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Chapter 4

Remediation of Contaminated Sites

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Additional information is available at the end of the chapter

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1. Introduction

Oil pollution in the environment is now being taken seriously by the oil industries and as such, these companies are always looking for cost-effective methods of dealing with this pollution. The global environment is under great stress due to urbanization and industrialization as well as population pressure on the limited natural resources. The problems are compounded by drastic changes that have been taking place in the lifestyle and habits of people. The environmental problems are diverse and sometimes specific with reference to time and space. The nature and the magnitude of the problems are ever changing, bringing new challenges and creating a constant need for developing newer and more appropriate technologies.

In this context, biotechnology has tremendous potential to cater for the needs and holds hope for environmental protection, sustainability and management [1-2] While some applications such as bioremediation are direct applications of biotechnology [3-4][5], there are many which are indirectly beneficial for environmental remediation, pollution prevention and waste treatment. Large-scale pollution due to man-made chemical substances and to some extent by natural substances is of global concern now. Seepage and run-offs due to the mobile nature, and continuous cycling of volatilization and condensation of many organic chemicals such as pesticides have even led to their presence in rain, fog and snow [6].

Every year, about 1.7 to 8.8 million metric tons of oil is released into the world's water. More than 90% of this oil pollution is directly related to accidents due to human failures and activities including deliberate waste disposal [7]. PAHs are present at levels varying from 1 μg to 300 g kg^{-1} soil, depending on the sources of contamination like combustion of fossil fuels, gasification and liquefaction of coal, incineration of wastes, and wood treatment processes [8]. Incomplete combustion of organic substances gives out about 100 different polycyclic aromatic hydrocarbons (PAHs) which are the ubiquitous pollutants.

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Except for a few PAHs used in medicines, dyes, plastics and pesticides, they are rarely of industrial use [9]. Some PAHs and their epoxides are highly toxic, and mutagenic even to microorganisms. About six specific PAHs are listed among the top 126 priority pollutants by the US Environmental Protection Agency. As much as the diversity in sources and chemical complexities in organic pollutants exists, there is probably more diversity in microbial members and their capabilities to synthesize or degrade organic compounds [10-11]-[12]. There are three main approaches in dealing with contaminated sites: identification of the problem, assessment of the nature and degree of the hazard, and the best choice of remedial action. The need to remediate these sites has led to the development of new technologies that emphasize the detoxification and destruction of the contaminants [13-14]-[15] rather than the conventional approach of disposal.

Remediation, whether by biological, chemical or a combination of both means, is the only option as the problem of pollution has to be solved without transferring to the future.

2. Manuscript

2.1. Measuring pollutant concentrations

The setting of soil pollution limits assumes an agreed method for measuring the concentration of a pollutant that is relevant to risk assessment across differing soil types. Limits are generally expressed in terms of 'total' concentrations as there is no consensus on alternative [16] methods more directly related to biological or environmental risk. Yet, assessing the bioavailability of soil pollutants is an essential part of the process of risk assessment and of determining the most appropriate approach to remediation [17]. With developing non exhaustive solvent extraction procedures that consistently predict the bioavailability of organic contaminants across a range of soil conditions [17].

As an alternative to extraction, solid-phase micro-extraction uses adsorbents added to soil–water slurries aiming to mimic the accessibility of organic contaminants to microorganisms. In relation to the assessment of risks to human health, much work is currently underway to develop physiologically based extraction tests; however, progress made in this respect for inorganic pollutants has not been matched by that for organic pollutants [18]. In recent years, there has been a growth in the use of onsite assays to improve decision making regarding the extent of pollution in batches of potentially polluted materials and, therefore, the need for treatment or disposal. In many cases, these new measurements are based on enzyme-linked immunosorbent assays linked to spectroscopy.

Specific assays have, for example, been developed for pentachlorophenol [19] and PAHs [20].Whilst these methodologies can provide useful supplementary and 'real-time' information on pollutant concentration variability in the field, care must be taken when extrapolating findings from the very small samples used in these assays to bulk soil properties.

Various microbiological assays have been proposed as indicators of pollutant bioavailability. Biosensors have been widely deployed to provide fast, cost-effective monitoring of pollutants and their biological toxicity.

