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Remediation of Petroleum Contaminated Soils: An Overview

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ABSTRACT

The removal of hydrocarbons from contaminated soil is an essential practice because of environmental and health concerns, and in order to avoid further contamination of surface and groundwater. A variety of oil-contaminated soil remediation methods, categorized as physiochemical, biological and thermal remediation were compiled and summarized. However, the efficiency of these methods depends on several factors, such as the amount of spilled oil and the penetration depth of the oil into the soil, the type of oil and polluted soil, and the age and degree of contamination. With respect to remediation in the Niger Delta Region of Nigeria, it has been shown by studies that bioremediation and phytoremediation are the best methods that have been used in the area for the remediation of petroleum in soil due to the fact that it is cheap, easy to manage (even by the community), proved to be effective in enhancing biodegradation and environmentally safe. Finally, as there is no universal method that can be generally applied to completely remove the oil from contaminated sites, thus, the prevention of oil spills or leakages should be the first concern. However, if oil spills or leakages occur, a response should be taken immediately to minimize the potential environmental consequences. Furthermore, constant environmental monitoring, assessment, and evaluation to determine the level of damage that is caused by oil spills on the environment.

1.0 Introduction

Soil is a fundamental and irreplaceable natural resource, which provides an essential, link between the components (air, bedrock, water, and biota) that make up our environment, these components interact with each other to provide essential needs like food, fuel, and fiber to support the organism (Department for Environment, Food and Rural Affairs DEFRA, 2009; Adipah, 2020). Soil is the material basis for sustainable economic and social development, and is one of the most valuable natural resources in each country, especially for our country (Wang et al., 2017). Petroleum contamination of soil is a widespread and well-recognized global environmental issue. Petroleum production, refining, transportation, and use contribute to environmental pollution. The contamination of soil with petroleum hydrocarbons causes a significant decline in its quality, and such soils become unusable. Petroleum or crude oil is a natural product, resulting from the anaerobic conversion of biomass under high temperature and pressure. Petroleum hydrocarbon contaminants characterize the vast majority of organic compounds and by-products that are classified as priority environmental pollutants such as persistent organic pollutants (POPs) and polycyclic aromatic hydrocarbons (PAHs) due to their persistence and recalcitrant nature (Ossai et al., 2020). They are persistent and stable, and thus remain long in the environment and do not undergo degradation easily (Dindar et al., 2013; Gennadiev et al., 2015; Jesus et al., 2015; Ossai et al., 2020). Contamination of this type is common because of storage tank and piping leaks, spills on land surfaces, and improper disposal practices.

Although, the prevailing environmental conditions affect the behavior of contaminants in soil, influence the partitioning of the organic compounds between the different phases, and affect their degradation rate (Chen and Wu, 1998). A variety of physical, chemical, and biological techniques have been successfully used to clean up soil and groundwater contaminated with petroleum hydrocarbons, including, excavation of shallow contaminated soils, and vapor extraction. To understand the scope and the best treatment options for remediation of soil surface water and groundwater contaminated with petroleum hydrocarbon, it is vital to understand the nature, composition, and properties of the contaminants, type of environment, fate, transport, and distribution of the contaminants in the affected environment, mechanism of contaminants degradation, the interactions and relationships with microorganisms and the intrinsic and extrinsic factors affecting degradation of the pollutants, in order to predict and mitigate effects of pollution and to limit exposure of human and animals to the contaminants (Artiola et al., 2004; Valentin et al., 2013; Ossai et al., 2020). This paper therefore gives an overview of all these techniques.

1.1 Composition of Petroleum

Knowledge of the constituent of petroleum is important as it will aid in the selection of a particular method that would be used in remediating a petroleum-contaminated site. However, a precise description of the chemical composition of crude oil is not practicable because of its complexity.

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These compounds of petroleum hydrocarbons can be categorized into four simple fractions:

i. Saturates (or alkanes);
ii. Aromatics, including such compounds as benzene, toluene, ethylbenzene and xylenes (BTEX) and polyaromatic hydrocarbons (PAHs);
iii. Resins, consisting of compounds containing nitrogen, sulphur, and oxygen, that are dissolved in oil; and
iv. Asphaltenes, which are large and complex molecules that are colloidally dispersed in oil.

The relative proportions of these fractions are dependent on many factors, including source, age, migration, etc. Of these fractions, the shorter alkane chain compounds and the lighter aromatics (such as BTEX) tend to be more readily biodegradable.

1.2 Sources of Petroleum Contamination

According to Ossai et al. (2020), sources of petroleum hydrocarbon entering the environment are numerous as the numbers of individual hydrocarbon components are quite large. In developing and developed countries, the main sources and polluting activities may vary from each other. In Europe for instance, contaminated oil is caused by industrial and commercial activities as a result of the treatment or disposal of waste (Environmental Agency EEA, 2007). Sources of oil spills could be classified as point and non-point sources. They are briefly discussed below.

Point Sources

Spills from tankers, pipelines, and oil wells are examples of *point sources* of pollution, where the origin of the contaminants is a single identifiable point. They also represent catastrophic releases of a large volume of pollutants in a short period of time.

