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Review Article

Worldwide Efficiency of Bioremediation Techniques for Organic Pollutants in Soil: A Brief Review

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ABSTRACT

Soil pollution is a major human and environmental issue. Among the several components of soil degradation, organic contaminant in soil is regarded as a significant factor that causes considerable damage to the environment along with several health dangers to humans. Polychlorinated biphenyls, polycyclic aromatic hydrocarbons, polychlorinated dibenzofurans, poly-brominated biphenyls, organic fuels particularly gasoline and diesel, herbicides, insecticides (carbamate and organophosphorus) are by far the most common forms of organic pollutants identified in soils. The employment of living organisms such as microorganisms and plants in bioremediation technology reduces/degrades, eliminates, and transforms pollutants found in soils, sediments, and water. This review examine and critically view the efficiency of bioremediation techniques for the polluted sites. The most common bioremediation technologies for the treatment of organic pollutants are bioventing, bio-sparging, bio-slurping, bio-augmentation, phytoremediation, bio-immobilization, bio-sorption, composting, land farming, aerobic degradation, co-metabolic and natural attenuation. The efficiency of these techniques depends on the pH, type of soil, level of oxygen, any other electron acceptors, temperature, and the nutrients. Selection of the treatment process depends upon the type of pollutant, concentration of the contaminant, site and source of pollution. All the treatment techniques are not good for all type of pollutants. Cost-effective techniques are mostly used worldwide as they have more public acceptance. Pump and treat methods were mostly used in Past but due to its non-reliability and excessive cost, these techniques are no longer in use.

Keywords : Bioremediation Techniques; Soil Pollution; Organic Pollutants; Efficiency, Environmental Contamination

1. INTRODUCTION

Organic compounds synthesized naturally or anthropogenically have always been stored in the soil. Soil pollution is a major human and environmental issue (Rajavel et al., 2014). Organic contaminants, in general, retain in relatively low quantities in the soil and accumulate over time (Alvarenga et al., 2018). Despite continuously growing levels, the low levels of organic pollutants in the impacted soil make a time-constrained toxicological investigation impossible (Bajaj et al., 2015). Such organic toxins are both hydrophobic and lipophilic in nature, and they can be found in soil in any geographical location of the world due to natural processes such as volcanic eruptions, forest fires, etc. as well as some anthropogenic practices (Ritter et al., 1995). These organic contaminants entered the plant system via various plant mechanisms. Although some organic waste components are biodegradable, metalloids and heavy metals pose a new concern owing to their long-term stability in the soil (Amoakwah et al.,2014). Organic pollutants' impact on the environment can be mitigated to some extent by implementing some bioremediation technologies (Fuentes et al., 2010).

Because of its ability to remove numerous organic and inorganic toxins from diverse components of the environment, the technique has received increasing adoption in recent years. Natural remediation of organic and inorganic pollutants is provided by the technology through in-situ and ex-situ environments (Aparicio et al., 2015). Microbes and plants have both been used to achieve maximal disposal and remediation of inorganic and organic pollutants (Bhupinder et al., 2017). Overall, bioremediation can be a useful tool for treating soil contaminated with a wide range of organic pollutants. By using microorganisms that can break down or metabolize these compounds, bioremediation can help to reduce the environmental impact of pollution and promote the health of ecosystems.

Table 1. Types of soil that are frequently exploited and can be treated by bioremediation

