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Bioremediation techniques for the management of agricultural soils contamination by oil spilling

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Abstract

Soil and land contamination as a result of diverse industrial activities, particularly oil spilling, pesticides and disinfectants, has affected quality of life, ecosystems and overall agricultural activities. Bioremediation is a scientific method in which biological microorganisms are used to remove contaminants via metabolic processes. This procedure has the advantage of providing the transformation and/or even removal of organic and inorganic pollutants, even at low absorption. This paper specifically focused on addressing the theories and models of some techniques involved in the processes of bioremediation. These techniques can be divided into two types: *in situ* and *ex situ*. The in situ techniques are defined as those that are applied to soil and groundwater at the site with minimal disturbance, whereas the ex situ techniques are those models that are applied to soil and groundwater at the site that have been removed from the site via excavation (soil) or pumping (water). It is believed that successful treatment of contaminated environments, particularly those polluted by oil spilling and dripping, requires an integrated and well-planned effort. This treatment will help improve the environmental soil quality for diverse agricultural activities and ensure better lifestyles among the rural communities where the activities of oil industries are present.

Key words: bioremediation, bioremediation techniques, oil spilling, soil contamination

Introduction

Changes in anthropogenic activity and unacceptable human environmental conditions have led to the release of liquid petroleum hydrocarbons into the environment. This has caused the pollution and contamination of land, soil, water bodies and forest areas (Maculay & Rees, 2014). Liquid petroleum hydrocarbons (LPHs) are considered naturally occurring fossil fuels that are formed from dead organic materials in the Earth's crust (Kingston, 2002). However, the quality of human life and biological soil–water-based communities depend greatly on the quality of the surrounding environment where they live on Earth. Historically, the human generation believed that there is an abundance of landscape and land resources for life interactions and life economic businesses. In the event of noticeable and unacceptable changes to these land resources and the surrounding environment globally, however, our carelessness and inattention in terms of managing them put many populations into serious problems and crises (Wexler, 2014). Contamination as a result of diverse industrial activities, particularly oil spilling, pesticides and disinfectants, has affected quality of life and the environment, and this problem is global and significant (Cairney, 1993; Usman et al., 2024). It is generally recognized that contaminated environments are potential threats to human health, agricultural soils, water bodies and surrounding species (Chen et al., 2020). The recurrent discovery of this problem over recent years has led many international bodies to put an effort into treating many of the affected sites, either as a response to the risk of adverse health or environmental effects caused by contamination or to enable the site to be redeveloped for agricultural use, forest rehabilitation and human interactions (Vidali, 2001). Early on, the predictable techniques and methods used for remediation and solution were to dig up contaminated areas, remove them to landfills, or restrict them from other activities (King et al., 1997). The methodologies used have some drawbacks and are tedious, costly and, to some extent, dangerous to workers. Recently, bioremediation has been used as a more sustainable way to remedy and minimize this contamination (Mora et al., 2008; Azubuike et al., 2016; Prasad et al., 2021). Bioremediation is considered a process used to treat contaminated lands, including water bodies, agricultural and nonagricultural soils and subsurface material, by altering environmental conditions to stimulate the growth of microorganisms and degrade target pollutants (Norris et al., 1993; Vidali, 2001).

The successful treatment of contaminated environments, particularly those polluted by oil spilling and dripping, requires an integrated and well-planned effort (King et al., 1997). This effort depends on ideas, which could be planned according to the objectives set by the researcher. However, environmental soil management plays a key role in achieving sustainable development goals in many aspects of human development (DESA, 2013). Broad environmental issues have been combined to put this management into a very complex and needful task (FAO, 1995). These environmental issues are considered damaging and hazardous to all components (soil, water, air and humans) of ecosystems (Cairney, 1993; Chen et al., 2020). These issues are of high concern and include contamination, pollution, climate change and degradation. Many factors cause or to some extent create these environmental issues; however, one of the most serious issues in oil drilling regions is oil spilling and oil dripping (Varjani & Upasani, 2017). This oil spilling and dripping has caused much contamination and pollution, which has led to both physical and chemical contamination in water bodies, agricultural soils, forest areas and overall human residents (García et al., 2010). Sustainable bioremediation is needed to help halt the progress of these problems and provide more friendly solutions to affected regions globally. This bioremediation process has many advantages compared to other early technologies (Vidali, 2001). This method detoxifies hazardous compounds, unlike transporting contaminants to other sites where contaminants may also contaminate the soil and ecosystem. Human engagement and the environment are less disruptive and less disorderly than excavation-based methods are (Prasad et al., 2021). The financial implication of treating contaminated sites using bioremediation-based techniques was that they were considerably less expensive than conventional treatment methods (Azubuike et al., 2016). However, because of the limited bioremediation of these pollutants, which are only biodegradable, the need to provide a background concept of bioremediation and its application processes has increased (Maculay & Rees, 2014). This overview will take into account the concept of bioremediation and its relevance to soil and land areas where contamination occurs due to either oil spilling or pesticides or toxic metals. This information will serve as a means of practical application to other related future studies globally.