2.2. Environmental pollution and biological treatments

The problems of environment can be classified into the following subheads as most of the problems can be traced to one or more of the following either directly or indirectly: Waste generation (sewage, wastewater, kitchen waste, industrial waste, effluents, agricultural waste, food waste) and use of chemicals for various purposes in the form of insecticides, pesticides, chemical fertilizers, toxic products and by-products from chemical industries (Fig 1). Waste generation is a side effect of consumption and production activities and tends to increase with economic advance. What is of concern is the increased presence of toxic chemicals such as halogen aliphatics, aromatics, polychlorinated biphenyls and other organic and inorganic pollutants which may reach air, water or soil and affect the environment in several ways, ultimately threatening the self-regulating capacity of the biosphere [5]-[21]-[22].

They may be present in high levels at the points of discharge or may remain low but can be highly toxic for the receiving bodies. The underground water sources are increasingly becoming contaminated. For example, the underground water sources have been permanently abandoned in the valley of the River Po in north Italy due to industrial pollution. Some substances may reach environment in small concentrations but may be subjected to biomagnification or bioaccumulation up the food chain, wherein their concentrations increase as they pass through the food chain [23]-[24]-[25-26].

All the more, rapid developments in understanding activated sludge processes and wastewater remediation warrant exploitation of different strategies for studying their degradation and some of the biological remediation terminologies such as bioleaching, biosorption, bioaugmentation, biostimulation, biopulping, biodeterioration, biobleaching, bioaccumulation, biotransformation and bioattenuation are being actively researched on [27]. Enzyme technology has equally been receiving increased attention. Hussain et al. (2009) have reviewed the biotechnological approaches for enhancing the capability of microorganisms and plants through the characterization and transfer of pesticide-degrading genes, induction of catabolic pathways, and display of cell surface enzymes[28], while Theron et al. (2008) have performed a thorough review of nanotechnology, the engineering and art of manipulating matter at the nanoscale (1–100 nm), and have highlighted the potential of novel nanomaterials for treatment of surface water, groundwater, and wastewater contaminated by toxic metal ions, organic and inorganic solutes, and microorganisms [29]. Husain et al. (2009) have analyzed the role of peroxidases in the remediation and treatment of a wide spectrum of aromatic pollutants[28].

Remediation approaches encompass applied physical, chemical and biological environmental sciences. The aim of this chapter will be to illustrate current understanding of the scientific principles underlying soil remediation and some of the challenges to their successful application. Remediation approaches that isolate treated soils are site rather than soil remediation technologies. These approaches, and the treatments that result in the destruction of soil function, will be referred to only in passing.

