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Overview of Oil Exploration in Nigeria: Contemporary Scope and Remediation Technology

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Abstract: Despite the economic advantages of finding and exploiting crude oil in Africa, oil exploration undoubtedly has far-reaching negative consequences for the air, land, and water as well as all life on Earth. The proliferation of various soil and water fixing techniques is a pointer to the need for urgent repair and remediation of various media that have been polluted as a result of the discharge of oil into the environment otherwise known as an oil spill. Bringing an environment that has been affected by oil spills back to their original form serves to reduce cost and other implications. But before arriving at the decision on which remediation technique to be adopted, one needs to know the features, as well as the characteristics and pullback of available technologies in terms of cost, speed, and environmental aftermaths of selected techniques. This review takes a foray into the numerous remediation strategies in the treatment of oil spillages with emphasis on their prospects and environmental implications by analyzing published works on scholarly sites. Methods reviewed range from natural attenuation to combined remediation methods. It was discovered that most remediation technologies end up altering the physio-chemical properties of soil thus limiting its functionality. These methods are first experimented outside of the place where the oil spill occurs hence little or no correction is made for variations in ambient conditions on the polluted site, and the laboratory. Hence the need to implement sustainable remediation practices. From literature, faster remediation of contamination media results in greater harm to the environment while environmentally friendly technologies are much slower. If oil spills can be prevented in the first instant the cost and attending implication of oil spill treatment will be minimal. There is the urgent need to imbibe sustainable remediation as a policy document in countries bedeviled with oil spills.

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1. Introduction

The proliferation of various soil and water fixing techniques is a pointer to the need for urgent repair and remediation of various media that has been polluted as a result of the discharge of oil into the environment otherwise known as oil spill (Sales da Silva and Maranho, 2019). Ecosystem functions of the natural environment cannot be substituted or adequately evaluated as they are interlinked according to (Turner *et al.*, 1998). Bringing environment that has been affected by oil spills back to their original form serves to reduce costs and other implications. But before arriving at the decision on which remediation technique to adopt, one needs to know the features, as well as the characteristics and pullbacks of available technologies in terms of cost, speed, and environmental aftermaths of selected techniques. From the available literature, the faster the remediation of contamination in soil and water, the greater the harm to the environment while environmentally friendly technologies are much slower (Paria, 2008, Peng *et al.*, 2009; Jodeh *et al.*, 2015). This review takes a preliminary look at oil exploration in Nigeria; as well as the remediation technologies globally used in addressing oil spills in the environment. While individual techniques have their comparative advantages, and prowess, an integrated/combined approach is good, but a sustainable approach is even better.

Oil pollution is a worldwide threat to the environment and the remediation of oil-contaminated soils, sediments and water represents a clarion call for environmental research (Chorom *et al.*, 2010). Nigeria's petroleum development and production activities are concentrated within the Niger Delta community. Nine states in the region produce oil (Okonkwo *et al.*, 2015). In the former Rivers State (now Bayelsa State), at the Oloibiri oil field, Shell British Petroleum reported the discovery of the earliest commercial oil within the Niger Delta in January 1956. Later, in the same Rivers State in Afam, a second oil field was discovered. Since that time, other oil wells have been found in the area and are currently being used by other international oil corporations like Mobil, Elf, and Chevron, Agip (Vassiliou, 2009).

Nigeria's economy has grown and developed significantly with the help of the oil sector. The Niger Delta's oil-related operations over the past 50 years have caused at least 9 million to 13 million barrels of oil to spill (Kadafa, 2012). However, oil exploration practices that are not sustainable have also made the Niger Delta among the five ecosystems in the world with the most severe petroleum degradation (Anifowose, 2008). In both the aquatic and terrestrial habitats of the Niger Delta area, spill occurrences have happened at different locations and times. These spills have a history of being linked to pipe corrosion, carelessness in the production process, and tanker mishaps (Nwilo and Badejo, 2005). When products from refined petroleum and crude oil are released into the aquatic and terrestrial ecosystems, there is harm to all forms of life over time (Balba *et al.*, 1998). There are considerable negative environmental effects from oil drilling in or close to mangrove shorelines. Mangrove forests are notorious for being particularly vulnerable to spills because floatable petroleum infiltrates and suffocates the feeder roots and breathing roots. Oil spills also remove local microorganisms that are vital to the soil's productivity (Okpokwasili and Amanchukwu, 1988). The ability of the soil to maintain plant development over time under specific climatic conditions and other pertinent aspects of the land is known as soil fertility (Aina and Adedipe, 1991). Major issues with agricultural productivity in Nigeria's oil-producing regions include the leaching of nutrients, loss of the nutrient-rich topsoil, changes in soil pH, reduction in cation exchange capacity, salinization, water logging, and other types of soil degradation. Although the Niger Delta's environmental contamination has been the subject of numerous studies, virtually little remediation is done (Solinu *et al.*, 2010). Occurrences of oil pollution are causing an increasing amount of farmland to be lost. It is hardly an exaggeration to argue that poor clean-up and delays in repairing environmental harm have made people's rights, particularly their access to uncontaminated food, clean water, and livelihood, more vulnerable (Gaughran, 2013).

An oil spill, according to (Nwilo and Badejo, 2005), is the unintentional discharge of petroleum products or crude oil into the environment as a result of errors made by people, calamities that occur naturally, technical failures, or sabotage; though the inclusion of sabotage as being linked to oil spill makes this definition contradictory. It therefore suffices to define an oil spill as an event involving the discharge of petroleum products into the environment both as a result of human factors (both deliberate and indeliberate) as well as natural phenomenon (rusting, earth movement among others). In advanced countries like U.S. and China, contaminated sites amount to 100,000 and 3,330,000 hectares respectively (Song *et al.*, 2017). It has been valued that 2.5 million contaminated locations remain uncounted in Europe. Decontaminating delineated areas are expected to gulp up to 6 billion Euros every year (Panagos, 2013).

Globally, there are more than 5,000,000 locations polluted with metals, signally that above 20 million hectares of land require remediation (Liu *et al* 2018). The wide reliance on petroleum hydrocarbons as an energy source presents them as one of the most unwanted guests in our groundwater. Hydrocarbons are quite complex and tenacious contaminants in the surroundings (Doherty and Otitoloju, 2013, Lang *et al.*, 2016). Most oil spills in Nigeria occur in the Niger Delta, which has severe effects like fire outbreaks, tainted drinking water, and the destruction of aquatic life (Raimi and Sabinus, 2017, Morufu and Clinton, 2017, Olalekan *et al.*, 2018, Raim *et al.*, 2022). The number of oil spills in this area keeps rising, and the ecosystem there is deteriorating as a result (Okoyen, 2020). The Nigerian government's biggest dilemma is how to solve it, with the pressing issue of how to restore the damaged ecology without first modelling or precisely anticipating how much oil has seeped into the ecosystem over time (Mba, 2019).