Type of Exploited Soil	Description
Petroleum-contaminated soils	These soils are contaminated with petroleum hydrocarbons, such as gasoline or diesel fuel, and can be treated by bioremediation using microorganisms that break down these compounds into non-toxic substances
Heavy metal-contaminated soils	These soils are contaminated with toxic heavy metals, such as lead, arsenic, or cadmium, and can be treated by bioremediation using plants or microorganisms that can absorb or precipitate these metals.
Pesticide-contaminated soils	These soils are contaminated with chemical pesticides, such as organochlorines or organophosphates, and can be treated by bioremediation using microorganisms that break down these compounds into non-toxic substances
Chlorinated solvent-contaminated soils	These soils are contaminated with chlorinated solvents, such as trichloroethylene (TCE) or perchloroethylene (PCE), and can be treated by bioremediation using microorganisms that degrade these compounds into non-toxic substances.
Polychlorinated biphenyl (PCB)-contaminated soils	These soils are contaminated with PCBs, which are toxic and persistent organic pollutants, and can be treated by bioremediation using microorganisms that degrade these compounds into non-toxic substances.
Polycyclic Aromatic Hydrocarbons (PAHs)-contaminated soils	These are organic pollutants that are formed during incomplete combustion of fossil fuels or biomass. They can accumulate in soil and can be toxic to plants and animals. Bioremediation can be used to break down PAHs using microorganisms that can metabolize these compounds.
Volatile Organic Compounds (VOCs)-contaminated soils	These are organic pollutants that can evaporate into the air and can be toxic to humans and animals. Examples include benzene, toluene, and xylene. Bioremediation can be used to treat soil contaminated with VOCs using microorganisms that can metabolize these compounds.

Pharmaceuticals and Personal Care Products (PPCPs)	These are organic pollutants that are commonly found in wastewater and can end up in soil. Examples include antibiotics, hormones, and fragrances. Bioremediation can be used to treat soil contaminated with PPCPs using microorganisms that can metabolize these compounds.

Source: (Yoon et al. 2020), (Wang et al. 2016) and (Mukherjee & Kumar 2019)

Controlling and optimising bioremediation operations seems to be a complex system with numerous variables (Babaei et al., 2020). These elements includes the incidence of a micro-flora capable of degrading pollutants, the availability of pollutants to the microbial community; and environmental factors (pH, type of soil, level of oxygen, any other kind of electron acceptors, temperature, and the nutrients) (Asiegbu et al., 2015). Depending on the saturation level and aeration in a given area, various strategies are used (Sidhu et al., 2018). In situ procedures are those that are employed to groundwater and soil, on-site with the minimal disruption (Borriss et al., 2020). Ex-situ procedures are those that are employed on groundwater and soil that has been extracted from a site through excavation (soil) (Vidali et al., 2001).

2. BIOREMEDIATION TECHNOLOGIES FOR ORGANIC POLLUTANTS

2.1 Bioventing

The bioventing technique introduces air/oxygen into contaminated media/soil at a pace optimized to maximize in-situ biodegradation while minimizing/eliminating off gassing of volatilized pollutants into the air/atmosphere (Wozniak-karczewaska et al., 2019). Bioventing, as opposed to bio-sparging, that entails pumping air nutrients into the saturated zone, simply pumps air into the unsaturated or vadose zone. Bioventing also destroys less volatile organic pollutants because it requires less air, it can treat soils that are less permeable (Mihopoulos et al., 2002).

2.2 Biosparging

The idea driving bio-sparging is basically that nutrients and air is inserted into the layers of soil below the water table, where they will help naturally occurring organisms degrade toxins. Microorganisms native to the area are typically used in this in situ method (Dzinonek et al., 2016). It can be used for the treatment various types of petroleum products that have been dissolved in groundwater, that have become adsorbent to the soil just below water table as well as within the capacity of capillary fringe (Zeneli et al., 2019). It is frequently employed in conjunction to SVE, particularly when volatile compounds are present (Muehlberger et al., 1997).

2.3 Bio-slurping

Bio-slurping is a revolutionary in-situ remediation system that combines aspects of vacuum-enhanced pumping and bioventing, to recover free product from soil and groundwater while encouraging aerobic bioremediation of hydrocarbons pollutants (Mapeli et al., 2017). Vacuum extraction removes free product as well as some groundwater from the vadose zone; vapor extraction eliminates high volatility vapors from vadose zone; whereas bioventing improves biodegradation in both the capillary fringe as well as the vadose zone (Roy et al., 2018). The bio-slurping system comprises of one or more wells where a slurp tube of an adjustable length is inserted. The slurp tube, which is coupled to a vacuum pump, is descended into a light non-aqueous phase of liquid layer and extracts free product as well as some groundwater. When LNAPL levels drop somewhat as a result of pumping action, the slurp tube removes vapors (vapor extraction) (Speight, 2018). All the liquids (solution of product and groundwater) extracted from a slurp tube are routed to the oil/water separator, while the vapors are routed to the liquid/vapor separator (Bodor et al., 2020).