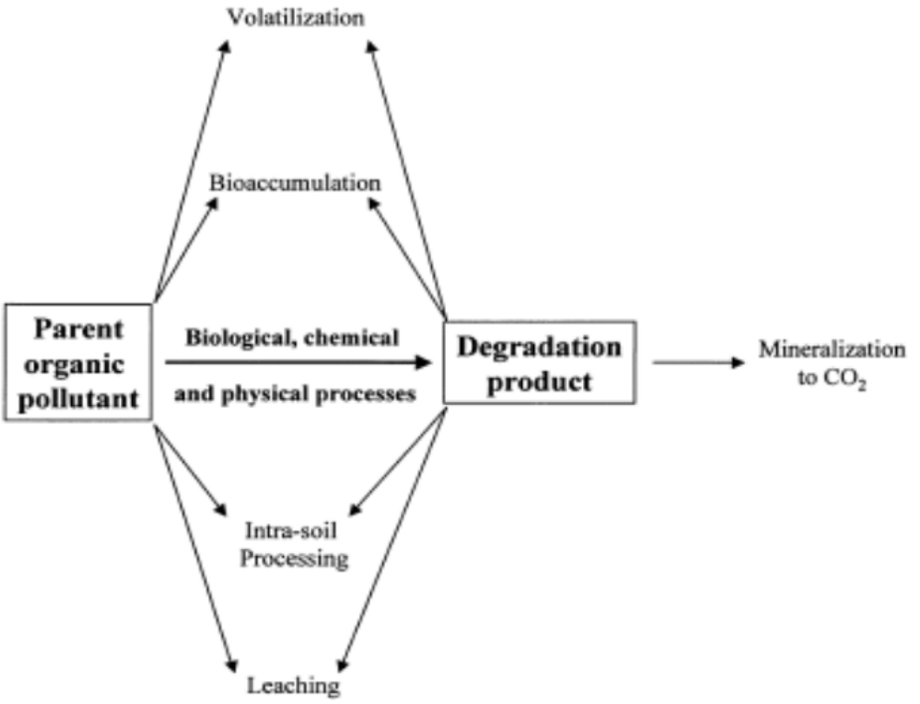


Figure 1. Summary of environmental fates on organic pollutants in soil.

2.2.1. Bioremediation

Interest in the microbial biodegradation of pollutants has intensified in recent years as humanity strives to find sustainable ways to clean up contaminated environments. Bioremediation, which is the use of microorganisms consortia or microbial processes to degrade and detoxify environmental contaminants [30]. It is also amongst these new technologies which derives its scientific justification from the emerging concept of Green Chemistry and Green Engineering, and is a fast growing promising remediation technique increasingly being studied and applied in practical use for pollutant clean-up.

Bioremediation techniques have been used for decontamination of surface and subsurface soils, freshwater and marine systems, soils, groundwater and contaminated land ecosystems. However, the majority of bioremediation technologies initially developed were to treat petroleum hydrocarbon contamination to immobilize contaminants or to transform them to chemical products no longer hazardous to human health and the environment. Where contaminants pose no significant risk to water supply or surface water bodies, biodegradation products will include carbon dioxide, water and other compounds with little deleterious effects on the environment [31].

Bioremediation of soils or any site may be enhanced by fertilizing (adding nutrients such as carbon, nitrogen and phosphorous) and/or seeding with suitable microbial populations. These days, using organic wastes is bioremediation process is going to be new method as a option of enhancing and motivating of microorganism to break down of organic compounds [32-33]. This is enhanced or engineered bioremediation. Intrinsic bioremediation, which utilizes existing microbial communities, is often the most cost effective method available for

land decontamination. Even in the most contaminated soils, indigenous microbial activity can be enough to clean the soil effectively. Bioremediation techniques are cost effective as compared to other technologies. Biological treatments compare favorably with alternative methods. Treatment periods generally last from 2 to 48 months, about the same for chemical or thermal methods. Physical processes (soil washing and soil vapour extraction) are faster, rarely lasting more than 1 year. Solidification is almost instantaneous.

Bioremediation (when used in solution) does not require environmentally damaging processes such as chemicals or heat treatment. It has beneficial effects upon soil structure and fertility, but with limitation on its effectiveness. These limitations may be summarized as follows:

- Space requirements
- Monitoring difficulties
- Extended treatment time

2.2.1.1. Bioremediation technologies

Bioremediation technologies can be broadly classified as ex situ or in situ. Table 1 summarizes the most commonly used bioremediation technologies. Ex situ technologies are those treatment modalities which involve the physical removal of the contaminated to another area (possibly within the site) for treatment.

Bioreactors, land farming, anaerobic digestion, composting, biosorption and some forms of solid-phase treatment are all examples of ex situ treatment techniques. In contrast, in situ techniques involve treatment of the contaminated material in place. Bioventing for the treatment of the contaminated soil and biostimulation of indigenous aquifer microorganisms are examples of these treatment techniques. Although some sites may be more easily controlled and maintained with ex situ configurations [34].

Bioaugmentation	Addition of bacterial cultures to a contaminated medium frequently used in bioreactors and ex situ systems
Biofilters	Use of microbial stripping columns to treat air emission
Biostimulation	Stimulation of indigenous microbial populations in soils and/or ground water
Bioreactors	Biodegradation in a container or reactor
Bioventing	Method of treating contaminated soils by drawing oxygen through the soil to stimulate microbial growth and activity

Table 1. Bioremediation treatment technologies

For example, many sites are located in industrial/ commercial areas, and these sites normally consist of numerous structures interconnected by concrete and asphalt. These physical barriers would make excavation extremely difficult, and if the contamination is deep in the subsurface, excavation becomes too expensive. As a result of these physical barriers, the required excavation efforts may make ex situ biotreatment impracticable. Other

factors could also have an impact on the type of treatment. At a typical site, the contamination is basically trapped below the surface.