Oil spills in Nigeria are caused by corrosion 50% of the time, sabotage 28% of the time, and oil production operations 21% of the time. 1% of oil leaks are caused by engineering drills, ineffective oil well control, machine failure, and negligence when loading and unloading oil tankers (Kostianoy *et al.*, 2014). Thousands of barrels of oil have leaked into the environment thanks to the country's oil pipelines, and storage facilities. International rules state that oil pipes should be changed every 15 to 20 years nevertheless, the majority of the current pipelines are 20 to 25 years old, making them susceptible to corrosion and leakage (Badejo and Nwilo, 2004). Some of these pipes are elevated above the ground without enough supervision, which puts them at risk for damage, and other dangers (Oyem, 2001). When oil spills are not adequately cleaned up, they harm terrestrial, and marine resources because they spread over a vast area. The most affected areas are farmlands and marine environments, which pose a threat to the survival of creatures there (Plessl, *et al.*, 2017). Shell Nigeria reported an average of 250 incidents annually, while the Nigerian National Oil Spill Detection and Response Agency (NOSDRA) reported 327 oil spill instances in 2006 (NOSDRA, 2006). The inconsistent nature of these reports, even though NOSDRA maintains a database of all oil spill incidents across the country through the Oil Spill Monitor, highlights regulatory bodies' carelessness in harmonizing data or their failure to reveal numerous oil spill incidents.

1.1 Impact of oil spill on the environment

Concern over environmental contamination's effects is growing, especially in Africa. Even with the financial advantage of discovering and exploring crude oil in Africa, it is certain that oil exploration has detrimental impacts on the water, land, air, and all species on Earth. The inadequate response is regularly seen in Africa to many avoidable disasters, including oil spills, gas leaks, noise, and improper waste management (Adeola *et al.*, 2022). When petroleum hydrocarbons permeate the environment as a result of oil spillage, weathering sets in. This involves dispersion, vaporization, dissolution, sorption, photo-oxidation, auto-oxidation, and the activity of living organisms in the catabolism of hydrocarbons which occurs unassisted. Microorganisms play key roles in fostering an ecologically balanced environment (Van Der Heijden *et al.*, 2008). When such organisms are absent, the capacity of the tainted environment to continue supporting large life forms becomes restricted hence the prevalence of small, microscopic life forms.

Illegal dumping of oil barrels, accidents, and oil spills can also have detrimental long-term implications on environmental quality, and human health. Crude oil is explored, refined, and transported to areas of need. All these processes entail the release of greenhouse gases into the environment, primarily carbon dioxide. Researchers like (Amendola-Pimenta *et al*., 2020, Cerqueda-Gracia *et al.*, 2020, Khursigara *et al*., 2021) have carried out studies on how oil pollution affects man and aquatic species where they observed negative effects on gut bacteria of Achirus *lineatus* fish species, depletion of oxygen concentration in the gastrointestinal tract as well as shunted growth. Humans are exposed to oil pollution, which increases the risk of cancer and cardiac problems in their progeny (Strelitz *et al*., 2019, McKenzie *et al*., 2019). Several physiological to fatal effects, including inflammation, suppression of the immune system, oxidative cell damage, Hemolytic anemia, lower reproductive success, organ malfunctions, and susceptibility to other diseases, have been found in a range of seabird and coastal bird species (Fallon *et al.*, 2020).

1.2 Natural attenuation

One of the many oil spill remediation strategies is Natural attenuation; a submissive remedial method that hinges on naturally occurring processes to destroy and expunge contaminants in both groundwater and sediment (Chen *et al.*, 2010, Declercq *et al.*, 2012, Neuhauser *et al.*, 2009, Dai *et al.*, 2014). Its potential as a clean-up technology for petroleum-polluted areas is premediated by the fact it has economic merits and a low impact on environmentally friendly features (Silva and Corseuil, 2012, Wang *et al*., 2012). But this potential is affected by both biotic and such factors that play roles in significantly affecting the capacity for microbial catabolism of polluting agents (hydrocarbon) like salinity, soil interaction, as well as water/nutrient availability which are in turn influenced by hydrocarbon contamination presence. Guo and his team (Guo *et al.*, 2002) used hydrogeochemical indicators like DO (Dissolved Oxygen), DOC (Dissolved Organic Carbon), Cl^{-} (Chlorine ion), HCO_3^{-}(Bicarbonate ion), pH, NO_3^{-}(Nitrate ion), and SO_4^{2-}(Sulphate ion), petroleum hydrocarbons elements, and environmental isotopes like δ15NNO$_3$, δ18ONO3, δ13CDIC, and δ13CDOC to reveal the degree of pollution and the natural attenuation features of petroleum hydrocarbons. They found an affirmative natural degradation sequence with a period of 30 years where innate biodegradation machinery was discovered to be the utmost significant influence on heralding degradation in the aquifer scheme.

Natural biodegradation falls under the green remediation concept which aims to control total energy use and increase energy from renewable resources; control air pollutants and greenhouse secretions; lessen water use and protect water quality; conserve material resources and lessen waste generation; as well as safeguard land and ecosystem, and, causing no tributary pollution aftermaths in the process (USEPA, 2010, Lee *et al*., 2019, EPA, 2012). (Abena *et al.*, 2019) also evaluated the effectiveness of natural attenuation and nutrient-aided bioaugmentation as well as a conglomerate of five exogenous bacteria, in the degradation of petroleum hydrocarbon in five extremely polluted sediments from China and Kuwait. After treatment, the concentration of Total Petroleum Hydrocarbon concentration reduced from 236, 500mg kg^{-1} of dry sediment to 176, 566mg kg^{-1} of dry sediment in 40 days, which indicated a 25.4% increase in degradation when compared to natural attenuation. This discovery, therefore, puts forwards that bioaugmentation treatment presented faster results than standalone natural attenuation.

1.2.1 Biodegradation

Biodegradation of petroleum hydrocarbons is a process where microorganisms can utilize compounds present in petroleum as a carbon source for metabolism under auspicious conditions (Chapelle, 2000, Das and Chandran, 2011). According to (Borden *et al.*, 1995), the microorganisms present in the sediment and under groundwater gradually uses oxygen, nitrate, iron oxides, and sulfate as collectors of the electrons to putrefy petroleum hydrocarbons into simple CO_2, (Carbon dioxide) and H_2O (water) through processes that require oxygen or those that do not require oxygen for biodegradation (denitrification, sulfate reduction, and methanogenesis). Geochemical indicators of these processes *visa vis* Nitrate (NO^-_3), Sulfate (SO_4^{2-}), and the evolution of Methane (CH_4) will change correspondingly; an indication of the biodegradation mechanisms at play (Kao, 2001, McMahon and Chapelle, 2008).

For these compounds, the intrinsic biodegradation process ensues as a series of redox reactions by hydrocarbons, and dissolved oxygen respectively under aerobic biodegradation conditions. While under anaerobic biodegradation conditions, NO_3^-, Mn_4^+ [Manganese (IV)], Fe_3^+ [iron (III)], $SO_4{}^{2-}$, and HCO_3^- (Bicarbonate) represent the primacy order of electron collectors (Cassidy *et al.*, 2015).

1.2.2 Bioremediation in water bodies

Bioremediation strategies first include natural attenuation, which can be aided either by as toting exogenous microbial inhabitants or instigating indigenous populations. Bioaugmentation tactics have been largely ruled out for marine oil spill remediation because they were not successful at Prestige oil spill sites (Lee *et al*., 1997, Murado *et al*., 2004). While biostimulation entails the supply of nutrients that may be lacking like nitrogen, phosphorus, and potassium to the affected sediment under investigation to stimulate the petroleum either naturally or via inorganic fertilizer application. Oleophilic enrichers have been reported as the ideal alternative for bioremediating rocky terrain areas in intertidal zones (Pritchard *et al.*, 1992).

