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Review

Petroleum Hydrocarbon Contamination: Its Effects and Treatment Approaches – A Mini Review

[1]**Ismail, H. Y.**, [2]**Grema, M. N.**, [1]**Isa, M. A.** [1]**Allamin, I. A.**, [1]**Bukar, U. A.**, [3]**Adamu, A. and** [4]**Fardami, A. Y.**

[1]Department of Microbiology, Faculty of Science, University of Maiduguri, Borno State Nigeria

[2] Department of Biological Sciences, Faculty of Science, University of Maiduguri, Borno State Nigeria

[3]Department of Science Laboratory Technology, Umar Ali Shikafi Polytechnic, Sokoto, Sokoto State Nigeria

[4]Department Microbiology, Faculty of Science, Usmanu Danfodiyo University, Sokoto State Nigeria

***Corresponding author**: hyismail@unimaid.edu.ng, doi.org/10.55639/607.3435

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ABSTRACT

Petroleum hydrocarbons are among the major driving forces of advancement in the last Century. Some of the hydrocarbons are however of health and environmental significance, due to their recalcitrance and persistence leading to adverse effects on health and ecosystem stability. Environmental pollution with petroleum and petrochemical products has been recognized as a significant and serious problem. Most components of oil are toxic to humans and wildlife in general, as it is easily incorporated into the food chain. This fact has increased scientific interest in examining the distribution, fate and behaviour of oil and its derivatives in the environment. The potential danger which petroleum hydrocarbons pose to humans and the environment makes testing and treatment unavoidable. As a result, a number of investigations over several years have led to the discovery of treatment technologies including physical, chemical, thermal and biological processes. Attempts to present a concise review on the status of hydrocarbon contamination, its effects on microorganisms, plants, animals and the ecosystem have been made. Different treatment technologies with their advantages and setbacks are also presented. This would enlighten individuals and stakeholders on the dangers pose by the petroleum products especially that oil prospecting in the Northeastern Nigeria is been intensified.

Corresponding author: Ismail, H. Y, Email: hyismail@unimaid.edu.ng
Department of Microbiology, Faculty of Science, University of Maiduguri, Borno State Nigeria

INTRODUCTION

Petroleum is a naturally occurring liquid found beneath the earth's surface that can be refined into fuel. Petroleum is a fossil fuel, meaning that it has been created by the decomposition of organic matter over millions of years. Petroleum is formed when large quantities of dead organisms–primarily zooplankton and algae–underneath sedimentary rock are subjected to intense heat and pressure (Chen, 2020). Petroleum is used as fuel to power vehicles, heating units, and machines, as well as being converted into plastics and other materials. Because the majority of the world relies on petroleum for many goods and services, the petroleum industry is extremely powerful and is a major influence on world politics and the global economy (FAO, 2018).

The extraction and processing of petroleum, and thus, its availability, is a major driver of the world's economy and geopolitics. Some of the largest companies in the world are involved in the extraction and processing of petroleum, and many other companies create products that are petroleum-based, including plastics, fertilizers, automobiles, and airplanes, for example. Asphalt, which is used to pave highways, is made from petroleum. Vehicles that drive on highways are made of materials derived from petroleum and run on fuels that are derived from petroleum.

Petroleum is recovered by oil drilling. After it has been recovered, it is refined and separated. It is most commonly refined into different types of fuels. Petroleum contains hydrocarbons of different molecular weights. In general, the denser the petroleum the more difficult it is to process and the less valuable it is (Chen, 2020).

In the petroleum industry, petroleum companies are divided into upstream, midstream and downstream. This refers to oil and gas company's position in the supply chain. Upstream oil and gas companies identify, extract, or produce raw materials. Downstream oil companies engage in business related to the post-production of crude oil and natural gas. Midstream oil and gas companies connect downstream and upstream companies, typically by participating in the storage and transportation of oil and other refined products (Michel and Fingas *et al*., 20016).

However, the extraction process and the byproducts of petroleum use are toxic to the environment. Underwater drilling causes leaks, extraction from oil sands strips the earth and uses precious water, and fracking destroys the water table if done poorly or improperly. Transporting petroleum through pipelines has the potential to destroy the local environment and shipping petroleum risks spills and uses energy. Global petroleum use has had a negative impact on the wider environment because the carbon released into the atmosphere increases temperatures and is associated with global warming (Abatenh *et al*., 2018). Many products created with petroleum derivatives do not biodegrade quickly, and the overuse of fertilizers has damaged water supplies (Sam *et al*., 2017).

