation processes. While Geng *et al.,* (2016) identifies bio- stimulation or nutrient augmentation in contaminants remediation through surface or sub-surface addition of rate limiting nutrients including oxygen, nitrogen, phosphorous as well as fertilisers such as Inipol through injection wells to enhance microbial growth at contaminated sites. Phytoremediation is another *in- situ* form of bioremediation that utilises green plants for bioremediation purposes through aeration and nutrient provision by plant organs (roots), as effectiveness of legumes such as alfalfa has been reported for bio-remediating hydrocarbon compounds such as diesel (Minoui *et al.,* 2015). Acosta-Gonzalez *et al.,* (2016): Jones *et al.,*

(2016) reported that bio-turbation which involves interaction between microorganisms, plants and micro fauna (nematodes) is also a form of biodegradation. For instance, burrowing animals (*Nereisvirens*) through their mobility processes may facilitate the dislocation of pollutants as well as aid aeration (oxygen) transfer to the microorganisms found within sediments.

Consortia of microorganism and enzymes involved in Bio-degradation:

Microbial consortia involves utilising multiple microbial species (natural or genetic) of broad enzymatic capabilities with variable degradation pathways rather than individual microbial species for complete hydrocarbon mineralisation, as consortium may lead to microbial biofilms (high density cells) or flocs formation as well as aid co-metabolism and co-oxidation (Mangwani *et al.*, 2015: Al-bahry, 2016). Table 2 summarises the diverse range of organisms and key enzymes involved in hydrocarbon degradation.

Organisms	Strains	Substrate	Type of microorganism	Enzymes	References
Nocardioides aromaticivorans	IC177	Chlorobenzene and polyaromatic hydrocarbons	Anaerobic	Lignin peroxidase	Chiekere, (2013)
Pseudomonas sp.	C18, PP2, DLC-P11, CA10	Aromatics derivatives	Aerobic and anaerobic	dioxygenase and Mg^{2+}-peroxidase	Pacwa-Płociniczak *et al.*, (2014)
Pseudomonas putida	P16, KT2440	Naphtelene, Toluene,benzoate.	Aerobic	Dioxygenase	Johnson *et al.*, (2013)
Pseudomonas aureginosa	NOO2	Aromatics	Aerobic and anaerobic.	Dioxygenase	Das *et al.*, 2015
Rhodococcus sp.	JZX-01	Alkylated dibenzothiophene	Aerobic	Versatile peroxidase	Li *et al.*, (2013).
Staphylococcus sp.	PN/Y	Dibenzo-p-dioxin	Anaerobic	laccase	Eddouaouda *et al.*, (2012)
Thermodesulforhabdus sp.	-	Aromatic sulfate derivatives	Anaerobic	Peroxidase	Fish-Low *et al.*, (2015)
Thauera sp.	-	Asphaltenes	Anaerobic	Peroxidases	Terron-Gonzalez *et al.*, (2016)
Xanthamonas sp.	-	Aromatics	Aerobic	Dioxygenase	Elkhir *et al.*, (2015)

Table 2: Microorganisms and their enzymes involve in biodegradation.

Hydrocarbons Bio-degradation Pathways:

Although hydrocarbons occupy an intermediate position between highly degradable (n-alkanes) and highly recalcitrant (poly-aromatics) compounds, yet partitioning by microbial population may yield complete mineralisation, as all degradation route (aerobic and anaerobic) utilises oxygenases as their primary mechanism as illustrated in figure 8 (Rojo*etal.,* 2009: Abbasian *et al.,* 2016). According to Wang *et al.,* (2013): Rojo, (2009), despite the lack of functional group (low reactivity) and low solubility of the aliphatic (alkanes) hydrocarbons, their accessibility to microbial cells due to surfactant- mediated processes enable their participation in both aerobic (predominant) and anaerobic degradation pathways as shown in figure(s) 9a & b respectively.