The first wholesome biostimulation in oil spills (Head and Swannell, 1999, Venosa and Zhu, 2003) premiered in Alaska where the Exxon Valdez spill occurred. The application of oleophilic and slow release played a significant role in the process. This was the benchmark of marine oil spill bioremediation based on the supply of exogenous nutrients according to (Oh *et al*., 2001, Maki *et al.*, 2003). Bacteria are the most effective petroleum hydrocarbon-degrading microorganism among their peers according to (Hassanshahian *et al*., 2012, Li *et al.*, 2016). Noteworthy bioremediation with the blend of microorganisms has also been reported because different microbes in consortia have variegated, and widespread metabolic capabilities needed for the simplification of complex hydrocarbons (Cerqueira *et al*., 2011, Shen *et al*., 2015, Varjani and Upasani, 2017).
Bioaugmentation is usually accomplished by injecting enhanced microbial inhabitants into the matrix of the polluted soil (Xu and Lu, 2010, Varjani, 2017, Okparanma *et al*., 2017, Ramadass *et al.*, 2018). Despite its prospects, bioremediation is under-utilized as a viable remediation strategy due to piecemeal hydrocarbon catabolism and prolonged remediation periods when paralleled with rival techniques (Truskewycz *et al.*, 2019).

2. Remediation of Oil Polluted Ground and Surface Water

A negative backlash on the quality of groundwater is the aftermath of anthropogenic activities. Authors have reported elevated strain due to the contamination of groundwater resources by petroleum hydrocarbon (US NRC, 1993, Hamed, 2005, Liu *et al.*, 2011, Maric *et al.*, 2015). (Marić *et al.*, 2015) measured total petroleum hydrocarbon, hydrochemical parameters, and other parameters to prove natural biodegradation activities in groundwater at the polluted site. Obtained results provided convincing evidence of the role of natural attenuation in the biodegradation mechanism under natural conditions. The well-known pump and treatment method for remediation has proven to be easier said than done (Mackay *et al*., 1989, Travis and Doty, 1990, Wiedemeier *et al*., 1999). These pollutants are stubborn organic contaminants in our environment (Lang *et al.*, 2016, Maric *et al.*, 2015) which are characterized by carcinogenic, teratogenic, and mutagenic compounds, as such, threatening biodiversity (Lv *et al*., 2019).

Once in groundwater, these pollutants present noteworthy health threats to people who utilize this water as their main source of water supply (Qian *et al.*, 2018, Van der Waals *et al.*, 2018). Long-term exposure of this water resource to petroleum hydrocarbons will greatly influence the isotopic and chemical configurations of the water since hydrocarbon can carry distinct isotopic signatures that can alter the default isotopic signature in the groundwater. As a result, spatial and temporal variation in hydrochemical indicators (DO, NO_3^-, Mn_4^+, Fe_3^+, SO_4^{2-}, and HCO_3^-) is used to characterize the corresponding mechanisms of biodegradation. Physical processes and other non-biological courses also determine the measure of geochemical indicators (Lv *et al*., 2019).

A notable technology for the bioremediation of oil-polluted water is *Permeable Reactive Barriers* which includes the situation of an in-situ barrier, with a sensitive medium, perpendicular to the prospective route of groundwater water. As the plume of contamination travels inertly through the sensitive medium propelled by the natural hydraulic gradient, the contaminants react with the medium. This either transforms the hydrocarbon there-in into less harmful compounds or immobilizes them, leaving only the water to pass through (Obiri-Nyarko *et al.*, 2014). Though zero-valent iron is commonly used inside the barrier, other reactive materials with similar purposes include stimulated charcoal, zeolite, oxygen discharge compounds, and peat.

3. Remediation of Oil Polluted Soil/Sediments

Soil pollution from oil contamination due to terrestrial oil spills is considered one of the twenty-first-century liabilities because if left unattended, the consequences can be devastating (Van der Heul, 2009). Adverse implications include loss of soil richness, a spike in soil toxicity, and a decline in aesthetic value as well as a reduction in water availability. More so, the majority of the organic pollutants and metals that gets into the atmosphere or water bodies are very likely to end up in the soil when the ambient condition stabilizes. According to (Kuppusamy *et al.*, 2017; Brahimi et al., 2015), only 10% of global environmental polycyclic aromatic hydrocarbons (PAHs), as well as numerous human carcinogens do not settle in soils. Remediation techniques like *microbial remediation*, *phytoremediation*, *adsorption*, and *chemical oxidation* (Ma and You, 2016, Agamuthu *et al.*, 2013, Xu *et al.*, 2011), have been comprehensively considered and tried out in some countries (Fatima *et al.*, 2015, Tian *et al.*, 2010, Varjani, 2017). Figure 1 shows some of the known remediation technologies used in treating contaminated soils and sediments according to (Thome *et al.*, 2017).

For the extensive areas of contaminated sediments, the in-situ process is to be explored since it is relatively simple, poses little disturbance to the site, and costs less than ex-situ treatment. A combination of techniques as a better alternative for the remediation of several organic and inorganic pollutants in the soil has also been prescribed (Song *et al.*, 2017). Limitations to effective soil remediation hinge on environmental protection, public health, and economic implications thus necessitating the need for an accelerated process.

Hansen, 2017 carried out a perception analysis from which he predicted continuous environmental contamination from oil spills arising from dependency on petroleum and its allied products by mining companies and the world at large. (Varjani, 2017) compared the influence of five different techniques in remediating petroleum hydrocarbons contaminated soil by studying soil microcosm and discovered that simultaneously augmentation and stimulation of soil microcosm resulted in 93.67 ± 1.80% hydrocarbons degradation within one and half month of the experiment and hydrocarbon utilizing bacterial count was recorded $4.11 \pm 0.11 \times 10^8$ CFU/g from an initial $4.80 \pm 0.05 \times 10^7$ CFU/g.