Non-Point Sources

The majority of pollution from oil is usually from nonpoint sources, where small amounts coming from many different places over a long period of time add up to large-scale effects. A large percentage of the oil released by human activity into oceans worldwide is a result of small spills during petroleum consumption. These minor unreported spills can include routine discharges of fuel from commercial vessels or leakage from recreational boats.

1.3 Fate of Petroleum Hydrocarbons (PHCs) in the Soil

Soil is one of the natural resources, which need to be protected with the utmost attention and care although only a meter in depth over the earth's surface, the soil is a key to sustaining life-affecting air and water quality, the growth of plants and crops, and the health of the entire planet (Bohn et al., 2001; Adipah, 2019). The soil is able to degrade more chemicals quickly and bring its components back to their natural cycles, and this minimizes the environmental disturbance brought by contamination (Bohn et al., 2001; Adipah, 2019).

Once the oil is spilled into the environment, thousands of compounds are formed, mainly hydrocarbons, and a small proportion of nitrogen, sulfur, and oxygen, in their right proportion are produced (CCME, 2001; Adipah, 2019). The fate of PHCs following an oil spill is summarized in Figure1, Once the PHCs are released into the soil, depending on their chemical properties the complex PHCs mixture then separate into individual compounds.

1.4 Effects of Petroleum Contamination

One fundamental problem that faces the oil-producing areas today is the degradation of the environment. The oil-producing communities in Nigeria, such as in the Niger Delta area of Nigeria are crisscrossed by thousands of kilometers of pipeline, punctuated by wells and flow stations. Much of the oil infrastructure is located close to the homes, farms, and water sources of communities and these have impacted on these communities in several ways, including:

Loss of Habitat**:** In the process of extracting oil in the past five decades, ecological devastation, on the one hand, and neglect arising from crude oil production, on the other hand, have left many of these communities desolate, uninhabitable, and poor. One fundamental problem that faces the oil-producing areas today is the degradation of its environment. These include: contamination of both surface and groundwater by benzene, xylene, toluene, and ethylbenzene; contamination of soil by oil spills and leaks; increased deforestation; as well as the economic loss and environmental degradation stemming from gas flaring

Thermal Pollution**:** The thermal state of Niger Delta is influenced by natural phenomena such as weather, climate, radioactivity and the greenhouse effect as well as artificial phenomena such as oil spillage, deforestation, and burning of materials which are either flammable or non-flammable (Akpabio et al., 2010). Although the thermal gradient increases with depth, the exposed surface of Benin Formation is predominantly made to depart from its natural thermal state through man's activities which are either deliberate or in-deliberate. Apart from the uncontrollable means or the agricultural contributions to the departure of the thermal silicic soil built on the deposits of the high-energy Niger Delta, oil spillage has among other things contributed greatly to the thermal destabilization. The impacts of oil spillage and gas flares have been experienced in Nigeria in recent years and its occurrence is at a very fast and alarming rate in the oil-producing communities (George et al., 2010).

Effects on Vegetation: The volatile, quickly penetrating, and viscous properties of petroleum have wiped out large areas of vegetation. When spills occur close to and within the drainage basin, the hydrologic force of both the river and tides force spilled petroleum to move up into vegetated areas. Oil pollution in many intertidal creeks has left mangroves denuded of leaves and stems, leaving roots coated in a bitumen-like substance sometimes 1 cm or thicker. Mangroves are spawning areas for fish and nurseries for juvenile fish and the extensive pollution of these areas is impacting the fish life cycle. Any crops in areas directly impacted by oil spills will be damaged, and root crops, such as cassava, will become unusable. When farming recommences, plants generally show signs of stress and yields are reportedly lower than in non-impacted areas.

When an oil spill occurs on land, fires often break out, killing vegetation and creating a crust over the land, making remediation or revegetation difficult. Without proper remediation, former mangrove areas which have been converted to bare ground could be colonized by invasive species such as nipa palm (which appears to be more resistant to heavy hydrocarbon pollution than native vegetation) (Adelana et al., 2011).

Effect on Soil/Farmland: Soil is important in agriculture. Its temperature depends on the pore spaces and the material making up the formation. In all ramifications, soil temperature depends on the environmental temperature (George et al., 2010). However, spillage of crude oil on the soil greatly affects the thermal properties of the soil samples. Soil contamination results in poor soil fertility, leading to poor crop productivity in the area. Contaminated soil can affect the health of organisms through direct contact or via ingestion or inhalation of soil contaminants that have been vaporized. Soil also acts as a reservoir of residual pollution, releasing contaminants into groundwater or air over extended periods of time, often after the original source of pollution has been removed.

***Effects on Human Health*:** The effects on human health are all related to the exposure of those hazardous air pollutants emitted during incomplete combustion of gas flares. These pollutants are associated with a variety of adverse health impacts, including cancer, neurological disorders, respiratory diseases, reproductive, and development effects (Kindzierski, 2000) (Figure 2). According to Omofonmwan and Odia, (2009) respiratory problems, coughing up blood, skin rashes, tumors, gastrointestinal problems, different forms of cancer, and malnourishment, were commonly reported ailments in many communities (Figure 2).