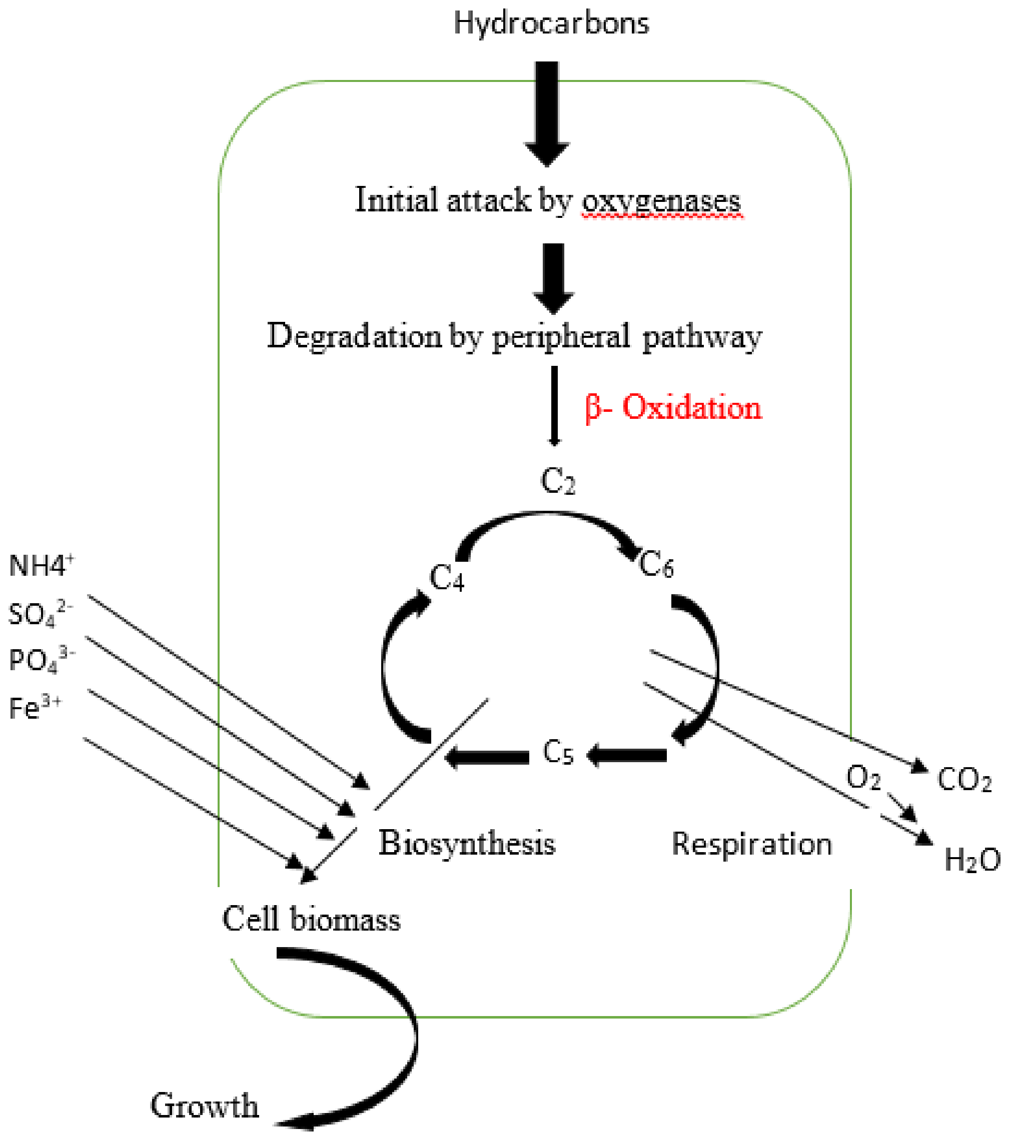


Figure 8: General pathway for hydrocarbon degradation. Source: (Rojo, 2009. pp23)