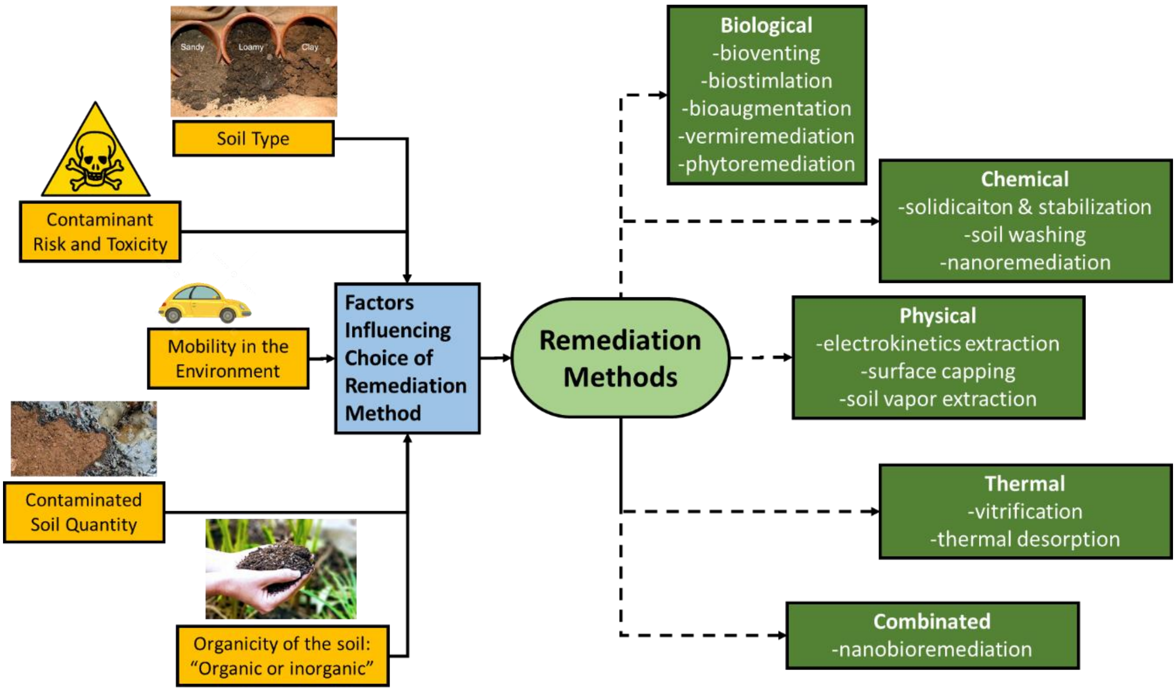

Figure 1: Technologies used remediating contaminated soils and sediments**.**

4. Physical Remediation Process

These are mature techniques that have been used for a long time, which results in the withdrawal of contaminants from the soil matrix through any physical configurations. Physical methods do not use any chemical compound and hence there is no prior permission required from governmental agencies to carry out the clean-up operations as the use of certain chemicals is Government controlled in certain countries (Huang *et al.*, 2012). The basic conception of this process is adsorption via innovative materials to hold molecules of pollutants as a thin film from soil (Dhaka and Chattopadhyay, 2021). Physical methods like.

4.1 Soil washing

Here, contaminants are concentrated into a much smaller volume of contaminated residue, which is either recycled or disposed of. This technique can be used to treat a wide range of inorganic and organic contaminants, being used independently or in combination with other treatment technologies (Benjamin and Lawler, 2013). It employs the use of aqueous solutions to retract contaminants from the environment (Thome *et al*., 2017, Song *et al*., 2017, Huang *et al*., 2012, Benjamin and Lawler, 2013).

After excavation, the soil is finally agitated after being combined with a solution that enhances extraction capabilities. It serves as an initial step to decrease the pollutant concentration in soils which can later be oxidized using a Fenton-like process (Rosas *et al.,* 2013). Achugasim posited that this process can be used to remove “BTEX” compounds like benzene, toluene, ethylbenzene, and xylene from contaminated soil with removal success of 95%, 95% and 97% for neutral, basic, and acidic pH ranges respectively. Despite this, soil washing was not as efficient in treating polycyclic aromatic hydrocarbons thus the need for an additive to persulphate washing agent. A schematic diagram of soil washing process is presented in Figure 2 below.

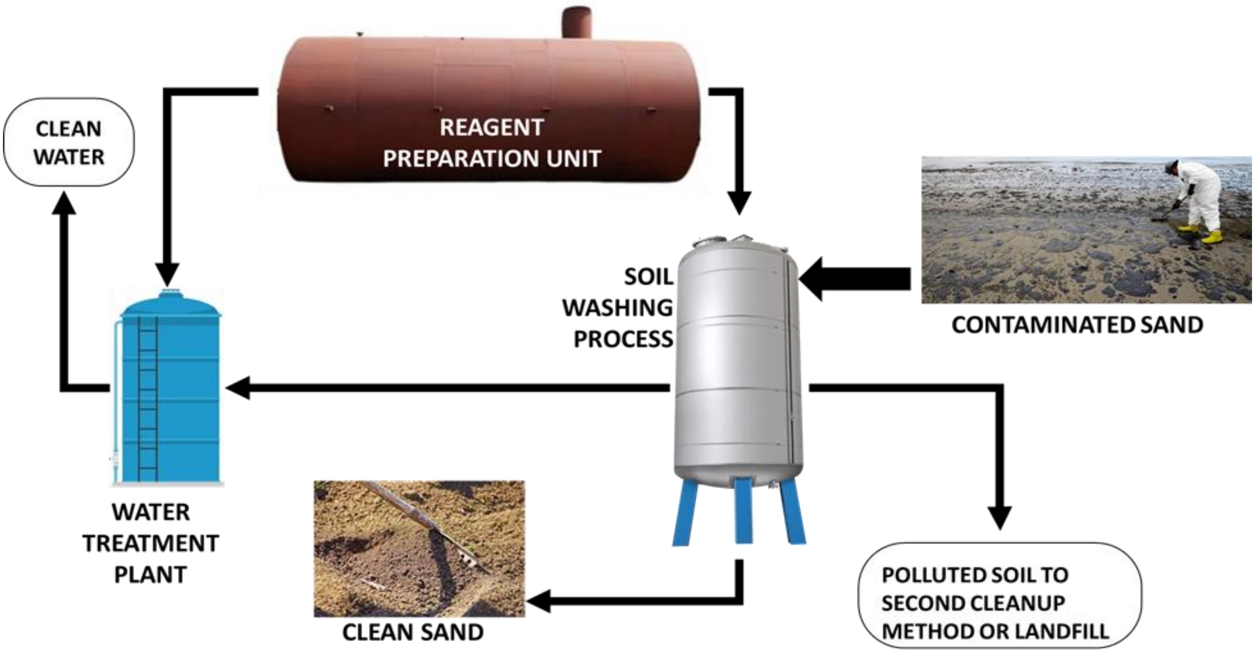

Figure 2: A schematic diagram of the soil washing process.

4.2 Soil flushing

This is an in-situ abstraction of pollutants from the soil via an appropriate washing solution. Here, the washing solution is incorporated through the sinking of wells or sprayed onto the area of contamination where the eventual solubilization of contaminants takes place; the contaminated elutriate is collected and pumped to the surface for removal, recirculation, or onsite treatment and reinjection (SEPA, 1997). Retrieval and surface treatment of the resulting solution is essential via water, a solution of chemicals in water or an organic extractant (Morillo and Villaverde, 2017).

4.3 Soil Vapor Extraction (SVE)

Is carried out in situ to get rid of volatile and sub-volatile carbon-based contaminants in poorly saturated soils (Morillo and Villaverde, 2017). It involves the creation of a void in the polluted soil thereby creating an airflow through the soil matrix that conveys the contaminants to extraction wells (Jankaite and Vasarevicius, 2005) and air treatment units before they can be released into the atmosphere These methods were proposed by (Khan *et al.,* 2004) but a year later, (Park and Zhan, 2003) contradicted him. They opined that the process had little to no effect in the removal of heavyweight contaminants like diesel and kerosene. It can also be applied to polluted air treatment (USEPA, 2004, Albergaria *et al*., 2012, Lim *et al*., 2016). Nonetheless, SVE is influenced by several factors that have direct consequences on the remediation time and the process efficiency. These factors can be grouped into operational conditions (temperature and airflow rate), properties of the contaminant (vapor pressure and solubility), and soil properties (water and natural organic matter content) (Albergaria *et al.*, 2012). Figure 3 below shows the operational procedure for SVE.