Problem arising: ***a case example of oil spilling leading to soil contamination***

The sites contaminated by oil spilling in oil drilling regions are progressive and affect different functional services of life and the environment (Juwarkar et al., 2010; Odukkathil & Vasudevan, 2013; Kapahi & Sachdeva, 2019; Sağlam et al., 2024). The quality of human and biological life, including that of biota (plants) and biodiversity, has been affected (Paniagua-Michel & Fathepure, 2018). Water bodies and species, drinking water and underground water qualities are also affected (Cerniglia & Pritchard, 1996). This has in turn affected the economic component of the human population in these regions. These problems are considerable and must be halted to help minimize complex environmental crises, which have also affected the overall environmental security between the oil companies operating, the government of the region and local communities or the public in the affected areas. The use of bioremediation technologies is believed to utilize naturally occurring microorganisms, such as bacteria, fungi, and yeast, to degrade hazardous and contaminated substances into nontoxic or less toxic substances to humans and their environment (Lee et al., 2018). It is an option that offers the possibility of destroying harmless diverse contaminants using only natural biological species and is considered a relatively low-cost, low-technology technique that is easily accessible to affected societies and simple for public/rural communities to understand (Vidali, 2001).

The global challenges to sustainable development and environmental health have been driven by a broad set of mega-trends, which include environmental contamination, changing demographic profiles, changing economic and social dynamics, advancements in technology and trends towards ecosystem deterioration (DESA, 2013). The World Economic and Social Survey (WESS) report noted that any contribution towards the considerations of sustainable development must focus on three (3) important issues: sustainable cities, food security and energy transformation (DESA, 2013). The contaminated environments in oil drilling regions are seriously facing challenges related to these three (3) important issues (Juwarkar et al., 2010; Prasad et al., 2021). Therefore, the aim of this study was to certify successful environmental health management and economic development for sustainable villages and food security through the use of bioremediation techniques at oil spill-contaminated sites.

Bioremediation: ***a background theory***

Biological microorganisms are used for bioremediation to remove and neutralize contaminated pollutants through metabolic processes (Coulon et al., 2010). The natural aspect of this bioremediation process in a naturally occurring environmental medium is known as bioattenuation (Mrozik & Piotrowska-Seget, 2010). It provides the transformation and/or even removal of organic and inorganic pollutants, even when they are present at low concentrations (Hlihor et al., 2017). There are many sources of information regarding bioremediation, its techniques, advantages, disadvantages or limitations and its application or adaptability to different environments (Shanker et al., 1998; Boopathy, 2000; Vidali, 2001; Mora et al., 2008; Juwarkar et al., 2010; Odukkathil & Vasudevan, 2013; Macaulay & Rees, 2014; Azubuike et al., 2016; Varjani & Upasani, 2017; Lee et al., 2018; Chen et al., 2020; Prasad et al., 2021; Marchetto et al., 2021). The handbook on bioremediation has since been written and has provided vital resource information on the subject matter (Norris, 1993).

For practical environmental bioremediation, a field guide was also available for optimum use (King et al., 1997). This information revealed that bioremediation is a vital process for the treatment of contaminated lands, soils, water bodies and plant areas. The technology involved in this process is also considered suitable for many contaminated sites affected by oil spilling and heavy metals (Chikere et al., 2012). However, many factors are considered in determining this suitability. These factors include the site conditions, indigenous microorganism population, and type, quantity, and toxicity of contaminant chemicals present (Varjani & Upasani, 2017). The lack of understanding of the processes and technologies involved, as well as the dynamic/hybrid nature of contaminated sites, limits the use and sustainable application of bioremediation (Azubuike et al., 2016). This indicated the need to generate information on different bioremediation techniques for a better understanding of suitable processes and their applicability to broader environments (Macaulay & Rees, 2014).