2.4 Bio-augmentation

Introduction of microbes with specialized catabolic capacities into a polluted environment for supplementation of the indigenous population as well as to speed up or enable pollutant breakdown is known as bio-augmentation (Zaneti et al., 2017). Efficacy of bio-augmentation process is a topic of debate, with both positive and bad findings documented. Bio-augmentation has been shown to be effective in the remediation of Poly-cyclic aromatic hydrocarbons in sediments with low or zero intrinsic degradation capacity. Other investigations, however, found that bio-augmentation did not significantly improve biodegradation in contrast to natural attenuation (Major et al., 2006).

2.4 Phytoremediation

Phytoremediation techniques are largely distinguished by the structure and functions of the plants. First, phyto-stabilization occurs when plant roots immobilize pollutants such as those deposited in the root surface along with pollutants that are precipitated in root zones (Awa et al., 2020). This method was typically used to decontaminate inorganic compounds, such as oil that included nitrogen, Sulphur, and some heavy metals. Secondly, rhizo-filtration, which occurs when plant roots precipitate contaminants in root zones or absorb polluted solutions into the roots (Cristaldi et al., 2020). This procedure was appropriate for a solution including both organic and inorganic components. Third, rhizo-degradation, which occurs when pollutants are broken down by bacteria in the root zone and is aided by fungi, yeast, and plant exudates like alcohol, sugar, and acids (Ashraf et al., 2019). The method was suitable for the detoxification of organic contaminants. In the fourth place, phyto-extraction is done, which involves the absorption of contaminants by plant roots and subsequent transport into plant organs. This method was appropriate for decontaminating inorganic compounds (Limmmer et al., 2016). Fifth, phyto-degradation, which involves the transformation of ingested contaminants via plant metabolic or enzymatic activities (Abdel Shafy et al., 2018). Sixth, phyto-volatilization, in which ingested contaminants are discharged into the atmosphere as liquid vapor (Ganjar et al., 2012).

2.6 Bio-immobilization

Bio-immobilization is a bioremediation technique used for the treatment of organic pollutants in soil. In this technique, microorganisms are immobilized in a matrix such as a gel, foam, or membrane, which is then applied to the contaminated soil. The immobilized microorganisms degrade the organic pollutants in the soil, while the matrix helps to protect them from environmental stresses and maintain their activity over a longer period of time. The immobilization mechanism is a biological phenomenon that is governed by bacteria that eat inorganic nitrogen and produce organic forms of biological macromolecules and amino acids (Cristorean et al., 2016). Mineralization and immobilization occur continuously and concurrently, transforming nitrogen from an inorganic to an organic state by immobilization and back from an organic to an inorganic state by breakdown and mineralization (Battle- Aguilar et al., 2011).

The use of bioimmobilization is an alternate remediation method for reducing the risk posed by pollutants that cannot be biodegraded, such as metals, metalloids, radionuclides, or persistent organic pollutants that can be biotransformed reasonably easily but not biodegraded. Overall, the efficiency of bio-immobilization for the treatment of organic pollutants in soil depends on a variety of factors, including the type and concentration of pollutants, the characteristics of the soil, and the design of the immobilization system. However, studies have shown that bio-immobilization can be an effective and sustainable bioremediation technique for the treatment of contaminated soil (Mateju et al., 2010).

2.7 Bio-sorption

Heavy metal and organic compound bio-sorption occurs as a result of physicochemical reactions between functional groups and metal on the bio-sorbent's surface. Ion exchange, physical adsorption, and chemical sorption are among the mechanisms involved, which are unrelated to metabolism (Salehi et al., 2017). Microorganisms' cell walls are mostly lipids, proteins and polysaccharides with amino, phosphate, sulphate and carboxyl groups to create interactions with metals and their complexes. This type of bio-sorption happens quickly and can be reversed (Mustapha et al., 2015).

2.8 Composting

Composting is the type of aerobic process that uses microbes to breakdown organic substances, resulting in thermogenesis and the formation of inorganic and organic chemicals (Macaulay et al., 2014). Composting matrices and composts are high in xenobiotic decomposing microorganisms including actinomycetes, bacteria, and lingo-lytic fungus, which can breakdown pollutants to harmless chemicals like carbon dioxide and water (Semple et al., 2001).