4.4 Electrokinetic Remediation

It is used to remove contaminants in the soil matrix, through electrical adsorption under field conditions. A low-voltage electrical current is passed through the matrix via electrodes which trigger the movement of cations, and anions from the impacted soil to the cathode and anode respectively through the established electrical field (Liu *et al*., 2018, Lim *et al*., 2016). Electrokinetic can remediate organic pollutants in soil when joined with enabling agents such as surfactants, co-solvents, and nanoparticles as well as oxidizing chemicals that ease the removal or degradation of the contaminants *insitu* (Cameselle and Gouveia, 2018). Electrokinetic remediation is quite competent for saturated and poorly saturated soils with low electrical conductivity (Reddy, 2013). But the removal of organic contaminants from soils by electrokinetic is limited by the neutrality of the molecules and the low solubility of most of the target contaminants (Cameselle and Gouveia, 2018).

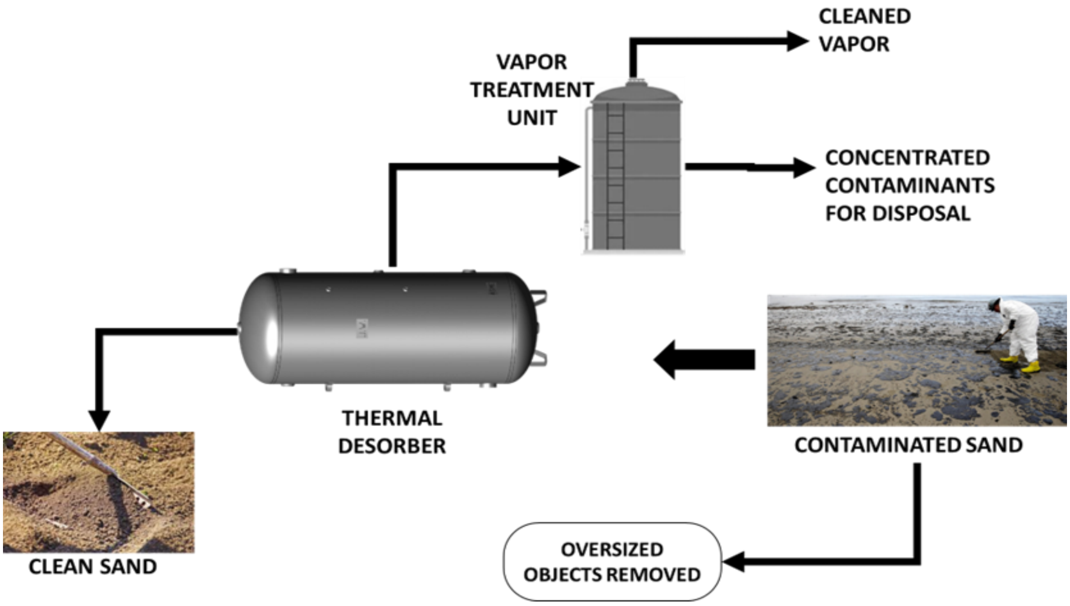

Figure 3: Schematic Representation of Soil Vapour Extraction Process.

4.5 Surface Capping

This is simply the act of covering the contaminated site with a layer of water-resistant material to form a stable, protected surface (Liu *et al*., 2018). The site to be treated is covered with a slightly pervious material which hinders the passage of water to shrink the migration of contaminants in the soil to create a new bottom substrate and to meet pre-defined objectives for cap performance (Jersak *et al*., 2016). This also reduces the risk to people within the vicinity of the spill. The remediated soil however ceases to perform its original function (Liu *et al*., 2018).

4.6 Nanotechnology

The use of nanoscale zero-valent metals (NZVI) like iron, nickel, and palladium for the remediation of various types of contaminants has been widely explored. The advantage of this technology and its usage for both insitu and ex-situ implementation is due to the small size of the metals which is less than 100 nm, and large surface area. These metals can stabilize or reduce chromium and arsenic and dehalogenase organic compounds (Albergaria *et al*., 2012, Lim *et al*., 2016; Aaddouz *et al*., 2023). Among the various nano-materials present, NZVI flies high because of their minimal toxicology and their low cost of production (Yan *et al.*, 2013). Nanomaterials enhanced reactivity and present effectiveness when compared to their bulkier counterparts due to their higher surface-to-volume ratio. They also offer the potential to leverage unique surface chemistry as compared to traditional approaches, in that they can be functionalized or grafted with functional groups for target molecules of interest for efficient remediation. Furthermore, the intentional edition and fine-tuning of the physical properties of these materials (size, morphology, and chemical composition) confer extra desirous characteristics which aid the performance of the material for contaminant remediation (Guerra *et al.*, 2018).

5. Chemical Methods

A common method of soil remediation is the use of chemicals. This method is applicable in the treatment of soils polluted with both organic and inorganic pollutants. The chemical remediation method can achieve the remediation target within a relatively short time. But it is expensive and some of the used chemicals can interfere with the soil's normal functioning. Chemicals used in the process include oxidants such as ozone, $KMnO_4$ (Potassium Permanganate), H_2O_2 (Hydrogen Peroxide), and Fenton's reagent (Masten and Davies, 1997, Ferrarese *et al*., 2008). The use of Chemical soil stabilizers like lime, and apatite (phosphate minerals) have also been used for the remediation of polluted soils (Collins *et al*., 2009, Venalainen, 2011). Techniques here include thermal stripping, chemical oxidation, and photochemical oxidation (Meuser, 2013, Ahmad *et al*., 2020, Ershadi *et al*., 2011, Cheng *et al*., 2016). It is an efficient method to remove dangerous waste from the soil at the oil spill site. The efficiency of this method strongly depends on the soil, matrix. It presents a quick way to treat contaminated soil but also poses serious threat to soil due to leaching, or side reactions (Ahmad *et al*., 2020). These methods are explained below.

5.1 Oxidation

Chemical oxidation exhibits strong effectiveness in removing oil hydrocarbons where diverse oxidants are used to degrade organic pollutants. It is suitable for remediating organic contaminants via reactive oxidants like hydrogen peroxide, (H_2O_2), ozone (O_3), permanganate (MnO_4^-), and persulphate ($S_2O_8^{2-}$) and is reliant upon soil medium for effective chemoradiation (Ahmad *et al*., 2020, David and Joel, 2013). A combination of hydrogen peroxide and ferric ion otherwise known as Fenton, reagent is frequently utilized in this process. This method may not be as effective in poorly perforated (Ahmad *et al*., 2020). Fenton and Persulfate oxidation are showing great remediation potential in that both oxidants need ferrous iron Fe (II) to produce stronger radicals through the following reactions:

$$Fe\,(II) + H_2O_2 \rightarrow Fe\,(III) + HO^- + HO^\cdot$$
$$S_2O_8^{2-} + Fe\,(II) \rightarrow SO_4^{\cdot\,-} + SO_4^{2-} + Fe\,(III)$$

5.2 Photochemical oxidation

Transforms chemical compounds with the aid of sunlight (Garrett *et al*., 1998). Here, the contaminant/ catalyst mixture is illumined by a light source either Ultraviolet or sunlight. This triggers an oxidation reaction where the organic pollutants are oxidized thereby forming new compounds (water and carbon dioxide). This process represents a strong remediation technique for treating oil-contaminated soils. Titanium dioxide/zeolite composite can also be used in degrading oil deposits but for the likely diffusing of titanium dioxide into the environment. Thus, the effect of photooxidation is different from that of biodegradation, because in biodegradation larger and more replaced compounds exhibit greater resistance to degradation. This process has great potential for the degradation of crude oil spilled at sea. The photooxidized products appear in the resin and polar fractions as determined by thin-layer chromatography (Ogunkeyede, 2016).