Challenges must be considered in practising any form of bioremediation for dealing with contamination caused by petroleum oil spills. The current challenges include the resistance of asphaltenes to biodegradation, the delay of heavy or high molar mass polycyclic aromatic hydrocarbon (PAH) biodegradation, eutrophication caused by biostimulation, the un-sustainability of bioaugmentation in the field, the poor bioavailability of spilled petroleum, the inefficiency of biodegradation in anoxic environments and the failure of successful bioremediation laboratory studies in the field (Macaulay & Rees, 2014). Generally, different techniques are employed depending on the degree of contamination and size of the contaminated site. The scope and definition of these techniques can be divided into two forms, namely, in situ and ex situ (King et al., 1997).

***In situ* and *ex situ* techniques for bioremediation**

Table 1 provides summary examples of some common in situ and ex situ methods of bioremediation. The in situ techniques are defined as those that are applied to soil and groundwater at the site with minimal disturbance, whereas ex situ techniques are those that are applied to soil and groundwater at the site that has been removed from the site via excavation (soil) or pumping (water) (Vidali, 2001). The US-EPA (1984) noted that in situ bioremediation techniques are more suitable than ex situ bioremediation techniques because in situ bioremediation has a lower cost and causes fewer disturbances because of its potential to treat contaminated sites and avoid the excavation and transport of contaminants to other safe environments. The differences between these two techniques have been reviewed in many articles (Johnson et al., 2001; Azubuike et al., 2016). Thanks to the work of Vidali (2001), who presented a comprehensive summary, as detailed below.

1. Bioventing process: This is the most common in situ treatment and involves supplying air and nutrients through wells to contaminated soil to stimulate indigenous bacteria. This process is considered to increase the flow of oxygen or air into the unsaturated zone of the soil, which in turn increases the rate of natural in situ degradation of the targeted hydrocarbon contaminant (Garcia et al., 2010). It employs low air flow rates and provides only the amount of oxygen necessary for biodegradation while minimizing volatilization and release of contaminants to the atmosphere; additionally, it works for simple hydrocarbons and can be used where the contamination is deep under the surface (Vidali, 2001). It also involves supplying oxygen and nutrients by circulating aqueous solutions through contaminated soils to stimulate naturally occurring bacteria to degrade organic contaminants (Vidali, 2001). Aerobic bioremediation is considered to be suitable for the treatment of contaminated soils and groundwater because of its characteristic infiltration capacity, which allows oxygen, water nutrients and other treatment compounds to enter groundwater areas (US-EPA, 2013).

2. Biosparging process (Vidali, 2001; Johnson et al., 2001): This process involves the injection of air under pressure below the water table to increase groundwater oxygen concentrations and enhance the rate of biological degradation

Table 1. Examples of in situ and ex situ methods of bioremediation

	In situ	Reference (e.g.)	*Ex situ*	Reference (e.g.)
1	Bioventing	Garcia et al., 2010	Land-farming	Vadali, 2001
2	Biosparging	Vidali, 2001	Composting	Usman, 2018
3	Biostimulation	Lee et al., 2018; Kapahi & Sachdeva, 2019	Biopile	Azubuike et al., 2016
4	Bioaugmentation	Macaulay & Rees, 2014	Bioreactor	Vadali, 2001
5	Bioaugmentation	Vidali, 2001	Windrow	Prasad et al., 2021
6	Bioattenuation	Ying, 2018	Pump and Treat Strategy	Boopathy, 2000
7	Bioslurring	Gidarakos & Aivalioti, 2007		

of contaminants by naturally occurring bacteria. This increases the mixing in the saturated zone and thereby increases the contact between the soil and groundwater. The ease and low cost of installing small-diameter air injection points allows considerable flexibility in the design and construction of the system.