Petroleum hydrocarbon contamination is the presence of hydrocarbon compounds from petrochemical process in to pristine environments. Environmental contaminations with petroleum and its derived products are frequent events although sometimes in small scales (Michel and Fingas *et al*., 20016). During the process of oil and gas exploration, activities such as, refining, storage, sales, accidents, equipment maintenances, bunkering and sabotage result in overflow and emissions of petroleum hydrocarbons to immediate environment (Wang *et al*., 2017).

Petroleum hydrocarbon (TPH) contamination of soil and groundwater may accounts for over 15% of all pollution in developed countries like United Kingdom (Stroud *et al*., 2007) but may be much more pronounced in developing countries. Nigerian being the 8th country with proven oil reserves (Organization of the Petroleum Exporting Countries; OPEC, 2019) it has suffered serious pollution problems due to oil spillage. It has been estimated that over 13 million tons of hydrocarbons have been spilled in the Niger Delta region in the last six decades (Sam *et al*., 2017) leading to considerable damage to the environment (Kadafa, 2012; Ite *et al*., 2013). Theoretically, an average of 240 thousand barrels of crude oil is spilled in the region every year (Ordinioha and Brisibe, 2013). In other parts of Nigeria, spillages of both crude and refined petroleum products are occasionally reported. Large amounts of engine oil are released into the environment when motor oil is changed and disposed into the vicinities as commonly practiced by motor mechanics and generator users (Odjegba and Sadiq, 2002).

For many decades, it was believed that the Earth had unlimited capacity to absorb the impacts of wastes generated by humankind. However, recent advances show that the Earth system is fragile and vulnerable to destruction as a result of anthropogenic activities (de Souza *et al*., 2013). Contamination of soil with petroleum hydrocarbons compromises the ability of the soil to filter, buffer and transform inorganic and organic contaminants (FAO, 2018). The soil environment contains various organisms, such as bacteria, fungi, invertebrates and plants that play a significant role in nutrient cycling and food production (Khan *et al*., 2018). It could also affect aquatic lives, impair plant growth and metabolism and stimulate massive decline in richness and diversity of soil flora and fauna (Salam and Idris, 2019). It is against this backdrop, the present study presented a succinct review on the negative impacts of petroleum contamination and the existing or proposed remediation methods.

EFFECTS OF PETROLEUM HYDROCARBON CONTAMINATION

Effects of petroleum Hydrocarbons on Soil Properties

The addition of petroleum hydrocarbons into the soil can alter the natural soil environment and cause micro and macro-scale biotic community changes (Khan *et al*., 2018). Due to the fact that petroleum is rich in carbon and small amount of nitrogen compounds, it can change the composition and structure of soil organic matter and impact the C/N, C/P, salinity, pH and conductivity of soil (Li *et al*., 2009). Similarly, its low density, higher viscosity and low emulsification ability, make it easily adsorbed on soil surface, affecting the permeability and porosity of soil (Wang *et al*., 2018). The presence of Nickel and Vanadium in crude petroleum increases the risk of pollution due to heavy metals (Efsun *et al*., 2015). Decrease in soil water retention capacity at high potential as a result of oil succeeding water in the competition for pore spaces and reduction in water film thickness around macro-aggregates, are also identified as effects of oil in soil environment (Udom *et al*., 2011).

Effects of petroleum Hydrocarbons on Microorganisms

Microorganisms as major components of soil biota are significantly affected by hydrocarbon contamination. Studies have shown that a number of microbial species are inhibited after oil spill and only few that rapidly adapt survive the exposure (Jin *et al*., 2014, Salam and Idris, 2019). *In-situ* studies have shown that immediately after contamination, there was an increase in microbial activity and a significant decrease in community diversity (Kaufmann *et al*., 2004). The extent of these changes to the microbial populations is dependent on several factors including: the composition of the microbial community prior to the contamination, the chemical composition of the crude oil, and the physiochemical factors in the contamination site (Kaufmann *et* al., 2004; Hazim and Al-Ani, 2019). Recent metagenomic study of contaminated microcosm conducted by Salam and Idris (2019) revealed a massive decline in the number of recovered microbial DNA sequences from 3,267,616 in the pristine control soil to 250,241 of the contaminated compared reference. Hydrophobicity and insolubility of petroleum hydrocarbons restrict its availability to microbial cells and is assumed to be the major cause of toxicity (Jin *et al*., 2014). Formation of oily scum impedes soil aeration and water availability thus creating an anoxic and wilting condition for the microbes (Udom *et al*., 2011).