2.9 Land farming

Land farming is a bioremediation technique that involves spreading contaminated soil on an area of land and then promoting the growth of microorganisms in the soil to degrade the organic pollutants (Li et al., 2020). The most common type some common land farming techniques used for the treatment of organic pollutants in soilis bioaugmentation and biostimulation. Bioaugmentation, microorganisms that are known to degrade specific organic pollutants are added to the contaminated soil to accelerate the biodegradation process. The microorganisms can be added as pure cultures or as a mixed consortium of microorganisms. Bioaugmentation has been shown to be effective in treating soil contaminated with hydrocarbons, such as polycyclic aromatic hydrocarbons (PAHs) and petroleum hydrocarbons (Haritash & Kaushik, 2016). Biostimulation, the growth of indigenous microorganisms in the contaminated soil is stimulated through the addition of nutrients, such as nitrogen and phosphorus, and other growth-promoting substances. Biostimulation can enhance the activity of the microorganisms already present in the soil, thereby accelerating the biodegradation of organic pollutants (Liu & Yang, 2021).

It is the technique has been commonly used by mineral oil-processing industries. It is very cost effective and simple technique for the treatment of PAHs due to oil spills (Juwarkar et al., 2010). This technique was first used by US to treat industrial oil waste (Sayara et al., 2010). Land farming converts the toxic oil waste into simpler compounds such as water and carbon dioxide. However its efficiency is effected by the release of volatile organic compunds to the atmosphere, during the early stages of the remediation process (Okere et al., 2012, Wick et al., 2011).

2.10 Aerobic degradation

It is the in-situ technique that is used for the treatment of hydrocarbon in the polluted soil. This technique is usually used for the treatment of hazardous material, as it is the cost effective treatment for oil spills (Hmidet et al., 2019). A crude oil contains different toxic compounds, so the single strain of bacteria is not enough for the treatment. Bio slurry is the technique used in the combination with aerobic degradation with aerobic degradation to increase the efficiency of the treatment process (Venkateswar et al., 2010, Venkata et al., 2010).

2.11 Co-metabolic

Cometabolic bioremediation is a technique used for the treatment of organic pollutants in soil. In this technique, microorganisms are stimulated to degrade pollutants in the presence of a primary substrate that is not itself degraded. The primary substrate serves as a source of energy and nutrients for the microorganisms, while the degradation of the organic pollutant occurs as a side reaction (Yang et al., 2016). It is in-situ bioremediation toluene injection technique effective for the removal of TCE (Tricycloethylene) (Banerjee et al., 2010). This technique gives the efficiency between87-99% depending upon the hydrogeological characteristics of the site (Arulazhagan et al., 2011; Fukushima et al., 2011). Overall, cometabolic bioremediation is a promising technique for the treatment of organic pollutants in soil, particularly for pollutants that are difficult to degrade using other bioremediation techniques. However, the efficiency of the technique depends on a variety of factors, including the availability and suitability of the primary substrate, the characteristics of the soil, and the design of the bioremediation system (Mangwani et al., 2020).

2.12 Natural Attenuation

It is the low cost soil remediation technique as it has no adverse effect on human and environment. It is used for the treatment of chemical spills (Iniguez Franco et al., 2016). It is mostly used in the groundwater aquifers where the pollution source is covered. It is non-engineered, natural and slow biodegradation process which requires long term monitoring (Gohil et al., 2014; Khodakovskaya et al., 2013). Natural Attenuation is mainly used for BTEX and chlorinated hydrocarbons. Biofilteration is used to remove VOCs and inorganic gases conventionally by incineration and chemical scrubbing. Removal of contaminant gases depends upon the soil porosity. Sufficient time is required for the complete removal of pollutants (Jin et al., 2014).