***Loss of Lives*:** Oil pipeline spillage and vandalization can cause fire disasters with tragic consequences. Many lives are lost in a most sudden tragic, and violent manner when the fire is mistakenly ignited (Lawal and Ese, 2012). When pipelines are vandalized, oil spills and marine organisms may become contaminated by poly-nuclear aromatic hydrocarbon (PNAS). Thus because many organisms such as oysters, crabs, lobsters, mussels, and many types of fin fishes are often part of man's diet their contamination could be a threat to human health (Lawal and Ese, 2012).

***Effects on Surface and Groundwater Resources*:** The spill of oil on soils especially in urban areas is a major concern, as they often spread out over a wide area, thus resulting to contamination of the groundwater and pollution of nearby surface water.

2.0 Remediation of Petroleum Contaminated Soils

There are various methods of remediating oil-contaminated soil such as bioremediation, soil vapor extraction, soil washing, thermal treatment, and chemical oxidation but the most common conventional method is excavation followed by landfilling or incineration (Lynn et al., 2002) (Figure 4). However, excavation and landfilling are costly and do not only destroy contaminants but also cause secondary pollution such as the formation of volatile organic compounds (VOCs). Studies have proved that there is a lack of sufficient qualitative and quantitative data due to rehabilitating and restoring soil contamination and also, this results in great costs to the society (European Commission EC, 2006). Due to this, U.S. Environmental Protection Agency (USEPA, 1986) has proposed; physical, chemical, biological and thermal approaches for treating soils contaminated by petroleum hydrocarbons. Regardless, this paper selected only physiochemical, biological and thermal remediation as methods of focus.

2.1 Physicochemical Remediation

Examples of physicochemical methods are soil excavation, soil vapour extraction, soil washing (with water, reagents, and solvents such as dispersants, demulsifiers, bio-surfactants), achievable through methods such as chemical immobilization, oxidation, vitrifying technology, chemical fixation, chemical leaching and electro-kinetic remediation (Zabbey et al., 2017; Adesipo et al., 2020).

Isolation and containment (in situ)

This technique uses physical barriers and mechanical barriers to minimize, restrict and prevent the contaminants from further movement such as the horizontal and vertical migration, seepage, permeability and leaching in the soil, sediments and groundwater, and prevent and restrict the spreading on surface water to avoid reaching potential receptors such as biologically sensitive environments (Jankaite and Vasarevičius, 2005).

Soil washing or soil flushing (in situ and ex-situ)

This process removes contaminants such as volatile and semi-volatile organic compounds from the soil through washing and scrubbing of the soil with a liquid, and then separates the clean soil from the contaminated soil and flushing water (USEPA, 1996). Soil washing or soil flushing is based on the physicochemical processes that occur in the soil, between the soil particles and the washing solution in which they are dispersed (Ossai et al., 2020).

Skimmers (in situ)

Skimmers are mechanical barriers designed to remove floating oil (oil slicks) from the water surface at sea before it reaches the sensitive coastline, and are classified based on the area where they are used such as inshore, offshore, in shallow water, or in rivers. Skimmers are designed to recover oil in preference to water and are in form of a belt, disc, drum, mop, and floating suction with the never-ending surface for spill oil to cling to (Ossai et al., 2020).

Pump and treat (in situ)

This technique is primarily for groundwater and soil remediation, and mostly for contaminants such as petroleum hydrocarbon compounds, volatile organic compounds (VOCs), semi-volatile organic compounds (SVOCs), fuel oil, metals, chemical compounds dissolved in groundwater. The process involves pumping groundwater to the aboveground treatment system where the contaminants are removed by other remediation treatment methods such as air stripping, ultraviolet, activated carbon, and biodegradation (Ossai et al., 2020).

These methods according to Adesipo et al. (2020) are very fast and can be effectively employed on heavily contaminated soils. However, they are generally intensive and cost demanding with the potential to re-contaminate other media.

2.2 Biological Remediation

Ossai et al. (2020) stated that the feasibility of a biological treatment method depends largely on the limiting factors as well as the location of the contaminants. It also depends on the contaminated soil, sediments, surface water and groundwater to be remediated, whether it is intact in the environment or to be removed, excavated, and transported for treatment to an off-site treatment facility (Ossai et al., 2020). If treatment is on-site, the term in-situ is used while if the treatment is offsite, ex-situ suffices (Hamzah et al., 2013; Ossai et al., 2020). Some examples are discussed below.

Phytoremediation (in situ and ex situ)

This is the process by which green plants are used to remove or extract contaminants in the soil, sediments, surface water, and groundwater. The technique removes the contaminants from the soil (decontamination) or sequesters the contaminants into the matrix (stabilization) (Adam, 2001). The process takes advantage of the natural processes of the green plants (Ossai et al., 2014).