Effects of petroleum Hydrocarbons on Plants

In plants, toxicity due to petroleum hydrocarbon contamination is obvious. The impact of hydrocarbon contamination on plants is often noticed immediately or after few days. Vegetation loss, phytotoxicity and plant stress which depends upon plant species type and degree of contamination are the major noticeable phenomena (Emengini *et al*., 2013; Mohamadi *et al*., 2016). Petroleum impedes plant growth by reducing the germination rate, soil fertility and reduces the resistance of plants to pests and diseases (Wang *et al*., 2017). Studies by Arellano *et al*. (2017) have shown significant decrease in plant biodiversity and richness in an Amazon sub-region after an oil spill incidence. Similarly, in a study conducted by Mohamadi *et al*. (2016) it was revealed that 73% of contaminated sites examined in the study had significant vegetation losses due to oil spill in Niger Delta, Nigeria. Disturbances of major physiological processes within plants systems manifest in a form of morphological, pigment, chlorotic and necrotic foliar patterns alterations. Traces of petroleum hydrocarbons are often detected in fruits and vegetables creating an important health hazard (Paris *et al*., 2018). Ordinioha and Brisibe (2013) have reported that oil spills could lead to 36% reduction in the ascorbic acid content of vegetables and 40% decrease in crude protein content of cassava and 60% reduction in household food security.

Effects of petroleum Hydrocarbons on Humans

Petroleum hydrocarbons especially the polycyclic aromatics have carcinogenic, mutagenic, teratogenic and other toxic effects in humans and other animals (Wang *et al*., 2017). Studies involving animals indicated that crude petroleum could be hemotoxic and hepatotoxic, and could cause infertility and cancer (Ordinioha and Brisibe, 2013). It impairs the normal function of vital human organs, therefore causing great threat to humans' health. Exposure to humans and animals is through breathing, skin contact and diet (Wang *et al*., 2017). Broad-spectrum acute health symptoms observed in a particular study included respiratory problems, irritations (dermal, eyes, and throat), neurological effects (headache, nausea/vomiting/dizziness), and trauma-related symptoms (Aguilera *et al*., 2010). Physiological effects, mental health effects, genotoxicity, immunotoxicity, and endocrine toxicity have been reported among individuals exposed to hydrocarbons after oil spillage (Laffon *et al*., 2016; Adipah, 2019). Occasionally, fire outbreaks leading to serious economic damages and loss of lives and properties occur. Lately (January 19, 2020), explosion of a pipeline belonging to NNPC in a Lagos suburb has left 11 buildings, 17 shops and 36 vehicles burnt to ashes. Five persons were officially reported dead, some unknown number of persons critically ill and other several hundred displaced (Energy Voice, 2020).

Effects of petroleum Hydrocarbons on Ecosystem

The impact of spilled petroleum hydrocarbon on ecosystem is enormous and often leads to disaster. In marine and fresh water ecosystems, aquatic resources like fish, plankton, benthic invertebrates, birds, marine mammals, intertidal fauna, marine plants, and habitats are critically affected (Michel and Fingas, 2016). For instance, seabirds are among the groups of animals that are most vulnerable. Small quantities of spilled crude oil is known to cause lethal effects on seabirds by destroying the waterproofing of their plumage, leading to loss of insulation and buoyancy and causing rapid death by starvation, drowning or hypothermia – especially in the colder climates (Jørgensen *et al*., 2019). Marine mammals such as whales, dolphins, seals, and sea otters are frequently killed; because oil clogs their respiratory organs making it impossible for them to breathe properly. Even when marine mammals escape the immediate effects, an oil spill can contaminate their food supply (Kovacs *et al*., 2009). Deadly toll on fish, shellfish, and other marine life are commonly experienced, particularly if many fish eggs or larvae are exposed to oil. Long-term damage to species and their habitats and nesting or breeding grounds is among the most far-reaching environmental effects caused by oil spills (Leighton, 1993). Of particular interest, is its slow disappearance from ecosystem and also accumulation along the global food web (Jørgensen *et al*., 2019).