6. Thermal Processes of Remediating Oil-Polluted Soils

This has to do with increasing the temperature of the soil subsurface towards conscription, volatilization, and destruction of contaminants therein. In this method, heating is achieved through conductivity, electric resistance, steam, and radio frequency (Samksaman *et al*., 2016). Thermal methods showed great efficiency of 99%, in decontamination of organic polluted soils (Soleimani and Jaberi, 2014). Thermal processes include:

6.1 Vitrification

Insitu vitrification is the process of melting contaminated soil, supressed wastes, or sludges in place to render the material non-harmful (David and Joel, 2013). Here, the soil is transformed into a glassy matrix. When the contaminated soil is heated by an intense amount of energy (around 1500 °C), it melts, and when the temperature drops, it forms a passive matrix that compresses the pollutants. This method is used for hazardous and inorganic contaminants and may not be suitable for soils with large quantities of organic matter in them (Liu *et al*., 2018, David and Joel, 2013). The high temperature destroys organic pollutants by pyrolysis. Most in-situ vitrification applications involve the melting of soils, however, process sludge, mill tailings, sediments, process chemicals, and other inorganics may also be treated effectively (Meuser, 2013). This process alters the soil and hence it can no longer be used for agricultural activities (Liu *et al*., 2018, David and Joel, 2013).

6.2 Thermal Desorption (TD)

Also makes use of increased temperature which increases the vapor pressure of carbon-based contaminants leading to their desorption and volatilization from the soil. Evolved gases should be treated after collection before being released into the atmosphere (Albergaria *et al*., 2012). This process can be carried out under field conditions as well as in a controlled environment. In the field, heating at great soil depths is done by using currents to heat rods inserted in wells. For shallow contamination, a heating blanket (thermal blanket) is employed to provide the required heat. In laboratory treatment, extraction of contaminants from the contaminated soil is carried out in a desorption unit (McMahon and Chapelle, 2008). (Falciglia *et al.*, 2011) in his work discovered that sandy and silty soils polluted with heavy oils like diesel required a temperature of 175 $°_C$ for effective desorption of contaminants while 250 $°_C$ was recommended for clayey soils. TD is appropriate for handling most volatile and semi-volatile contaminants, like polycyclic aromatic hydrocarbons (PAHs), polychlorinated biphenyls (PCBs), dichlorodiphenyltrichloroethane (DDT), total petroleum hydrocarbon (TPH), and Hg, in soils. It has several advantages, such as the capability to treat diverse types of contaminants, a short treatment schedule, high efficiency, and recycling of soil and contaminants. It is basically used to remediate sites with high concentrations of contaminants in small areas with urgent needs for treatment (Soleimani and Jaberi, 2014).

6.3 Ultrasonic Remediation

Ultrasonic technology represents a clean and green technique for the degradation of toxic organic pollutants (Zhao *et al*., 2019, Liu *et al.*, 2018). Here, three varieties of frequencies are described for three distinct uses of ultrasound: high frequency, or diagnostic ultrasound, low frequency or conventional power ultrasound, and medium frequency, or "sonochemical-effects" (Wang *et al*., 2019), (Ince *et al*., 2001). (Effendi *et al*., 2019) indicated the two processes that occur in this technique to be desorption and chemical degradation.

This process has indicated considerable effects in the desorption of petroleum hydrocarbon in fine soil. Works by Li and his team discovered a decrease in Total Petroleum Hydrocarbon (TPH) in the soil from 61% and 49% to 27.6% and 55.3% in silty and clayey soils using this method (Li *et al*., 2013). A higher removal rate can be obtained by increasing the power input in this system according to (Wang *et al*., 2019). (Effendi *et al*., 2019) also posted a 61 % reduction in TPH within 15 minutes by applying 160 watts of power into the system, however beyond 160 watts of power further removal of TPH was not recorded which can be traced to steady-state re-adsorption of the compounds back into the soil. This method can be used to sort out reasons for reduced bioremediation of oil-contaminated clay soil when as a pre-bioremediation strategy. The success rate of this ultrasonic method is influenced by several factors such as soil type, soil/water ratio, water flow rate, irradiation duration, wave frequency, and energy used (Kim and Wang, 2003), (Feng and Aldrich, (2000).

7. Biological Remediation Techniques

This has to do with remediation by the biotic components of the environment. Here, in which biological processes (microorganisms) are used to degrade and metabolize chemical substances thereby restoring environmental quality. It is an affordable, sustainable remediation method that is gentle on the environment (Ndimele *et al*., 2018). Biological remediation encompasses adsorption and transformation processes leading to the eventual degradation of contaminants (Song *et al*., 2017). The feasibility of this technique reduces in soils having high concentrations of substances that are harmful to microorganism's examples of such substances include Cadmium (Cd), Lead (Pb), and Sodium chloride (NaCl) (Speight, 2018). Living form-induced remediation includes:

7.1 Bioventing

Here oxygen is added to the pore spaces in the soil voids to rouse the development of microorganisms. Bioventing combines the proficiencies of soil venting and improved bioremediation to cost-effectively remove light and middle distillate hydrocarbons from the vadose zone of soils and the groundwater table. Soil venting gets rid of the more volatile fuel components from unsaturated soil and fosters aerobic biodegradation by directing large volumes of air into the subsurface (Hoeppel *et al*., 1991). Oxygen is needed for the microbial breakdown of organic contaminants, thereby serving as a substrate that initiates the biodegradation process. It also serves as a collector of electrons needed for power generation during the breakdown process (Lim *et al*., 2016), (Karamalidis *et al*., 2010). Bioventing is reliant on the capability of gases to permeate the soil. Hence, soil particle size and ease of penetration are vital requirements for the effectiveness of this technology (Thome *et al*., 2014).

7.2 Bioaugmentation

This advances the performance of microorganism numbers by adding modified microbes from other consortia with specific catabolic activities, and strains that increase the degradation rate of contaminants present (Abdulsalam *et al*., 2011). The efficiency of bioaugmentation has been supported by studies show-casing the incompetence of indigenous microorganisms in certain cases and the enhanced bioremediation rate after the addition of other microorganisms that are more competent (Vogel, 1996). Soils from contaminated sites are injected with specially cultivated consortia of microorganisms with proven capabilities for the degradation of certain contaminants (Yaman, 2020). Since crude oil consists of a mixture of compounds, and specific microorganisms metabolize only a limited range of hydrocarbon substrates, biological degradation of petroleum hydrocarbon requires a blend of different bacterial groups to degrade a wider range of hydrocarbons (Adams *et al.*, 2015).