To expose the contamination to the open environment through excavation can result in potential health and safety risks [34]. In addition, the public's perception of the excavation of contaminants could be negative, depending on the situation. All of these conditions clearly favor in situ biotreatment. Nonetheless, the key is to carefully consider the parameters involved with each site before evaluating which technique to use [34].

2.2.2. Land farming

This technology involves the application of contaminated material that has been excavated onto the soil surface and periodically tilled to mix and aerate the material [35-36]. The contaminants are degraded, transformed and immobilized by means of biotic and abiotic reactions. Sometimes, in cases of very shallow contamination, the top layer of the site may simply be tilled without requiring any excavation. Liners or other methods may be used to control leachate. This technology is designed primarily to treat soil contamination by fuels, PAHs, non-halogenated VOCs, SVOCs, pesticides, and herbicides. The process may be applied to halogenated organics, but is less effective.

simple and inexpensive, it does require large space, and reduction in contaminant concentrations may sometimes be due to volatilization rather than biodegradation [37-38]. Marı´n et al. (2005) assessed the ability land farming to reduce the total hydrocarbon content added to soil with refinery sludge in low rain and high temperature conditions [39]. It was seen that 80% of the hydrocarbons were eliminated in 11 months, half of this reduction taking place during the first 3 months.

2.2.3. Phytoremediation

Using plants in soil and groundwater remediation (i.e., phytoremediation) is a relatively new concept and the technology has yet to be extensively proven in the marketplace. However, the potential of phytoremediation for cheap, simple and effective soil and groundwater remediation is generating considerable interest.

Phytoremediation may be used for remediation of soil and groundwater contaminated with toxic heavy metals, radio nuclides, and organic contaminants such as chlorinated solvents, BTEX compounds, non-aromatic petroleum hydrocarbons, nitro toluene ammunition wastes, and excess nutrients [40]. Other applications of phytoremediation include Land fill caps, buffer zones for agricultural runoff and even drinking water and industrial wastewater treatment. Phytoremediation may also be used as a final polishing step, in conjunction with other treatment technologies. While indeed promising, the applicability of phytoremediation is limited by several factors. First, it is essential that the contaminated site of interest is able to support plant growth. This requires suitable climate, soil characteristics such as pH and texture, and adequate water and nutrients. Second, because plant roots only go so deep, phytoremediation is practical only in situations where contamination is shallow

(less than 5 m), although in some situations with deeper contamination it may be used in conjunction with other technologies. Third, since the time requirements for phytoremediation are sometimes long relative to some conventional technologies such as land filling and incineration, it is not suitable for situations requiring rapid treatment. Plants facilitate remediation via several mechanisms (Fig 2):

1. Direct uptake, and incorporation of contaminants into plant biomass
2. Immobilization, or Phytostabilization of contaminants in the subsurface
3. Release plant enzymes into the rhizosphere that act directly on the contaminants
4. Stimulation of microbial mediated degradation in the rhizosphere