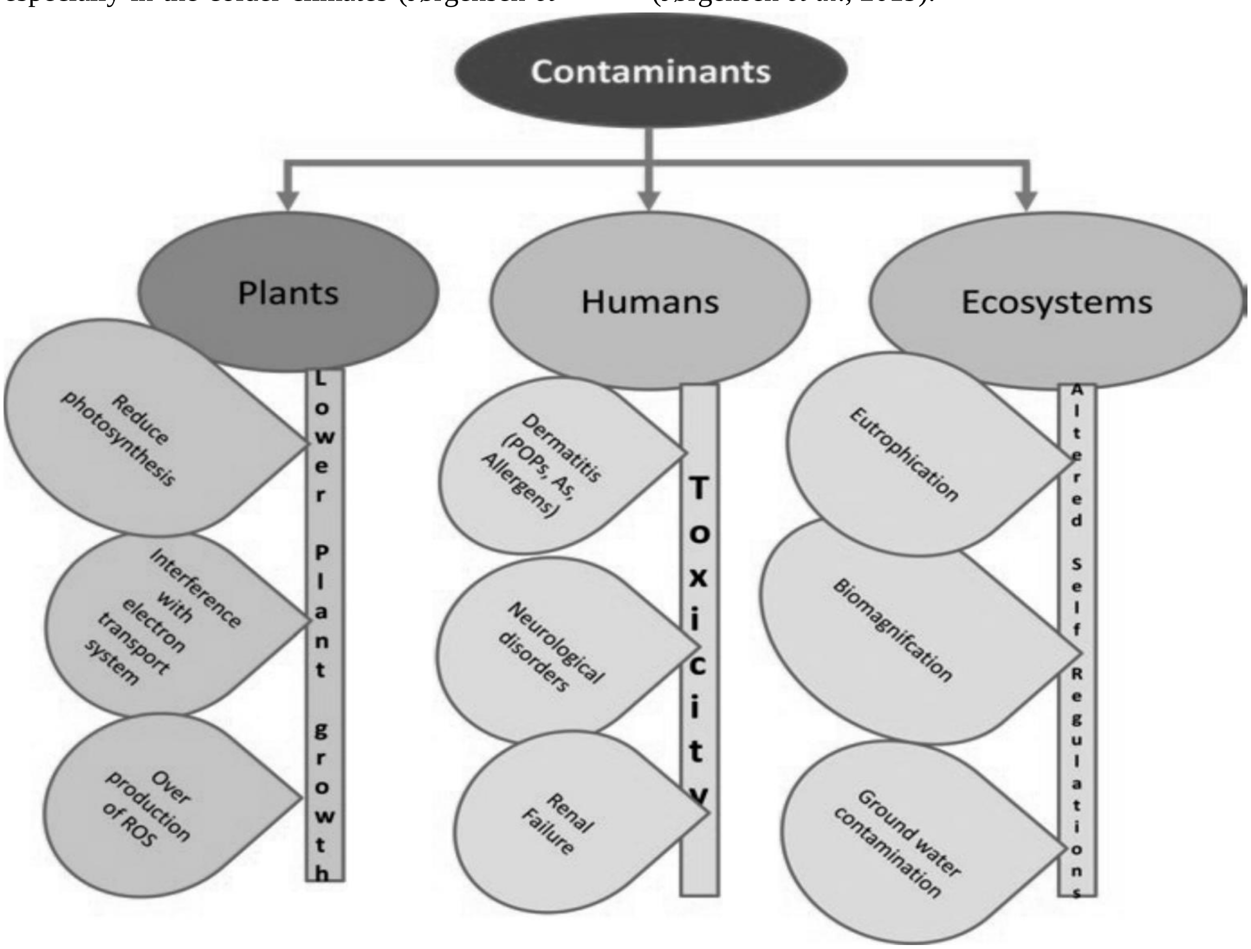

Figure 1: Impacts of contaminants on the essential components of environment (Source: Chakravarty *et al*., 2017).