7.3 Biostimulation

Entails changing prevailing environmental parameters like nutrients, increasing the dissolvability of selected contaminants, including biosurfactants, and increasing the number of electron acceptors within the matrix by adding oxygen. It may also include controlling temperature and humidity in the laboratory to provide optimum surroundings for the activity of microorganisms (Bio Rangers). Limiting factors to the biodegradation of hydrocarbon includes nutrients, pH, temperature, moisture, oxygen, soil properties, and contaminant presence (Abad *et al.*, 2015). Modification of the environment to stimulate existing bacteria capable of bioremediation can be achieved by the addition of various forms of limiting nutrients and electron acceptors, such as phosphorus, nitrogen, oxygen, or carbon, which when available in small quantities can constrain microbial activity (Adams *et al.*, 2015).

7.4 Vermiremediation

Little research has been carried out on this research. Here, worms are employed in the removal of contaminants in the soil. They devour, and break down mainly organic contaminants thereby, altering the structure, and biomass, and increasing microbial activities of the soil. Since smaller life forms are already breaking down or metabolizing the organic contaminants, a symbiotic association known as co-metabolism with available soil microorganisms occurs which stimulates the needed minerals and nutrients that enhance the overall microbiological activity in the contaminated site (Rodriguez-Campos *et al*., 2014). Available research on the potential of earthworms as a biodegradation agent has shown an ability to manage polluted land and even sewage sludge. It has been discovered that they are forbearing to, and have the ability to remove, or help in the removal of a wide range of organic and inorganic contaminants like pesticides, polycyclic aromatic hydrocarbons (PAH), crude oil, and heavy metals from the soil media (Shahmansouri *et al.*, 2005), (Pattnaik and Reddy, 2011). (Hickman and Reid, 2008) pointed out possible methods for vermiremediation to include:

- by direct application of earthworms to polluted soils;
- co-application of earthworms to contaminated soils along with organic media (compost);
- use of contaminated media as food for earthworms as part of a feeding schedule;
- indirect use of earthworms through the application of vermidigested (material like vermicompost).

7.5 Phytoremediation

It is the insitu use of plants and their associated microorganisms to degrade, contain, or render harmless contaminants in the soil or water (Cunningham *et al.*, 1996). Otherwise known as plant-assisted bioremediation makes use of plants and their features to remediate oil-polluted soils. Plant species like Centrosema *brasilianum*, Brachiaria *brizantha,* and Mirabilis *jalapa* have been used under this scheme (Merkl *et al.*, 2005), (Peng *et al.*, 2009)**.** The potency of this process lies upon the availability of organic materials which are easily broken down in the root system of plants as the root exudates and secrete mucilage (Peng *et al.*, 2009). This method is based on the perception of using nature to cleanse nature. By harnessing the natural ability of plants, contaminated soils, water, and sediments can be restored to their former state. For optimal result results, this technique can be used alongside mechanical clean-up procedures (Nwaichi *et al.*, 2015). Phytoremediation also provides habitat to various animals and promotes biodiversity which helps to speed up the restoration of ecosystems with pseudo appearances caused by human activity at a site (USEPA, 2000), (Wilson, (2004).

Like natural attenuation, this process is also recognized as a green technology which has also increased its acceptability by the public. Phytoremediation is time-consuming that can last for more than five years which is a major pullback (Yakubu, 2007). Phytoremediation can be used to achieve:

Extraction: Used in remediating soils contaminated with metallic compounds and radionuclides. After the process of removing these contaminants, there is a need to uproot such plants so that the contaminants do not get back into the same soil (USEPA, 2006).

Degradation: Involves itself with the absorption of soil contaminants through the roots and subsequent simplification of these compounds through the metabolism of plant life. Plants can also release enzymes that accelerate this process (Germida *et al*., 2002).

Volatilization: Occurs in a sequence; first is the absorption of contaminants via the roots, then metabolization, and then transmission through the plant's system before eventual volatilization which is done by the exposed spore spaces in the plant. Such contaminants must be both soluble and volatile (Lim *et al.*, 2016).

Stabilization: This mechanism immobilizes metallic pollutants in the root of the plants. Characteristics of this immobilization process include adsorption, pH-induced precipitation, creation of metallic complexes resulting from a change in the redox state of the contaminants (Effendi *et al.*, 2019).

Biodegradation: Here, moderate humidity and increased aeration in the root create favourable conditions for the unset of bioremediation. The roots release sap as sugars, amino acidic and other compounds which are beneficial to the microbial community by stimulating microbial growth, and eventual decontamination of contaminated soil (Nwaichi *et al.*, 2015).

Spill Sorb Technique: Some mining firms in Africa use land farming along with spill sorb materials to remedy oil-polluted soils. Spill sorb is synthetic organic oil absorbent from Canadian peat. It has a biological catalyst in its cell structure. This catalyst acts in conjunction with the microbial community present in kick-starting bioremediation. The cells store oxygen in the mitochondria which is necessary for the process. Certain compounds in crude oil are recalcitrant thus, are not degraded by the microorganisms found in the soil (Khan *et al.*, 2004). This may result in increased toxicity in the soil instead of the initial plan of detoxification this is a major fallback for the spill sorb technique (Chibwe *et al.*, 2015).

8. Landfarming Remediation Technique

Land farming involves the dispersion of the hydrocarbon-contaminated soils on an overlay of about 0.5 meters in thickness as well as the mixing of contaminated soil with added nutrients (Straube *et al.*, 2003). After excavating, the soil is shallowly spread over the ground surface where the process will be kick-started. This is trailed by the stimulation action by microbes embedded in the soil after which there is enhanced aeration, the addition of nutrients, minerals, and water (SEPA, 1997). This process relies on the multiplication of oil-degrading microorganisms. Therefore, optimal settings for microbial growth must be created and sustained (Paudyn *et al*., 2008). A downside of this method however is that incomplete degradation can result in toxic compounds that can harm the microbial environment. The time factor is another impediment to this process (Mosbech, 2002). During the process of landfarming, the Total Petroleum Hydrocarbons, (TPH), may be lost through volatilization or biodegradation. Treatment routines for land farms vary with climate, location, and temperature as well as soil type. Enhanced land farm bioremediation of contaminated soil classically involves the addition of nutrients, and water, and periodic tilling to amalgam and aerate the soil (Sharma, 2012). Bulking agents, co-substrates, and bacterial inoculations were added to speed up the remediation process (Straube *et al*., 2003, Mphekgo and Cloete, 2004). Landfarming has proven consistently successful in warmer southern climates (Sharma, 2012). For instance, in the 1-year operational period of an Australian land farm TPH levels were remediated from 4644 ppm to less than 100 ppm (Line *et al*., (1996).

8.1 Excavation remediation technique

Here, the polluted soil is transported from the site of contamination to a new place to reduce the risk of exposure. It is used in the treatment of both inorganic and carbon-based pollutants (Lombi and Hamon, 2005). It has the advantage of being done both *insitu* and *ex-situ*. The procedure is a sustainable and fast way to remedy oil-polluted because it is neither advanced nor expensive (USEPA, 2000).