3. Biostimulation process: This process involves the use of nutrients or bacterial and bacterial groups, which naturally exist in the affected environment (Lee et al., 2018; Kapahi & Sachdeva, 2019). Slonczewski (2009) considered pH to be the most important factor in determining the use and application of biostimulation in soil- and water-contaminated sites. Kalantary et al. (2014) noted that in a decision to employ the idea of adding nutrients as a biostimulus, nitrogen, phosphorus, oxygen and carbon would be effective. These nutrients are important for the biodegradation of water contaminated by oil spill compounds (Varjani & Upasani, 2017; Chen et al., 2020). Indeed, biostimulation has been considered to help hasten the biodegradation of heavy polycyclic aromatic hydrocarbons (PAHs) if applied to polluted sites, which are rich in oleophilic microbes, and the possibility of harvesting indigenous microbes from contaminated sites and culturing and reintroducing them to the site may solve the problem of environmental intolerance caused by exogenous microbes (Mrozik & Piotrowska-Seget, 2010).

4. Bioaugmentation process: This process frequently involves the addition of indigenous or exogenous microorganisms to contaminated sites. According to Vidali (2001), there are two (2) factors limiting the use of added microbial cultures in land treatment using bioaugmentation: (a) nonindigenous cultures rarely compete well enough with an indigenous population to develop and sustain useful population levels, and (b) most soils with long-term exposure to biodegradable waste have indigenous microorganisms that are effectively degraded if the land treatment unit is well managed. Bioaugmentation is a technology used for both soil and aquatic oil spill clean-up (Macaulay & Rees, 2014).

5. Bioattenuation process (Ying, 2018): This process is considered to occur naturally, although nutrients and bacteria are known to be supplied for the treatment of contaminated sites. This process is very useful because of the consideration of indigenous microbes and/or plants, which determine metabolic biodiversity in contaminated environments (Ying, 2018).

6. Bioslurring process: This process is considered a comparatively new in situ bioremediation process and involves a strategy that combines bioventing with a free-product recovery system with the potential to achieve two aims at the same time (Macaulay & Rees, 2014). Kittel et al. (1994)