REMEDIATION OF PETROLEUM HYDROCARBON CONTAMINATED SITES

Since the occurrence of the world's early major oil spills (Michel and Fingas, 2016), authorities and researchers have employed several strategies for cleanup of the polluted media. Today, technologies involving physical, chemical, thermal and biological processes are widely used in oil pollution treatment (de Souza *et* al., 2013; Wang *et al.*, 2017). The treatment technologies are aimed at anyone or all of the following:

i. Elimination or alteration of contaminants,
ii. Extraction or separation of contaminants from environmental media,
iii. Immobilization of contaminants.

Remediation approach may be classified as *in situ*, where treatment occurs in the place of contamination or *ex situ*, where contaminated medium is removed and transported away prior to treatment (O'Brien *et al*., 2017).

Physical Treatment

Treatment of petroleum hydrocarbon contaminant using physical methods involves the restriction and or containment of the pollutant depending on the environment affected (Michel and Fingas, 2016). In polluted soil, Berms or dikes can be built to contain oil spills and prevent oil from spreading horizontally. The use of sorbents and water with an aim of oil recovery and preventing penetration respectively has been reported (Michel and Fingas, 2016; Hoang *et al*., 20018). Mechanical recovery equipment, such as bulldozers, scrapers, and frontend loaders are also used as *ex-situ* remediation strategies especially if urban areas are affected, although they can cause severe and long-lasting damage to sensitive environments. Electrokinetic remediation is gaining more acceptance in hydrocarbon remediation in recent past (Kim *et al*., 2010; Streche *et al*., 2018) especially in soils with low permeability (O'Brien *et al*., 2017). In addition, encapsulation is found very effective method in which the spilled oil is isolated and contained by covering it with low permeable material such as textile and clay caps to avoid infiltration, leaching and resultant migration (Asghar *et al*., 2016).

In aquatic medium, skimmers and booms are frequently used individually or in combination to contain and or recover spilled oil from water surface without bringing any change in properties of the oil (Hoang *et al*., 2018). Where traces of oil are still suspected, natural or synthetic adsorbent are applied to convert oil into semi-solid form for its complete removal (Adebajo *et al*., 2003). Soil washing using hot water is often considered physical treatment that does not require any specialized equipment (Asghar *et al*., 2016).

Physical treatment approaches are advantageous because of their simple design and treatment of large volume of contaminated area within relatively short period of time. However, high operational cost, equipment failure, secondary contamination, prevailing environmental conditions (e.g. water currents, edaphic factors, oil volume etc.) and sometimes their destructive nature limit their wide application (de Souza *et al*., 2015; Arvanaghi *et al*., 2017).

Chemical Treatment

A number of chemical spill-treating agents are available to assist in cleaning of oil polluted sites. The major chemical approaches to remediate petroleum contaminated soil include the use of dispersants, solidifiers, encapsulation, and chemical oxidation (Asghar *et al*., 2016). Dispersants are mixture of surface active agents dissolved in solvents and stabilizers; applied with a view to diluting highly viscous oil spilled on water surface (Kim *et al*., 2010). In a situation where contaminants are in high concentration, the use of solvent extraction or chemical oxidation is recommended depending on a decision to treat the contaminants *ex-situ* or *in-situ* respectively. More so, surfactants can be used to separate contaminants from the soil particles by dissolution, and based on the desired outcome of the treatment (elimination or extraction of the oil) the surfactants can be used in low or high concentration (Silva-Castro *et al.*, 2015). This method is becoming popular because it can be applied both *ex-situ* (surfactant washing) and *in-situ* (surfactant flushing) (O'Brien *et al*., 2017). Solidifiers in form of granules are sprayed on contaminated site to congeal oil which is later contained or recovered using booms (Hoang *et al*., 2018).