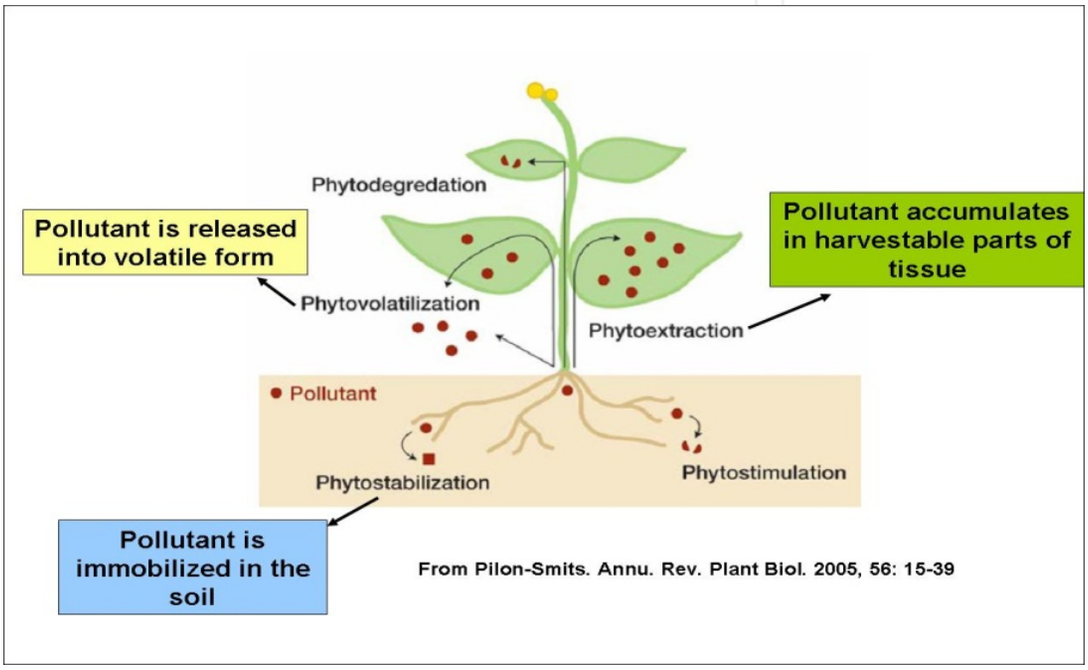


Figure 2. Phytoremediation mechanisms.

2.2.4. Biopiling

Biopiles piles are a form of soil treatment where bulking agents, nutrients, and water are added. However, static piles are not mixed and temperatures are usually near ambient. Aeration can be passive or forced by applying a vacuum or blowing air through the pile. Bulking agents used are usually made up of manure or compost, which supports a larger microbial population than soil and provides inorganic nutrients, and relatively inert materials such as sawdust, wood chips, or compost. Water is added periodically, as needed to sustain the microbial population [41-42].

2.2.5. Composting

Composting is an aerobic process that relies on the actions of microorganisms to degrade organic materials, resulting in the thermo genesis and production of organic and inorganic compounds. The metabolically generated heat is trapped within the compost matrix, which

leads to elevations in temperature, a characteristic of composting. In deed composting is the biochemical degradation of organic materials to a sanitary, nuisance-free, humus-like material [43]. Composting has been defined as a controlled microbial aerobic decomposition process with the formation of stabilized organic materials that may be used as soil conditioner [44]. The main factors in the control of a composting process include environmental parameters (temperature, moisture content, pH and aeration) and substrate nature parameters (C/N ratio, particle size, and nutrient content) [45-46].

Various factors correlate with each other physically, chemically and biologically in complicated composting processes. A slight change in a single factor may cause a drastic avalanche of metabolic and physical changes in the overall process. In other words, there may be extremely strong non-linearities involved in these processes [47]. These processes occur in matrix of organic particles and interconnected pores, and the pores are partially filled with air, aqueous solution, or a combination of the two. A multitude of microorganisms and their enzymes is responsible for the biodegradation process [48], resulting in a complex biochemical–microbial system.

2.2.6. Electrokinetic remediation

Electrokinetic treatment is emerging and innovative technology to complement traditional technology limitations and to treat fine-grained soils. Electrokinetic technology evaluated most suitable to remove contaminants effectively from low permeability clayey soil.

In situ electrokinetic remediation can be applied to treat low permeable soils contaminated with heavy metals, radionuclides and selected organic pollutants. The principle behind this method is the application of a low level direct current electric potential through electrodes, which are placed into the contaminated soil. Ionic contaminants are transported to the oppositely charged electrode by electromigration. Additionally, electroosmotic flow provides a driving force for the movement of soluble contaminants [49].

Although the technology has been known and utilised for more than a decade, application to removal of hydrophobic and strongly adsorbed pollutants such as PAHs especially from low permeability soils is recent. Solubilising agents are therefore used in these cases to enhance the removal efficiency of PAHs [50].