Phytoremediation has five approaches which include phyto-stabilization, phyto-volatilization, phyto-extraction, phyto-degradation, and rhizodegradation (Lim et al., 2016; Ngene and Tota-Maharaj, 2019). Phyto-stabilisation is the use of plant roots to absorb and precipitate contaminants thereby fixing them to a point and reducing their bioavailability and migration to other ecological systems such as the food chain and underground water (Yao et al., 2012). Phyto-volatilisation is the transfer of contaminants (e.g. mercury) to a gaseous state using special matters secreted by plant roots (Watanabe, 1997; Ngene and Tota-Maharaj, 2019). Phyto-extraction on the other hand involves the use of tolerant and accumulating plants to absorb contaminants from soil, which are transferred and stored in over-ground parts (Yao et al., 2012).

Bioremediation (in-situ and ex-situ)

Bioremediation is using micro-organisms to reduce or break down hazardous organic material into harmless compounds, such as CO_2 and water (Ngene and Tota-Maharaj, 2019). This is a facile, environmental-friendly, sustainable, and cost-efficient method for the restoration and cleaning of contaminants in the soil (Ossai et al., 2020). It involves the natural degradation of petroleum hydrocarbon contaminants by hydrocarbon-degrading microorganisms such as bacteria, fungi, and yeast.

Ngene and Tota-Maharaj (2019) posited that bioremediation is an approach that facilitates the natural biodegradation process of hydrocarbons through the provision of nutrients and oxygen required by microbes. Bioremediation technologies are cost-effective and resource-conservative approaches (Susarla et al., 2002; Lim et al., 2016). Before adopting bioremediation, it is important to evaluate all the limiting parameters that can effectively affect the efficacy of the remediation process (Ossai et al., 2020). The aliphatic hydrocarbons are more easily degradable by the microorganisms whereas the long chain and the branched or cyclic chain hydrocarbon are more resistant to bioremediation (Maletic et al., 2011). Three distinctive approaches are adopted in the context of bioremediation, namely, bioaugmentation, biostimulation, and bioventilation (Ngene and Tota-Maharaj, 2019).

Bioaugmentation

Bioaugmentation is used to enhance the performance of the microbial population through the addition of bacteria with specific catabolic activities, strains, or enrichment consortia to increase the rate of contaminant degradation (Lim et al., 2016; Ngene and Tota-Maharaj, 2019). Covino et al. (2015) demonstrated bioaugmentation by using autochthonous fungi from petroleum hydrocarbon contaminated soil to degrade clay soil contaminated with petroleum hydrocarbons band achieve a removal efficiency of 79.7% after 60 days period.

Biostimulation

The adjustment of environmental parameters such as nutrient introduction, biopolymers, and biosurfactants is described as biostimulation (Jiang et al., 2016). The adjustment of these parameters could stimulate the growth of oil-degrading microbes and thus the rate of responsive degradation by the microbes (Ngene and Tota-Maharaj, 2019). Biostimulation is the most successful and efficient bioremediation method in comparison with other in situ remediation in simulated soil contaminated with petroleum hydrocarbons (Simpanen et al., 2016; Ossai et al., 2020).

Bioventilation

Bioventilation on the other hand involves the addition of oxygen to the soil voids to stimulate the growth of microbes (Ngene and Tota-Maharaj, 2019). Oxygen is a necessity and often the limiting factor in the process of biodegradation as it enhances microbial metabolism of organic matter and generates more energy (Lim et al., 2016). In a study demonstrated by Agarry and Latinwo (2015), bioventing was conducted on diesel oil-contaminated soil amended with brewery effluents as an organic agent over 28 days period and achieved a removal efficiency of 91.5%.

2.3 Thermal Remediation

These treatment methods involve the use of heating systems to bring about volatilization and desorption of organic compounds through an increase in heating temperature above 300 ◦C to cause the removal of low and high molecular weight petroleum hydrocarbons and volatile and semi-volatile compounds in the contaminated media or cause destruction of contaminants in the media (Ossai et al., 2020). In Ossai et al. (2020), the methods include thermal desorption, steam injection, and extraction, conducive heating, pyrolysis, smoldering combustion, incineration, and vitrification. Three are discussed briefly below.

Thermal desorption (ex-situ and in situ)

This is based on a physical separation system involving volatilization and desorption of the contaminants from the contaminated soil through the direct or indirect application of heat under vacuum or into a carrier gas to separate target contaminants from the impacted soil (Mirsal, 2008; Ivshina et al., 2015; Ossai et al., 2020).

Pyrolysis (in situ and ex-situ)

This involves the thermal heating or thermal cracking of soils contaminated with organic compounds, semi-organic compounds, and oily sludge in an anoxic condition or inert atmosphere at elevated temperatures ranging between 400 ◦C to 1200 ◦C under pressure (Venderbosch et al., 2010; Moldoveanu, 2019; Ossai et al., 2020).

Vitrification (in situ and ex situ)

This involves the use of high-temperature heating ranging between 1600 ◦C to 2000 ◦C for conversion of contaminants such as contaminated soil and a variety of organic and semi-organic compounds into vitreous products comprising chemical durable glass-like solid, bulk glass, frit, and crystals, (Yeung, 2010; Abousnina et al., 2016; Godheja et al., 2016; Ossai et al., 2020).