3. DISCUSSION

Bioventing is used to treat the petroleum pollutants such as diesel. It is 95% effective for TPH. Bioventing is easy to install and maintain. It requires less treatment times. It requires highly permeable soil for good efficiency. It is effective for unsaturated or vadose zone. Too much concentration of pollutant may affect the process efficiency. It is also a cost-effective process. (Li, et al., 2011). Biosparging is usually applied to the site where there are homogenous soil conditions. Presence of silt and sand can affect the efficiency of the process. It is not effective for non-biodegradable compounds and only effective for VOCs treatment. Cost of the treatment process depends upon the thickness of the saturated zone (Girma et al., 2015).

Bio-slurping is usually applied to the sites where there is shallow ground water below 30m. It is used to speed up the natural remediation process in the unsaturated zone of soil. Low permeability of soil may negatively affect the treatment efficiency. Too much or too little moisture content affects the microbial activity. It is the cost-effective treatment process but the low temperatures may results in decreasing the speed of the whole treatment process (Sabale et al., 2012; Dixit et al., 2015)

In order to improve the efficiency of the process, bioagumentation is the process in which we usually use microbial consortium instead of pure culture. This improves the efficiency of the whole process from 60% to 75% within the time period of 42 days. The overall efficiency of the bioaugmentation depends upon the temperature. pH, moisture content, nutrient level and the type of pollutant. Bioagumentation is effective for the treatment of PAHs mostly (Kulshrshtha et al., 2014).

Phytoremediation is usually applied to heavy metals, PCBs, PAHs, insecticides, surfactants, explosives, etc. This technique has minimum environmental impacts. It can be used to treat various compounds cost-effectively but it requires proper disposal of the used plants. Flooding and drought may negatively affect the efficiency of phytoremediation. Pollutants are converted into less harmful or simpler compounds such as water and carbon dioxide. Biomobilization is the treatment of the contaminated zone to avoid human and animal exposure. The process depends upon the depth of biological activity in soil and the depth of the polluted area. If the contaminated zone is out of the reach of animals and plants specie, then we leave the site to be naturally treated with the passage of time (Bell et al., 2014).

Biosorption is the cost effective method for the treatment of heavy metals in the soil. It is a cost effective and easy to maintain remediation technique. It requires some optimal parameters such as temperature, organism population for the effective treatment process. Temperature should be maintained at 40-45°C. Different types of bacterial strain used in the process affect the efficiency of the treatment process. Most effective bacteria for Biosorption are *Proteus Mirabilis* and *Bacillus Subtilis* (Barruita et al., 2010).

Table 2. Comparison of efficiencies of the different treatment technologies

Sr. No.	Treatment technologies	Pollutants to be treated	Efficiency
1.	Bioventing	Petroleum pollutants / TPH / diesel	95%
2.	Biosparging	VOCs	95-99%
3.	Bio-slurping	PAHs	85%
4.	Bioagumentation	PAHs	75%
5.	Phytoremediation	Heavy metals / PCBs / PAHs / insecticides/ explosives, etc.	95%
6.	Biomobilization	PAHs	90%
7.	Biosorption	Heavy metals	95%
8.	Composting	PAHs	99%
9.	Aerobic degradation	Hazardous materials / TPH / PAHs	95%
10.	Land Farming	PAHs /Oil spills	99%
11.	Co-metabolic degradation	TCE	87-99%
12.	Biofilteration	VOCs / inorganic gases	99%
13.	Natural Attenuation	BTEX and chlorinated hydrocarbons	95-99%

Source: (Uqab et al., 2016; Adams et al., 2015).

The efficiency of composting depends upon temperature, moisture content which should be 60%, pH should be 6-7.5, aeration rate should be 5-15%, nutrient content includes C:N:P which should be 100:10:1 and porosity of the soil. All the values must be in the optimal range (Carre et al., 2017; ASTS, 2010). Biodegrading process of PAHs depends upon the biological, chemical and physical properties of the soil, environmental conditions and waste type. Soil polluted with PAHs contains low organic content and high C: N ratio, microbes are already rich in that type of soil (US-EPA, 2012).

This result in increasing the moisture content of soil and affecting the efficiency of soil, thus composting integrated with land farming provides better degradation of organic waste as it provides additional carbon to the soil. The purpose of this strategy is to convert the harmful material into less toxic or harmless compounds such as carbon dioxide and water (Bolton et al., 2012).