2.2.7. Photocatalytic degradation

The photocatalytic degradation process uses photocatalysts to promote oxidising reactions which destroy organic contaminants in the presence of light radiation. The technology has been widely established for treatment of wastewater, and recently, its application has extended to treatment of contaminated soils.

Zhang et al. [51]conducted a comprehensive study of the photocatalytic degradation of phenanthrene, pyrene and benzo(a)pyrene on soil surfaces using titanium dioxide (TiO_2) under UV light. Compared to the absence of catalyst, the addition of TiO_2 as catalyst revealed that TiO_2 accelerated the photodegradation process of all three PAHs, with

benzo(a)pyrene being degraded the fastest. Nonetheless, variation in TiO_2 concentration from 0.5 to 3wt. % did not provide any significant effect on PAH degradation. Under distinct UV wavelengths, photocatalytic degradation rates of PAHs were different. Soil pH was discovered to affect the process whereby the highest pyrene and benzo(a)pyrene degradation rates were obtained at acidic conditions, while phenanthrene was most significantly degraded at alkaline conditions. Additionally, the presence of humic acid in soil was found to enhance PAH photocatalytic degradation by sensitising radicals capable of oxidizing PAHs.

Rababah and Matsuzawa [52]developed a recirculating-type photocatalytic reactor assisted by the oxidising agent H_2O_2 solution to treat soil spiked with fluranthene. It was observed that the degradation efficiency of fluoranthene was 99% in the presence of both TiO_2 and H_2O_2 compared to a lower degradation efficiency of 83% in the presence of TiO_2 alone.

2.3. Physico- chemical treatments

2.3.1. Solidification and Stabilization

Solidification/Stabilization (S/S) is one of the top five source control treatment technologies used at Superfund remedial sites, having been used at more than 160 sites. “Solidification” refers to a process in which materials are added to the waste to produce an immobile mass. This may or may not involve a chemical bonding between the toxic contaminant and the additive. “Stabilization” refers to converting a waste to a more chemically stable form. This conversion may include solidification, but it almost always includes use of physicochemical reaction to transform the contaminants to a less toxic form [53-54].

Solidification is a technique that encapsulates hazardous waste into a solid material of high structural integrity. Solidifying fine waste particles is termed microencapsulation; macro encapsulation solidifies wastes in large blocks or containers. Stabilization technologies reduce a hazardous wastes solubility, mobility, or toxicity. Solidification and stabilization are effective for treating soils containing metals, asbestos, radioactive materials, in organics, corrosive and cyanide compounds, and semi-volatile organics. Solidification eliminates free liquids, reduces hazardous constituent mobility by lowering waste permeability, minimizes constituent leach ability, and provides stability for handling, transport, and disposal [55].

2.3.2. Soil vapour extraction

In cases where the contaminants are volatile, a venting and ex-situ gas treatment system can be applied. Soil vapour extraction is a technology that has been proven effective in reducing concentrations of VOC and certain semi-volatile organic compounds. Principally, a vacuum is applied to the soil matrix to create a negative pressure gradient that causes movement of vapors toward extraction wells. Volatile contaminants are readily removed from the subsurface through the extraction wells. The collected vapors are then treated and discharged to the atmosphere or where permitted, reinjected to the subsurface [56-57].

2.3.3. Soil washing

Soil washing is an *ex situ* treatment technology for the remediation of contaminated soil. It has been applied to a variety of inorganically, organically, and even radioactively contaminated soils. Although it is a well established technology in continental Europe and North America, there are very few applications in the UK.

The selection of soil washing for a particular contamination problem will depend on a variety of factors. Particularly important is whether the contamination is specific to particular groups of particles within the soil and whether these particles can be removed from the contaminant-free bulk of particles by physical or physico-chemical processes [58].