3.0 Remediation of Petroleum Soils So Far In Nigeria

The Niger Delta is the region that sits directly on the Gulf of Guinea on the Atlantic Ocean in Nigeria. It is located within the nine coastal Nigerian states of Abia, Akwa Ibom, Bayelsa, Cross River, Delta, Edo, Imo, Ondo, and Rivers (Ngene and Tota-Maharaj, 2019). The region extends over an area of about 112,000 square Km and makes up about 12.0 percent of Nigeria's landmass. With a population of about 31 million people in about 3000 communities (NDDC, 2014), the region is one of the most densely populated regions of Africa (Steiner, 2010). Several technologies have been employed for the remediation of crude oil contaminated land in the Niger Delta, but these efforts have yielded little or no success as they are either inappropriate for the environment and thus complete remediation is not achieved (Gaidom, 2015) or they negatively impacted the environment (e.g open dump burning) and consequently led to pollution (Ngene and Tota-Maharaj, 2019).

For instance, Adekunle et al. (2015) did an overview of past and present field-scale petroleum hydrocarbon biodegradation techniques utilized in Nigeria was conducted using the tools of literature review and field survey (Figure 6). Pilot-scale biodegradation of hydrocarbons in the petroleum-impacted clay soil of up to 42-year-long contamination using novel and eco-safe CNB-Tech was carried out (Figure 7). This was followed by a comparative evaluation of crop growth performance on crude-oil-polluted soil remediated using a biodegradation technique adopted by a reputable oil company in Nigeria and the innovative CNB-Tech.

This study revealed that CNB-Tech is an innovative, time-effective, cost-effective, and eco-friendly bioremediation technique and has the potential to excel over some existing biodegradation procedures employed by many oil industries especially in the developing countries (Adekunle et al., 2015).

Recently, Adesipo et al. (2020) in their paper discussed the prospects of in-situ remediation of the crude oil contaminated sites on a large scale in Nigeria. In consideration of current Nigeria's status of crude oil contamination and associated limiting factors to remediation, phytoremediation is the most preferable treatment technique recommendable. According to Adesipo et al. (2020), it is cheap, easy to manage (even by the community), liable to gain public acceptance, and restore livelihood (agriculture and fishing) to the inhabitants.

They also outlined practical factors such as site conditions, plant characteristics, agronomic measures, cost estimation, operation and maintenance, the fate of the harvested plants, and regulatory standards. Herbaceous species and trees (i.e. for dendroremediation) which are climatically and environmentally adapted to Nigeria (and other tropical climates) were listed. However, on heavily contaminated soils, phytoremediation can be employed as a final "polishing step" after conventional clean-up and can be combined with other techniques such as vermiremediation so as to enhance efficiency (Adesipo et al., 2020).

The authors suggested that since it requires little skill/management technique, it can be further employed and managed in each community by the citizens with less continuous demand from the government. However, they stated that provision needs to be made for it in the national environmental law in order to enact necessary standards and monitoring regulations. Capacity strengthening, adequate attention, and funding, as well as the active involvement of the stakeholders and the affected community, should accompany this. These prospects are not limited to Nigeria; it is applicable to neighbouring countries as well to other tropical countries with similar climate conditions around the globe (Adesipo et al., 2020).

Effect of Bioremediation on Crude Oil Contaminated Sites (Niger Delta)

The effect of bioremediation on some sites within the Niger Delta are briefly discussed below.

Goi Community in Ogoniland: Samples of soil from crude oil contaminated area in this Niger Delta community was subjected to application of nitrogen-phosphorous-potassium fertilizer at proper aeration and watering (Ngene and Tota-Maharaj, 2019). The result showed that 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 lowland environments and environmental parameters besides nutrients affect degradation rates in the field (Akpan et al., 2013; Ngene and Tota-Maharaj, 2019).

Ajoki Community in Ikpoba Okha: The remediation process was done using denitrifying bacteria for 27 days at 7 days intervals (Ngene and Tota-Maharaj, 2019). The results show that the remediation method adopted yielded a positive result which, however, reduced the soil organic content, total nitrogen, nitrate, and phosphorus (Imasuen et al., 2014; Ngene and Tota-Maharaj, 2019).

According to Ngene and Tota-Maharaj (2019), several remediation technologies have been tried in the Niger Delta region of Nigeria to address the persistent hydrocarbon contamination with little or no success as they are either inappropriate for the environment and thus complete remediation is not achieved or they negatively impacted the environment which consequently leads to air pollution. The removal of hydrocarbons from contaminated soil is an essential practice because of its attendant environmental and public health concerns. With respect to remediation, it has been shown by studies that bioremediation and phytoremediation are the best methods that have been used in the area for the remediation of petroleum in soil due to the fact that it is cheap, easy to manage (even by the community), proved to be effective in enhancing biodegradation and environmentally safe.