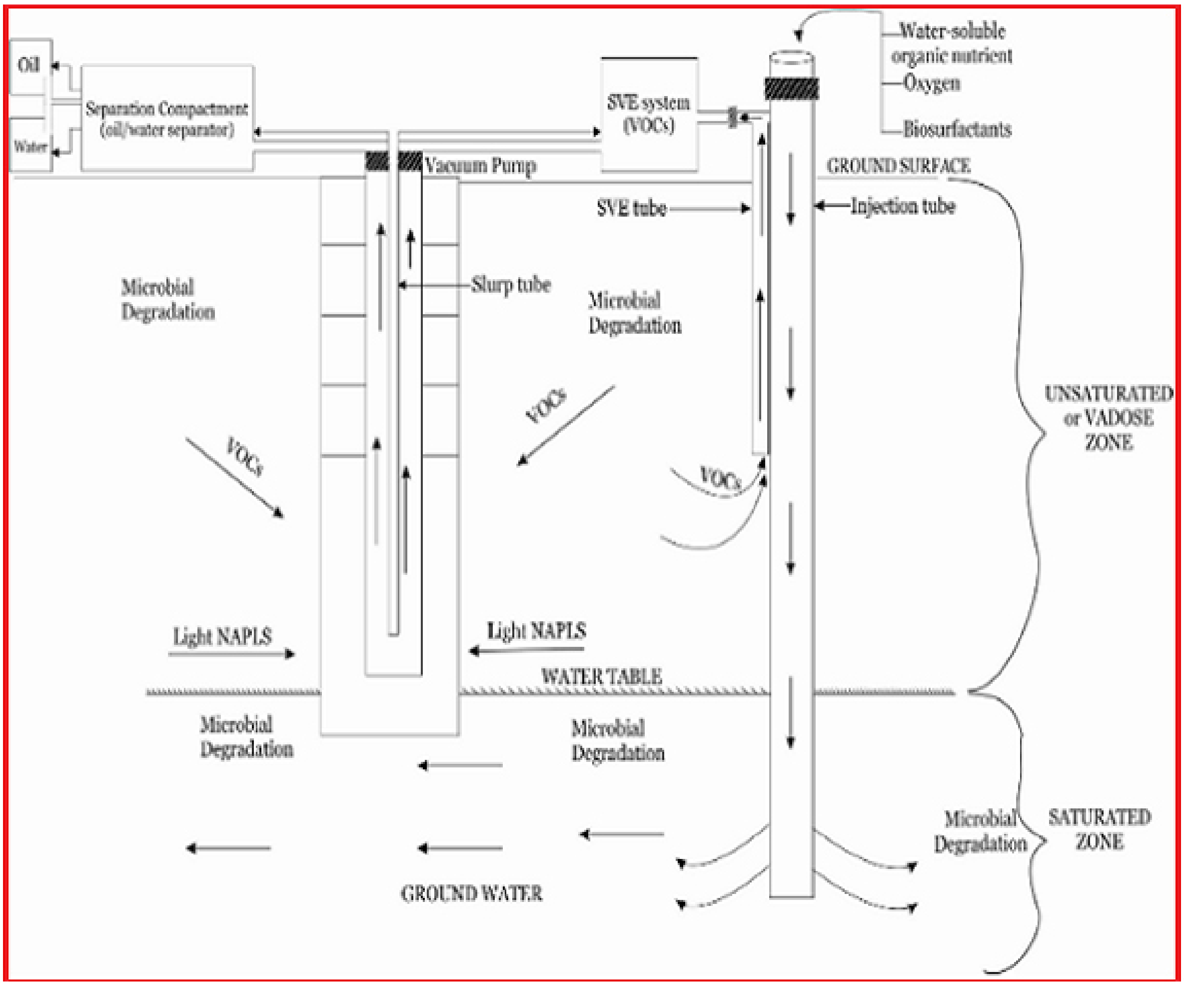

Fig. 1. A bioslurping-biosparging technique (adapted from Macaulay & Rees, 2014)

considered these two aims to be aerobic microbial biodegradation of the unsaturated (vadose) zone through air injection and SVE and the removal of light nonaqueous phase liquid saturates (NAPLS-free-phase petroleum pollutants) from the capillary fringe and water table via dual pumps (through a gravity gradient, the first pump forces the flow of petroleum from the vadose zone into the well, and the second pump skims off the petroleum to the surface). This method has been tested successfully and efficiently for large-scale and long-term application in cleaning petroleum spills at a Greek petroleum site (Gidarakos & Aivalioti, 2007).

The processes involving ex situ bioremediation include the excavation and removal of contaminated soil from oil spill sites (Vidali, 2001; Prasad et al., 2021). These methods of bioremediation require the digging of contaminated soil or groundwater before the initial treatment and, as such, are more costly than in situ processes (King et al., 1997). These methods are explained as follows:

1. Land-farming process (Vidali, 2001): The land-farming process is considered a simple technique in which the site contaminated by an oil spill is removed and spread over a well-prepared bed-like layer; the spread of contaminated soil is ploughed and monitored on a regular basis (6–12 months) until the pollutants are degraded. The primary aim of this exercise is to encourage indigenous-based biodegradative microorganisms or soil biota and facilitate their aerobic degradation of contaminants. The limitation of this process is that it can be controlled only within a surface area of 10 to 35 cm. However, it has an advantage over other ex situ methods because of its potential to reduce monitoring and maintenance costs as well as clean-up liabilities. These attributes have attracted much attention as a disposal alternative when the decision is made to employ ex situ methods.

2. Composting process: Composting is performed under a combination of soil and environmental factors and is engineered through decomposition processes called mineralization and humification (Strauss, 2009; Usman, 2018). According to Usman (2020), composting potentially affects the physical, chemical and biological components of soil by changing the morphological and genetic systems in the soil environment. Bioremediation involves the combination of contaminated soil and nonhazardous decomposed organic compounds such as manure, biofertilizers and agricultural residues (Misra et al., 2003; Chen & Zhou, 2021). Bioremediation of compost also involves the mixing of hydrocarbon contaminants with fresh organic amendments to produce rich microbial consortia that are heat-loving (mainly thermophiles) (Macaulay & Rees, 2014). Fahnestock et al. (1998) reported that the presence of these decomposed organic particles enhances the biodiversity of microbial populations and elevates the temperature characteristics of compost manures. This provides an environment suitable for changing contaminated sites by oil spilling to lively and healthy sites favourable for agricultural activities and fish farming.

3. Biopile process: This process is an ex situ method of excavating and pouring contaminated soils using an aeration system and, as such, is considered a hybrid of landfarming and composting (Vidali, 2001). The components of this technique are aeration, irrigation, nutrient and leachate collection systems, and a treatment bed (Azubuike et al., 2016). Aeration systems have been reported to serve as a means of attracting microbial biodiversity because of their potential for making oxygen available under positive pressure and freeing it under negative pressure (Chen & Zhou, 2021). Vidali (2001) noted that engineered cells are constructed as aerated composted piles, which are used for the treatment of surface contamination with petroleum hydrocarbons, and they are a refined version of land farming that tends to control physical losses of contaminants by leaching and volatilization. Under these conditions, the process provides a favourable medium for indigenous aerobic and anaerobic microorganisms.