Table 1: Major differences between various remediation processes

	PHYSICAL REMEDIATION TECHNIQUE	BIOLOGICAL REMEDIATION TECHNIQUES	THERMAL REMEDIATION TECHNIQUE	CHEMICAL REMEDIATION TECHNIQUE	LANDFARMING REMEDIATION TECHNIQUE
NATURE	Entails activities resulting in the withdrawal of contaminants from the soil matrix through any physical configurations.	Involves remediation by the biotic components of the environment and encompasses adsorption and transformation processes leading to the eventual degradation of contaminants.	Requires increasing the temperature of the soil subsurface towards conscription, volatilization, and destruction of contaminants therein	It is an efficient method to remove dangerous waste from the soil at the oil spill site through the use of chemicals.	Involves the dispersion of the hydrocarbon-contaminated soils on an overlay of about 0.5 meters in thickness as well as the mixing of contaminated soil with added nutrients.
CONCEPT	The basic conception of this process is adsorption via innovative materials to hold molecules of pollutants as a thin film from soil.	Biological processes (microorganisms) are used to degrade and metabolize chemical substances thereby restoring environmental quality	Heating is achieved through conductivity, electric resistance, steam, and radio frequency.	Strongly depends on the soil, matrix. Fenton agent is used for chemical oxidation.	Treatment regime for land farms vary with climate, location, temperature, and soil type
EXAMPLES	Soil washing Soil flushing Soil vapor extraction Electrokinetic Surface Capping	Bioventing Bioaugmentation Biostimulation Vermiremediation Phytoremediation	Vitrification Thermal Desorption Ultrasonic Remediation	- Oxidation - Photochemical oxidation	Dispersion Excavation stimulation

8.2 Combined processes

The combined process of remediation oil contaminated soils seeks to galvanize the power of as many other remediation strategies into one, thereby surmounting the limitations of individual processes (Cecchin *et al*., 2017). It represents a novel method that explores the advantageous properties of the physicochemical and biological process resulting in what is called *Nanobioremediação*. Here, nanoparticles are employed in the initial treatment, and microorganisms are used to complete the degradation process. Combined remediation processes are sustainable because it reduces the amount of nanoparticles needed and make use of the available microbial communities therein (Ahmad *et al*., 2020). Most remediation combination methods are designed to increase the microbial commotion and aeration of polluted soil because of the hydrophobicity and fluidity of petroleum. To increase the system's degradation rate, an electric field, fertilizers, biocarrier, biochar, biosurfactants, and plants are usually applied to the petroleum-contaminated soil (Mukome *et al*., 2020, Dong *et al*., 2013, Tahseen *et al*., 2016).

Solidification/Stabilization (S/S) is a widely used treatment for the proper management and disposal of a wide range of contaminated media; with special reference to those contaminated with substances classified as hazardous in the United States (Wilk, 2004). This method reduces the movement of both organic and inorganic chemicals that are hazardous to the soil. It involves mixing a binding reagent into the contaminated media or waste (Federal Remediation Technology Roundtable, 2002). Solidification curtails the movement of contaminants, and is widely applied in treating metallic, and radioactive contaminants. The solidifying process traps the contaminant in a solid form which can be used for other purposes apart from agriculture (Tajudin *et al*., 2016). Immobilization within the treated material prevents migration of the contaminants to human, animal, and plant receptors. Grey steering wheel, and are the main materials used in solidification. Mixing Cement, asphalt, and thermoplastics as solidification materials can employ either injection or the use of a bulldozer. In general, solidification is the conversion of a liquid material into a non-liquid material. Stabilization denotes a purposeful chemical reaction that has been taken to make waste elements less leachable (Barth, 1990).

Before kick-starting the process of remediation of oil-polluted soils, the choice of materials to be used needs careful consideration, and selection to reduce costs, harm to the environment, and increase results. Such considerations may include; (I) The nature of the pollutant, its concentration, and which mechanism best suits its removal process (II) The hydrological, geological, and biogeochemical characteristics of the aquifer when the aquatic body is affected.; (III) The environmental and health implications of the remediation strategy to be employed (IV) The mechanical stability of the medium and (V) The economic indices as well as the availability (Fallico *et al*., 2010).

8.3 Drawbacks of remediation technologies

Many uncertainties regarding long-term environmental implications and results are yet to be fully comprehended (Farre *et al*., 2009), (Libralato *et al*., 2017). Some of these remediation methods are mostly applied on-site therefore knowledge gap on potential side effects and toxicity information needs to be filled up (Lofrano *et al*., 2017). While for controlled environments like laboratories, prevailing data on field implementation characteristics could very largely from what was obtained in the laboratory. Available toxicity data are supplied in piece meals and hence not aggregated if not completely absent. There is a general bias in the selection of microorganisms for remediation. Certain natural groups have been researched more than others. The interpretation of available data is no child's play due to the complexity of various technologies, the utilization of several species, their life stages, and experimental designs coupled with a lack of baseline point reference (Ellis and Hadley, 2009).

8.4 Sustainable remediation

In the early 2000s, professionals in the remediation field teamed up to recast and rethink the known processes for the remediation industry. An organization was birthed from this meeting known as the

Sustainable Remediation Forum (SURF). The mission of SURF is to create a framework that incorporates sustainable concepts throughout the remedial action process while continuing to provide long-term protection of human health and the environment and achieving public and regulatory acceptance (Ellis and Hadley (2009).

The need for the remediation of contaminated sites is premeditated on the negative externalities and consequences of such remediation on human health and the environment in general. Every remediation process has its own environmental, social, and economic implications (Feng and Aldrich, 2000). Consequently, the decision to treat contaminated areas is witnessing changes due to the general awareness that we are in a connected ecosystem where, and a change in one sector affects the normal function of other sectors (Onyemachi *et al.*, 2022). Initially, the ease of implementing remedial procedures was the main focus as well as the overall efficiency of the process (Harclerode *et al*., 2015). The concept of sustainability is now being inculcated into the scheme of action. This new awareness of the complexities of remediation projects was birthed by the institution of green remediation which considers most if not all of the effects and aspects of the proposed remedial measure. Sustainable remediation portrays the sensitivity to the effect of remediation activities on the environmental and human communities in general (social and economic) whether both positive and negative (Rizzo *et al*., 2016).

Conclusion

The problem of environmental pollution as a result of crude oil utilization and exploration persisted long before the need for remediation was brought to the limelight. Nigeria like many other oil exploration countries is not relenting in her search for appropriate remediation technology from oil spills. The lack of an updated data bank on spill numbers, and characteristics is a major setback to effectively tackling this problem. Many approaches and technologies were x-rayed with all apart from Natural attenuation resulting in a pseudo soil that is no longer ideal for initial soil functions. Bioremediation process in seas and water bodies can only be stimulated but not augmented. Even though combined techniques appeared to produce the fastest remediation results, sustainable remediation approaches are highly recommended in this review. If oil spills can be prevented in the first instant the cost and attending implications of oil spill treatment will be minimal this is highly recommended for the Nigerian oil industry. There is an urgent need to imbibe sustainable remediation as a policy document in countries bedevilled with oil spills.

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