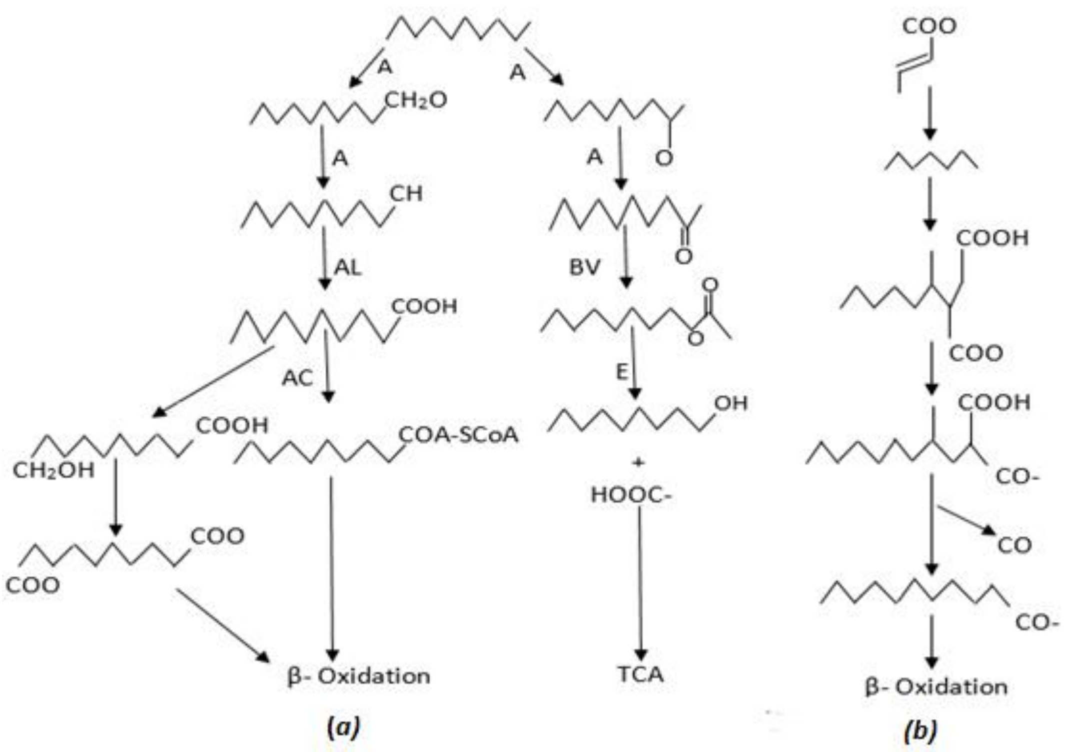


Figure 9(a&b): Aerobic and anaerobic degradation of aliphatic (alkanes) hydrocarbons. Source: (Rojo et al., 2009. pp2577-2490).

Factors affecting microbial degradation:

Microbial degradation of hydrocarbon is a complex process as its effectiveness is being influenced by many factors such as "concentration" level of both the microbes and that of the pollutants/hydrocarbons. For instance, high concentrations of branched chain aliphatic hydrocarbons tend to inhibit degradation by limiting oxygen and nutrient up-take (Sharma *et al.,* 2016). However, Lin *et al.,* (2014): Mdagri *et al.,* (2013): Slamet *et al.,* (2015) reported increased degradation rate of hydrocarbons due to high active cell density (biofilms) formation through various immobilisation methods (alginate beads, pumice stone and cotton fibre) that increases the cells ability to withstand high substrate concentrations.

Structural features, concentrations and solubility of some hydrocarbons enhance their "toxicity" as concentrations of poly-aromatic hydrocarbons at >100µg/ml for water and total petroleum hydrocarbons >12.57mg/g for soil have chronic toxic effect on some microorganisms (Wang *et al.,* 2016). Toxicity effect of 4mg/L of benzene on anaerobic bacteria *Dechloromonas strain RCB* and *Bacillus cereus* has been reported (Shadi *et al.,* 2015).

Bioavailability is another limiting factor encountered by microorganism as most hydrocarbons display hydrophobicity (low solubility). As such, most degrading microorganisms have shown the ability to produce surface acting agents or bio- surfactants such as glycolipids to reduce surface tension due to their polarities including pseudomonas spp. (rhamnolipids) (da Rosa *et al.,* 2015). Zahid *et al.,* (2015) reported a 78% degradation of benzene within 12days by *Pseudomonas aeruginosa* due to rhamnolipids production that facilitates degradation via pthalic acid pathway.