4. Bioreactor process: This process involves the utilization of reactors called slurry or aqueous compounds, which are used for ex situ treatment of contaminated soil and water derived from contaminated sites (Vidali, 2001). The process of bioremediation in reactors involves the dispensation of contaminated solid material (soil, sediment, or sludge) or water through an engineered containment system. A known slurry bioreactor is defined as a containment vessel and apparatus used to create three-phase (solid, liquid, and gas) mixing conditions to increase the bioremediation rate of soil-bound and water-soluble pollutants as a water slurry of contaminated soil and biomass (usually indigenous microorganisms) capable of degrading target contaminants (Vidali, 2001). In this situation, the short- or long-term operation of a bioreactor containing crude oil-polluted soil slurry allows tracking of changes in microbial population dynamics, thus enabling easy characterization of the core bacterial communities involved in bioremediation processes (Chikere et al., 2012). The rate and extent of biodegradation in this ex situ process are greater in a bioreactor system than in situ or in solid-phase systems. This is because the contained environment is more manageable and hence more controllable and predictable. However, despite the advantages of reactor systems, there are some disadvantages, which have been described as a situation in which the contaminated soil is said to require pretreatment (physical digging) before being placed in a bioreactor (Vidali, 2001).

5. Windrow process: This is another ex situ method that typically employs the processes involved in composting and usually involves putting contaminated soils on a turning exercise on a yearly basis or preferably between 6 and 12 months to ensure favourable aeration (Prasad et al., 2021). This annual change in contaminated soil would allow pollutants to be despoiled consistently and enhance bioremediation (Azubuike et al., 2016). This process has the advantage of a higher rate of removing pollutants from contaminated sites than from biopiles (Coulon et al., 2010).

6. Pump and Treat Strategy process: This process has been designed to treat contaminated groundwater and water at the surface. This process primarily involves the pumping of polluted groundwater to the surface and the injection of treated groundwater back to the initially polluted site (Boopathy, 2000). However, during this exercise, the extracted groundwater is cleaned through aerobic biodegradation, although other nonmicrobial cleaning processes could also be used, including phase separation, air stripping and liquid-phase granular activated carbon adsorption (Erickson et al., 2000). It constitutes the building of the withdrawal and injection well as the treatment of the groundwater; these components have been noted to make the process very costly and difficult (Macaulay & Rees, 2014).

Other methods of consideration

1. Genetic engineering: There are also growing studies and advancements concerning the use of genetic processes known as genetic engineering (Shanker et al., 1998; Sayler & Ripp, 2000; Menn et al., 2001). This genetic process is another aspect of bioremediation that creates an environment for genetically modified microorganisms produced primarily and specifically for bioremediation (Lovley, 2003). Studies by Ripp et al. (2000) and Sayler & Ripp (2000) demonstrated the success of applying genetic engineering in the bioremediation of contaminated sites, particularly those affected by oil spills. However, the impact of this application on environmental health and stability has been a concern of gene transfer (Davison, 2005), although measures are being developed to address this serious concern.

2. Multiple-component techniques: Numerous bioremediation techniques have been used to achieve different research objectives, but the majority of these techniques are designed for soil/land oil spill management (Macaulay & Rees, 2014). Some of these techniques are explained above; however, if these techniques are combined, they would be more advantageous for achieving better management. According to Ledin (2000), a multicomponent strategy rather than a single-component approach is recommended to facilitate the breakdown of a wider range of hydrocarbon compounds (Ledin, 2000). Commonly, one of the possible techniques of this multicomponent strategy in an advanced scientific concept is Bioslurping, and biosparging is typically called 'Bioslurping and biosparging technology'. These combined techniques are regarded as bioremediation technologies specially designed to clean up saturated (groundwater) and unsaturated (surface land) water independently (Macaulay & Rees, 2014). The theoretical concept is depicted in Figure 1. The method is believed to have the potential to extract insoluble light hydrocarbons through a swallow tube from a water table and then separate them from the surface where they might be transported to a chamber for treatment (Macaulay & Rees, 2014).