Conclusion and Recommendations

Many operations in petroleum exploration, production, and transportation have the potential to affect the environment to different degrees. Apart from affecting the chemical properties of the soil, it also resulted to poor soil fertility or nutrient, leading to poor crop productivity in the area as well as pollution of rivers and streams where fishing activities were carried out. People in the affected areas complain about health issues including breathing problems and skin lesions; many have lost basic human rights such as health, access to food, clean water, and the ability to work. Some of the hydrocarbon components in crude oil have a certain degree of water solubility and are toxic. Therefore, the removal of hydrocarbon from soil and from water surfaces is an essential practice to prevent contamination of water aquifers. There are many remediation techniques (physiochemical, biological and thermal) available to treat the oil-contaminated sites offshore as well as onshore; however, the removal efficiency of these methods depends on the type of oil, type of soil, weather conditions, penetration depth, the sensitivity of the location and the toxicity of the chemicals. As there is no universal method that can be generally applied to completely remove the oil from contaminated sites, thus, the prevention of oil spills or leakages should be the first concern. However, if oil spills or leakages occur, a response should be taken immediately to minimize the potential environmental consequences. Furthermore, constant environmental monitoring, assessment, and evaluation to determine the level of damage that is caused by oil spills on the environment.

Table 1. The composition of oilfield sewage (Adapted from Wang et al., 2017)

Type	Primary Materials
Crude oil	Oil content 1000-200 mg/l, oil spills, dispersed oil, emulsified oil, and dissolved oil
Inorganic salts	Ca^{2+}, Mg^{2+}, K^{+}, Na^{+}, Cl^{-}, HCO^{3-}, CO^{2-}, SO_4^{2-}
Organics	Aliphatic hydrocarbon, aromatic hydrocarbon, phenols, organic sulphide, aliphatic acid, polymers
Inorganic matter	H2S, FeS, clay particles, silt and fine sand
Microorganism	Sulphate reducing bacteria, saprophytic bacteria and iron bacteria

Table 2. Trees for potential phytoremediation of oil-contaminated lands in Nigeria (Adesipo et al., 2020)

Species	Country	Outcome / Suggestions
Treculia africana	Nigeria	*Treculia africana* can potentially remediate low contaminated soils. Number of leaves, leaf area, plant height, collar girth and dry biomass of the plant were insignificant up to 4.56 %, but significant at higher level.
Irvingia gabonensis	Nigeria	Efficient for remediating low concentration of crude oil impacted soil and influence its growth significantly.
Thespesia populnea, Cordia subcordata, Prosopis pallida	Hawaii USA	The three species show phytoremediation potential in coastal tropics, however, the first two appeared more promising
Jatropha curcas	Nigeria	Effect of spent engine oil contamination on *J. curcas* growth, development and yield (biomass accumulation) is significantly negative and increases in its trace elements
Acacia angustissima, Acacia auriculiformis, Acacia holosericea, Acacia mangium, Mimosa artemisiana, Mimosa caesalpiniifolia, and *Samanea saman*	Brazil	Decreasing potential of *Samanea saman* is high due to its symbiotic micro-organisms. *A.angustissima* and *M.caesalpiniifolia* have high tolerant ability but did not decrease TPH. *M. artemisiana* significantly decreased soil TPH but its growth was severely affected, suggesting that plant growth and adaptation were not directly related to its TPH reduction but to the plants association with symbionts.
Tectona grandis (Linn.), *Gmelina arborea*	Nigeria	At 10 and 15 % respectively, plant height, number of leaves, leaf area, plant girth and dry biomass were significantly affected but effect was not significant in comparison with uncontaminated site.

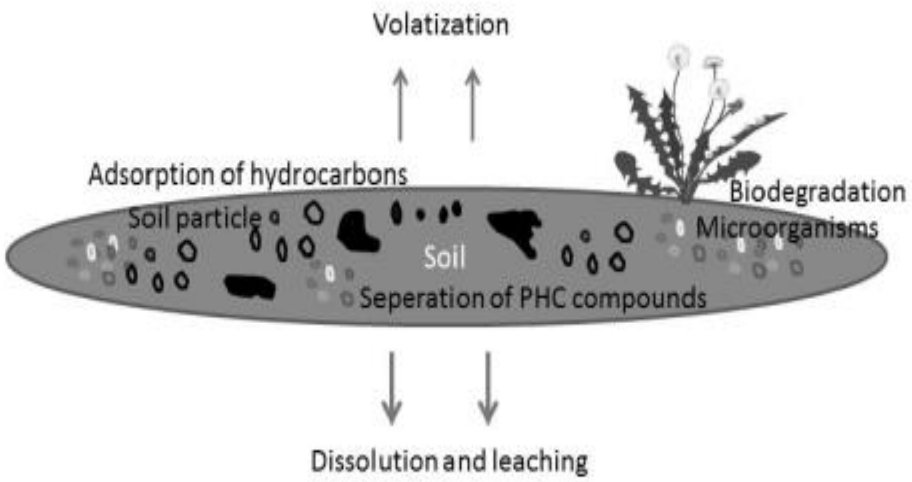

Figure 1. Physical and biochemical behavior of petroleum hydrocarbons in the soil according to ATSDR (1999).