According to Cai *et al.,* (2015): He *et al.,* (2015), hydrocarbon degradation takes place both in the presence and absence of "oxygen". However, aerobic conditions (+O_2) are more common as the oxygenase reactions are the primary route for most hydrocarbon degradation. Thus, Optimum oxygen value for most microorganisms is 2- 3ppm in water phase or 0.3g of oxygen per gram of oil in soil remediation. Zengguang *et al.,* (2015) reported an 86% benzene degradation in groundwater treatment due to accelerated bacterial growth facilitated by the availability of dissolved oxygen provided by a novel slow-release oxygen source (SOS) technique.

Nutrients supplementation of nitrogen, pottasium and phosphorus enhances biodegradation at appropriate ratios of 15: 1: 1 of N: P: K respectively. Thus, 300µg of nitrogen as KNO_3 and 100µg of phosphorus as KH_2PO_4 optimise degradation rate (Goa *et al.,* 2013). Abed *et al.,* (2014) reported a 67% and 46% degradation of benzoate and benzene with initial concentration of 22mg/g and 55mg/g respectively, within 23 days after the addition of 2g/g of NH_4CL and 0.3g/g of $NaH_2PO_{4.}$

Although some psychotropic organisms can degrade hydrocarbons below 0^oC while some thermophilic organisms degrade at 70^oC, yet low temperature decreases enzymatic activities and affect oil fluidity by high viscosity and low emulsification formation which may increase toxicity (Sundaravadivelu *et al.,* 2015). El-Naas *et al.,* (2014) reported that temperature adjustment from 25^0C to 35^0C in an ex-situ biodegradation of benzene contaminated water by *Pseudomonas desmolyticum NCIM 212* yielded an increase in viable cell count from 5.1x 10^4cfu/ml – 3.5x 10^8cfu/ml that led to increase in degradation days from 12 to 24days. Thus, optimum temperature for aerobic and anaerobic degradation was reported as 15- 37^oC and 15- 25^oC respectively (Liu *et al.,* 2016).

According to Sawadogo *et al.,* 2014 neutral pH of 6.5- 7.0 enhances degradation as 50% increase in degradation rates of benzene in an acidic soil (pH 4.5) by pH adjustment to 7.4 was observed. Salinity concentrations of >3.3- 28.2% tend to inhibit degradation due to osmotic pressure exerted on cells, while low moisture content (< 25%) tends to affect microbial activities (Adam, 2016). Although barophiles (deep marine) are reported to require high pressure (100Mpa) for growth, yet some microbial growths are inhibited under high pressure. In addition, availability of light does have a positive impact on photosynthetic algae and fungal (Khan *et al.,* 2016). Table 3 summarises the optimum conditions required for hydrocarbon mineralisation.

Environmental factors	Optimum Conditions	References
Soil moisture content	25- 80% water holding capacity	Adam, (2016)
Oxygen	2-3ppm water phase and 0.3g/g soil	He *et al.*, (2015)
Redox potential	>50mill Volts	Hambrick *et al.*, (1980)
Nutrients	N:P:K = 15:1:1	Goa *et al.*, (2013)
Temperature	15- 37°C (aerobic), 15- 25°c (anaerobic)	Liu *et al.*, (2016)
pH	6.5- 7.0	Sawadogo *et al.*, (2014)
Contaminants (hydrocarbons)	5- 10% dry weight of soil	Horel et al., (2015)

Table 3: Hydrocarbons degradation optimum conditions.

Conclusion/Recommendation(s):

In conclusion, oil spills are not only hazardous to the public and environment but also on the upsurge with increase in demand of fuels due to rapid urbanisation and growing population. As such, continuous treatment via conventional remediation methods may not only prove unsafe due to the production of secondary pollutants such as methane as in the case of thermal treatment but also expensive. For instance, the Ogoniland clean-up in Nigeria which is stated to be the largest and most expensive clean- up in history is budgeted at 1billion dollars alongside 20yrs before full restoration. In view of this, bioremediation could be the best clean up alternative as not only it is a green method with less damage to the ecosystem but also cost effective that requires less start up material, less labour force and less restoration time as the microorganism utilises the pollutants as their carbon source. Hence, the writer recommends a future investigation into the utilisation of such microbes (bioremediation) in the treatment of soil and groundwater sampled from such oil drilling sites including the Ogoniland region.

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