One of benefits of most chemical treatment methods is being applied *in-situ* and thus, causes minimum disruption to other site operations. Destruction or oxidation of the contaminants is complete and rapid and where residual oil still exists, deployment of secondary remediation processes is possible (Kim *et al*., 2010; de Souza *et al*., 2015; Ashgar *et al.*, 2016). On the other hand, there is great concern and debate on adding chemical agents to the aquatic environment, as it is seldom without poisoning of fish, corals, other marine species and even humans. High cost of chemicals, contaminants accessibility (most especially in soil with low permeability), secondary contamination and equipment maintenance have been identified as major setbacks (Michel and Fingas, 2016; O'Brien *et al*., 2017; Hoang *et al*., 2018).

Thermal Treatment

This treatment method use different forms of heating to achieve remediation. The common heating techniques include *in-situ* burning (incineration), thermal desorption, electrical resistant heating, steam injection and extraction (Asghar *et al*., 2016). As incineration involves the use of extreme heating for complete combustion of oil sludge, thermal desorption desorbs volatile components from polluted soil without excessive heating of soil. In practice, it involves heating spilled oil at a temperature that most of its volatile components will vaporize and desorb (Ezeji *et al*., 2007; de Souza *et al*., 2015). Electrical resistance heating uses electric currents to heat moisture within soil spaces, which leads to vaporization of the contaminants (Arvanaghi *et al*., 2017).

Thermal methods can be used quickly but with high efficiency if supported by specialized devices. It is cheap, and suitable for area of open water, snow or ice. However, these methods showed many disadvantages such as lack of oil recovery, emission of many polluting components to air and marine environment, threat for marine creatures, human life and other resources (Hoang *et al*., 2018).

Biological Treatment

Biological treatment also called bioremediation, involves the use of living organisms to cleanup an environment. Microorganisms especially bacteria and fungi are commonly used. In recent times, technologies that make use of plants are also employed. The technology is applicable *in-situ* and *ex-situ* in soil, unsaturated zones and ground water (Leahy and Colwell, 1990; Ezeji *et al*., 2007; Hoang *et al*., 2018). In biological treatment, most of the technologies employed are based on addition of limiting nutrients and optimizing environmental conditions for the better growth of participating organism (s). For instance, simpler and traditional technologies like composting and land farming provide additional nutrient in form of organic matter and aeration respectively (de Souza *et al.*, 2015). In biopiling, contaminated soils can be excavated and made into hips into which air, nutrients and other amendments are supplied (USEPA, 2012). Other technologies that operate on similar principles are bioventing and biosparging which involves aeration in vadose and ground water respectively (USEPA, 2012; Asghar *et al*., 2016). Advanced biological treatments include addition of potent microbial cells (bioaugumentation), specific nutrients (biostimulation), engineered microbes (bioengineering), plants (phytoremediation) and animals (vermiremidiation) (Silvia *et al*., 2006; Chachina *et al*., 2016; Almutairi, 2019).

Generally, bioremediation requires less resource input than other techniques, and it is perceived as an environmentally friendly approach that can easily be applied where contaminations are in large-scale, as well as those with low risk for contaminant migration. However, bioremediation is often slow and unreliable, and thresholds of toxicity to living organisms may preclude its use in some circumstances. Uncontrollable surface and prevailing weather conditions, inability to recover oil and periodic and rigorous monitoring are among its limitations (de Souza *et al.*, 2015; O'Brien *et al*., 2017; Hoang *et al*., 2018).

Microbial Remediation

According to Yap and Peng (2019), microbial remediation can be simply defined as a process employing microorganisms to lower the bio-availability of pollutants so as to make it less toxic to ecosystem. It is also referred to bioremediation by majority of researchers, although the term generally represents remediation carried out by any type of living organisms (Banerjee *et al*., 2016). Bioremediation is an acceleration of the natural fate of oil pollutants and hence a natural or 'green solution' to the problem of oil pollutants that causes minimal (if any) ecological effects (Atlas, 1995). The major goal of this technology is to degrade organic pollutants to concentrations that are undetectable, or if detectable, to concentrations below the limits established as safe or acceptable by regulatory agencies (Okoh and Trejo-Hernandez, 2006). Microorganisms are able to transform (mineralize or co-metabolize) contaminants by using them as carbon and energy source through a process called biodegradation (Kothari *et al*., 2013; Unimke *et al*., 2018).