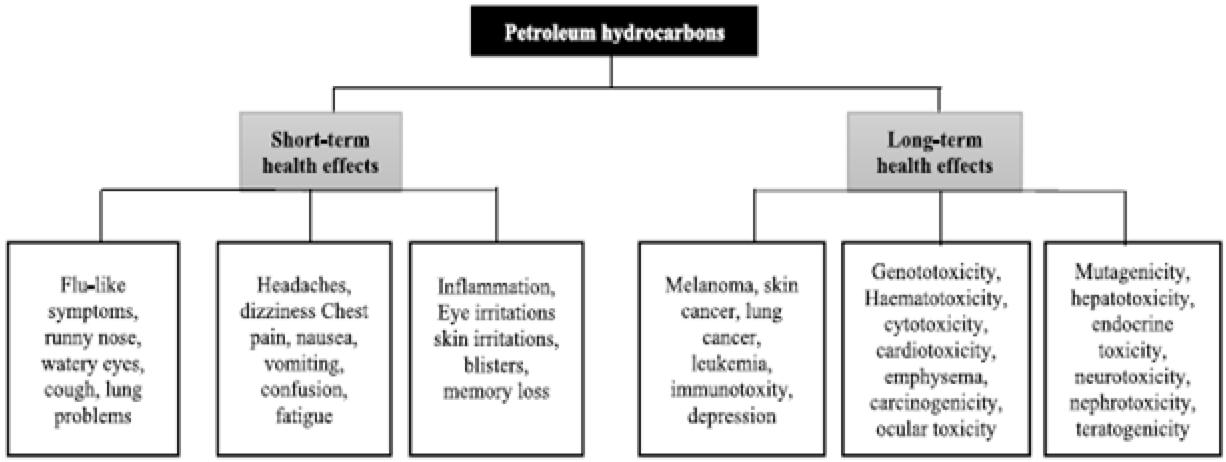

Figure 2. Toxicological health effects of overexposure to petroleum hydrocarbons (Adapted from Ossai et al., 2020).

Figure 3. Fire outbreak on a farmland in Niger Delta (UNEP, 2012)

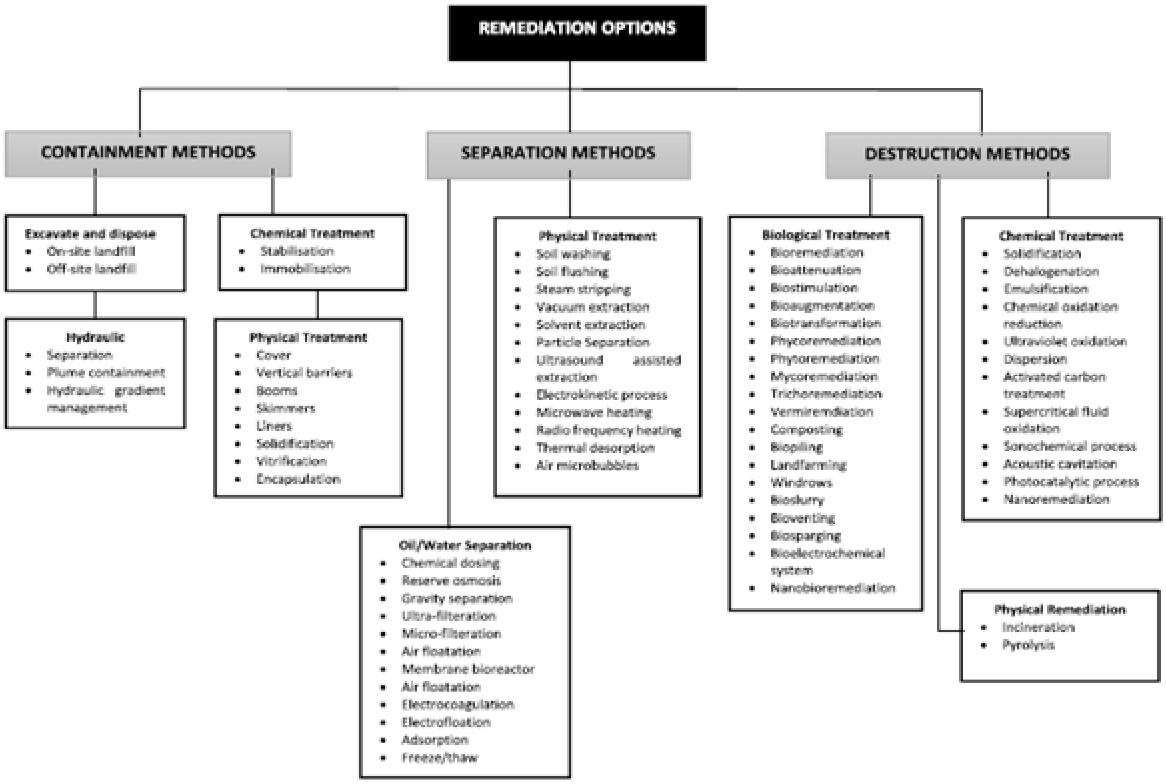

Figure 4. Remediation options for containment, separation and destruction of petroleum hydrocarbons in polluted environments (Adapted from Ossai et al., 2020).