An overview discussion

Bioremediation is the use of microbial organisms such as bacteria, fungi, or plants to reduce or decompose environmental pollutants, which can be catabolized, degraded, or removed to obtain nutrients and energy (Sağlam et al., 2024). Bioremediation technology is effective in the treatment of oil pollutants primarily because majority of the molecules in petroleum hydrocarbons are considered biodegradable (Ward et al., 2009). Soil contamination by toxic compounds are serious environmental concern because of the penetration and non-degradable nature of metals such as nickel (Ni), lead (Pb), cadmium (Cd), cobalt (Co), aluminum (Al), and mercury (Hg) (Raskin et al., 1994). However, the compatibility of bioremediation with land or soil and water oil spill treatment processes can be considered a promising technique, which could have the potential to attract even excellent biodegradation of hydrocarbon compounds in the affected environment (Prasad et al., 2021). Compared with ex situ techniques, in situ techniques have more advantages, are less expensive and are more environmentally friendly (Azubuike et al., 2016). Practical experience in using these techniques has been noted in many studies with different opinions and contributions (Mora et al., 2008; Juwarkar et al., 2010; Odukkathil & Vasudevan, 2013; Varjani & Upasani, 2017; Lee et al., 2018; Chen et al., 2020; Marchetto et al., 2021). The idea of using two or more techniques in combination with technology was introduced and is believed to improve the efficiency and effectiveness of bioremediation under practical conditions (Wilson et al., 1993; Vidali, 2001). In this regard, Ledin (2000) suggested the methodology of combining two in situ processes in a technology called 'bioslurping-biosparging technology'. Macaulay & Rees (2014) recommended the use of this technology and strongly advised the government and oil industries to financially support any relevant research to test and retest its adaptability at contaminated sites. This recommendation is encouraged by the US-EPA (1984) Handbook on in situ Treatment of Hazardous Waste Contaminated Soils.

Overall, these bioremediation processes can be understood from the background opinion that some of them involve the addition of organic amendments to stimulate the biodiversity of other indigenous microorganisms through composting (Vidali, 2001). Some of these processes involve the addition of microorganisms to degrade pollutants and enhance the biodiversity of soil-based microbes (Kapahi & Sachdeva, 2019). Excavation is also another option but is considered unsustainable and costly compared to in situ excavation (Prasad et al., 2021). Genetic engineering has been used but has negative effects on overall environmental sustainability (Davison, 2005). However, choice and adaptability as well as applicability must be addressed depending on the objectives and nature of the contaminated site and this must also be considered at all levels of the study.

The use of bioslurring-biosparging technology was five years ago, as recommended by Macaulay & Rees (2014); however, the individual aspects of this technique have long been tested successfully in oil-contaminated regions. For example, Gidarakos & Aivalioti (2007) used bioslurring techniques to test the large scale and long-term application of this technique at the Greek petroleum refinery site. Kittel et al. (1994) used a bioslurring couple with bioventing to achieve enhanced free-product recovery. Paniagua-Michel & Fathepure (2018) used related techniques to achieve the objectives of applying microbial consortia and biodegrading petroleum hydrocarbons in marine environments. Vidali (2001) strongly recommends the use of biosparging and its application to contaminated land and water environments. For example, this concept of bioslurping-biosparging can be used in cleaning agricultural soils contaminated by oil drips or pesticides (Usman, 2020). The result of this cleaning might lead to improved agricultural activities in the affected areas (Usman, 2013).

Conclusion

This paper has compiled the synopsis theory of bioremediation and its techniques, advantages and disadvantages as well as those areas of scientific attraction. The integrated concept of bioremediation known as 'bioslurping-biosparging technology' has been found to be worthy of consideration for the removal or control of pollutants in contaminated environments. According to Macaulay & Rees (2014), when governmental and nongovernmental institutions are able to sponsor studies on bioremediation, researchers can compare the efficiency of the existing bioremediation technologies and devise eco-friendly ways in which they can be improved/enhanced at minimum cost. This entails the need to focus on soil and environmental studies relevant to the management of contaminated areas. This will help ensure better environmental management and improve soil health for varieties with agricultural benefits. It will also help communities affected by the activities of the oil and gas industries, where most of their agricultural lands are polluted and contaminated by different pollutants.

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