Phytoremediation

Phytoremediation is a sustainable and green process in which live plants are used to remove or degrade contaminants from the environment (Cameselle *et al*., 2013). Phytoremediation is an *in situ* remediation technology that utilizes the inherent abilities of living plants. Over the years, synergistic relationships among plants, microorganisms, water and soil have been demonstrated to play an important role in shaping all the environmental components and it is on this principle the concepts of phytoremediation are established (Ahalya and Ramachandra, 2006). General information on phytoremediation has been developed from a variety of research areas including constructed wetlands, oil spills, and accumulation of heavy metals by agricultural plants (Sumiahadi and Acar, 2018). It is a solar-energy driven clean-up technology, based on the principles of using nature to cleanse nature and hence its eco-friendliness (Nwaaichi *et al*., 2015). Currently, phytoremediation provides a promising solution to the most disastrous problem of pollution that is faced by mankind. Phytoremediation not only addresses the problem of environmental pollution but also provides several ecosystem services (Chakravarty *et al*., 2017).

Phytoremediation can be applied in terrestrial and aquatic environments as a preparative or finishing step for other clean-up technologies (Ahalya and Ramachandra, 2006). Presently, phytoremediation is the only known most-passive cleanup technology in which growing, and in some cases harvesting the plants on a contaminated site renders it safe; especially where shallow or low to moderate levels of contaminants are involved. It can be used to clean up heavy metals, organic pollutants (e.g. pesticides, crude oil, polyaromatic hydrocarbons, and solvents), explosives, radioactive contaminants and landfill leachates. In essence, phytoremediation is an efficient cleanup technology for a variety of organic and inorganic pollutants (Pilon-Smits, 2005).

Vermiremediation

Vermiremediation is a process that uses animals particularly invertebrates with a view to eliminating or removing organic and inorganic pollutants most especially in the soil environment (Njoku *et al*., 2017). Earthworms (*Eisenia* spp.) and other related species have commonly been used as remediation agents. Research on the potential utilization of earthworms has shown an ability to manage polluted land and even sewage sludge. It has been discovered that earthworms are tolerant to, and can remove, or aid the removal of a wide range of organic and inorganic contaminants such as pesticides, polycyclic aromatic hydrocarbons (PAH), crude oil and heavy metals from the soil (Asubiaro *et al*., 2018). Earthworms can either be applied directly or indirectly. Direct application methods include the addition of the worms to the contaminated sites as the main remediation agents, co-application with compost and addition of the contaminated soil as feeding regimen. Indirectly, vermidigest or vermicompost is applied to the contaminated site (Njoku *et al*., 2017; Asubiaro *et al*., 2018; Almutairi, 2019).

Currently, technologies involving physical, chemical and thermal treatments are more commonly used than biological treatments for the purpose of rapid oil and or environmental recovery. Desirably, the biological approaches cause less environmental disruption than all other treatments, and it can be far less expensive to remediate a hazardous waste site than it would be to use traditional treatment techniques. Instead of just moving toxins from one environmental medium to another, biologically based remediation techniques detoxifies hazardous compounds. If properly designed, the techniques reduce health risks, save biodiversity, naturally recover the damaged ecosystem, generate direct and indirect job possibilities, as well as facilitate the long-term management of polluted soils, all of which will help to promote and facilitate the integration of new sustainable socioeconomic activities. It is pertinent to point out that most bioremediation protocols are laboratory-based and many of the few field trials were not properly designed and executed, resulting in uncertainty when selecting remediation approach. As a result, future researches should be field-based in order make substantial efforts to use scientifically sound methodologies and collect the highest quality data possible for proper cleanup exercises.

CONCLUSION

Petroleum hydrocarbon contamination creates stressful conditions in the ecosystem and its individual components. Different cleanup technologies have been developed overtime with a view to mitigating the adverse effects. Although each technology has its own limitations, the prevailing environmental conditions and pollutant characteristics determine the choice of a particular approach and its success. It shall be noted however that, for an effective petroleum hydrocarbon cleanup, selection of appropriate treatment method is essential even though it might be difficult. As a result, risk assessment visits before deployment of equipment and resources even during quick response are needed. This would significantly reduce the risk of secondary contamination and other undesirable and unpredictable eventualities. Therefore, more research is needed to improve the existing technologies and also discover new ones.

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