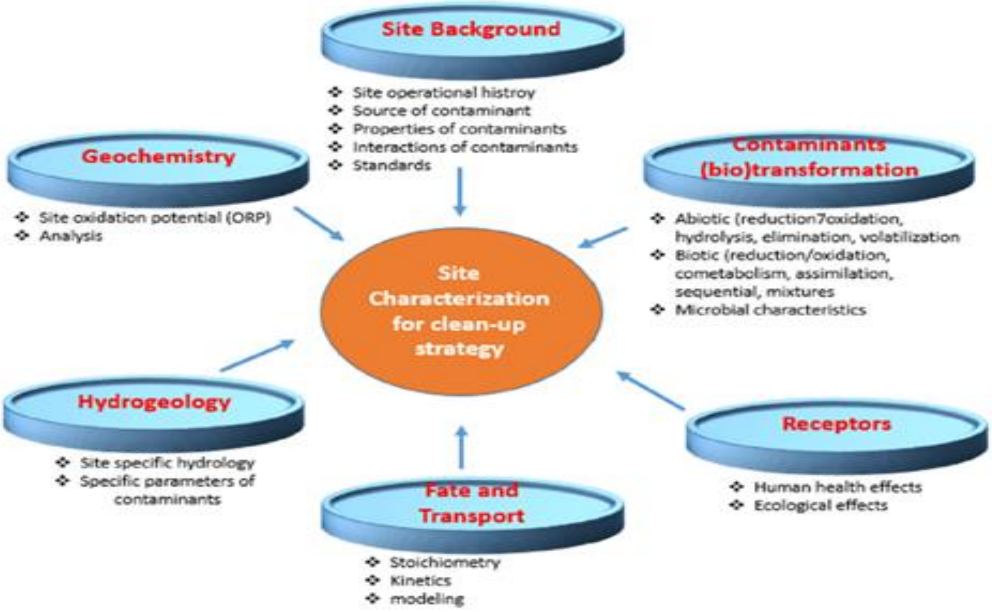

Figure 5. Characterization factors in determining clean-up strategy (Adapted from ITRC, 2002; Adesipo et al., 2020).

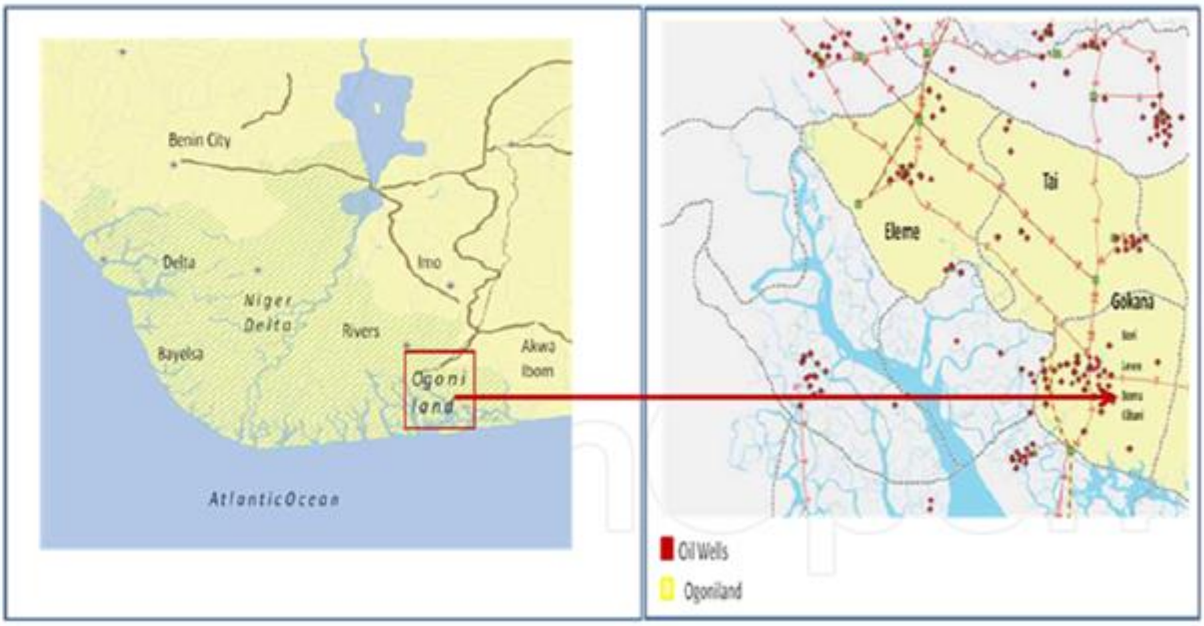

Figure 6. Bomu in Ogoniland, Nigeria (sourced from UNEP, 2011; Adekunle et al., 2015).

Figure 7. The three different sample bulks showing a grid template of 12 cells created on each sample, from which samples were collected for physicochemical analyses (Adekunle et al., 2015)

Figure 8. Appearance of the crude-oil-impacted clay soil before and after CNB-Tech treatment (Adekunle et al., 2015)

Figure 9. Digital capture, illustrating the growth of cassava crop grown in RENA remediated soil (RMS) and CNB-Tech remediated soil (CRMS), where DAG stands for the day after germination, H stands for height, SG stands for stem girth, and ME02 stands for *Manihot esculanta Crantz* (Cassava) (Adekunle et al., 2015).

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