Some important parameters that must be considered while applying the land farming technique are the type of microorganisms which should be heterotrophic bacteria's, moisture content should be between 30-85%, nutrient availability C:N:P should be 100:10:1 but 100:10:0.5 is also acceptable, pH range must be between 6-8, temperature of the soil should be between 10-45°C. Soil must be porous for the effective efficiency of the process (Othman et al., 2011; Zhang et al., 2011).

Some physical, biological and chemical parameters affect the efficiency of the land farming process which includes the concentration, type and level of contaminants (Hmidet et al., 2019). This process requires a very long time to achieve the efficient results. Microbial population could also act as a limiting factor, if the microbial population is less than 1000 CFU per gram, it could decrease the process efficiency. Furthermore, if heavy metals are present along with PAHs, it could negatively affect the efficiency of land farming (Cui et al., 2013).

Domestic sewage is usually added to the contaminated soil as microbial base in the slurry reactors under aerobic conditions for aerobic degradation. Microbial diversity increases the biodegradability rate. Degradation process requires 10-15 days (Lukic et al., 2017). Most of the efficiency could be achieved by using control conditions and by applying different bacteria strains. pH should be maintained at 7 during the process. DO must be kept at 4mg/L (Rocha e Silva et al., 2019). This technique is very effective on total petroleum hydrocarbons (TPH) and polyaromatic hydrocarbons (PAHs) (Oberoi et al., 2015).

During the process of co-metabolic degradation, under balanced flow conditions 86% of TCE could be removed during 80 days (Jiang et al., 2018). There are some degradation in the process as toluene is difficult to be treated once added to the ground water. As long as the nutrient level is maintained in the aquifers the degradation process continues with good efficiency. But toluene is biodegradable anaerobically, so if the system fails to maintain oxygen level, the efficiency of the treatment process may not be affected (Campos et al., 2019). Low conductivity in the aquifers can clog the aquifers due to excessive biological growth; this can also reduce the efficiency of the whole process. Hydrogen peroxide is used to solve the problem which is an expensive chemical. This issue can be resolved by having larger sized materials than the fine in aquifers (Jiang et al., 2014; Megharaj et al., 2011).

Natural Attenuation gives the maximum efficiency in completely destroying the contaminant. It is the most acceptable method due to its cost effectiveness. This technique has some limitations depending upon the site and characteristics of the pollutant as it requires longer time periods. Inorganic contaminants are difficult to treat by this method due to the lack of knowledge. By products can be toxic for the environment so regular monitoring is required (Wu et al., 2012).

In biofilteration, moisture content must be present in soil in order to improve the efficiency of process. Soil bacteria's like *pseudomonas* and *nacardia* are used for biofilteration technique (Invally et al., 2019). Soil bed temperature should be maintained between 10-60°C, to achieve this temperature soil may need to be heated or cooled down a bit. This process is 99%effective for gases but ineffective for halogenated compounds (Ren et al., 2015; Rajavel et al., 2014).

4. CONCLUSION

Contaminants enter the soil directly or through spills, leakage, accidents or disposals. Problems related to clean up the contaminated site emphasis that there is need to develop the treatment methods which are eco-friendly and cost-effective as well. Many techniques are present to treat different type of contaminants. Selection of the treatment process depends upon the type of pollutant, concentration of the contaminant, site and source of pollution. All the treatment techniques are not good for all type of pollutants. As the biological treatment technologies are good for petroleum pollutants. Cost-effective techniques are mostly used worldwide as they have more public acceptance. Pump and treat methods were mostly used in Past but due to its non-reliability and excessive cost, these techniques are no longer in use.

DECLARATIONS

Conflict of Interest

The authors declare that in the research and preparation of this article, there are no conflict of interests related to certain organizations, institutions, and individuals or groups.

Ethical Approval

On behalf of all authors, the corresponding author states that the paper satisfies Ethical Standards conditions, no human participants, or animals are involved in the research.

Informed Consent

On behalf of all authors, the corresponding author states that no human participants are involved in the research and, therefore, informed consent is not required by them.

DATA AVAILABILITY
Data used to support the findings of this study are available from the corresponding author upon request.

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