Contamination can occur on or in soil particles in a variety of ways. Six types of association are identified:

- *Adsorbed contamination*. Contaminants may be adsorbed to particles and, in many cases, this adsorption may be preferential to particular particle types. For example, the adsorption of inorganic or organic contaminants on peaty organic fraction or on clay particles.
- *Discrete particles*. Some contaminants may occur within the soil matrix as discrete particles that are not necessarily associated with soil particles. Contaminants of this type can include discrete metal grains or metal oxides, tar balls and some waste materials (e.g. used catalyst fragments).
- *Coatings*. Contaminants may occur as coatings on individual particles that have resulted from precipitation of the contaminant from solution. For example, metal salts and iron oxides can precipitate on sand particles.
- *Liquid or semi-liquid coating*. Liquid or semi-liquid viscous substances may occur as coatings around individual soil particles. Contaminants of this type can include oils, tars and some other organic contaminants.
- *Liquid or semi-liquid coating*. Liquid or semi-liquid viscous substances may occur as coatings around individual soil particles. Contaminants of this type can include oils, tars and some other organic contaminants.
- *Internal contamination within pores*. Contamination may also occur inside individual grains but within the pore structure. Here it may be adsorbed (e.g. heavy metal or organic contamination), occur as a coating to the pore walls (e.g. inorganic compound precipitated from solution) or occur within and possibly occlude the pores (e.g. contaminants such as mineral oils).
- *Part of individual grains*. Contamination may occur within the matrix of an individual grain, or as part of an individual grain. Heavy metal contamination may occur in this way, for example, in slags where the heavy metal can occur within the vitrified matrix or associated with specific mineral phases such as magnetite.

Soil washing technology involves mixing the solvent (water) and contaminated soil in an extractor vessel [41, 59]. The mixing dissolves the organic contaminant into the solvent. Solvent and dissolved contaminants are then placed in a separator where the solute and solvent are separated and treated. The soils can be stockpiled, tested and used as inert material (Fig 3).

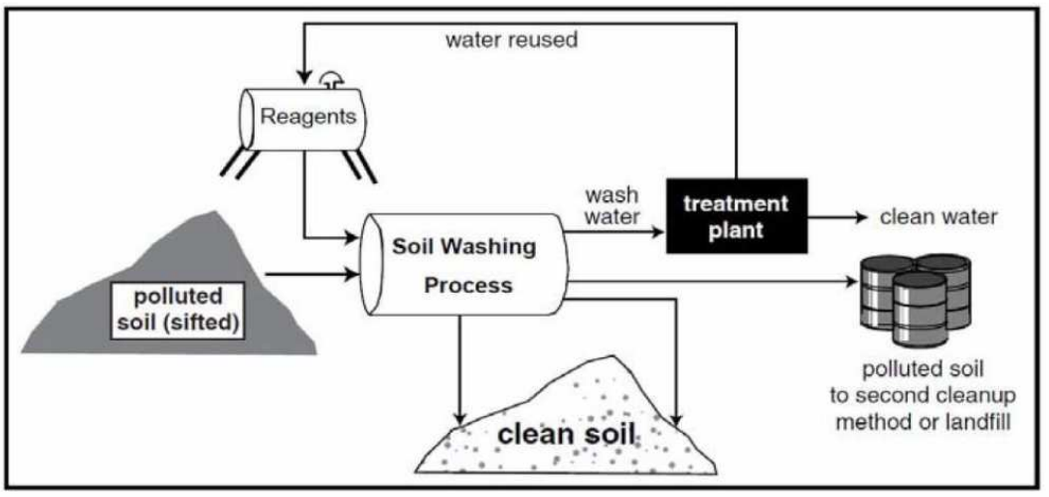


Figure 3. Schematic diagram of soil washing.

2.3.4. Air-sparging

Air sparging is an in situ technology in which air is injected through a contaminated aquifer. Air-sparing stimulates aerobic biodegradation of contaminated groundwater by delivery of oxygen to the subsurface [60]-[61]. This is accomplished by injecting air below the water table. This technology is designed primarily to treat groundwater contamination by fuels, non-halogenated VOCs, SVOCs, pesticides, organics, and herbicides.

Air sparing has also been demonstrated to be an innovative groundwater remediation technology capable of restoring aquifers that have been polluted by volatile and (or) biodegradable contaminants, such as petroleum hydrocarbons. The process may be applied to halogenated organics, but is less effective (Fig 4).

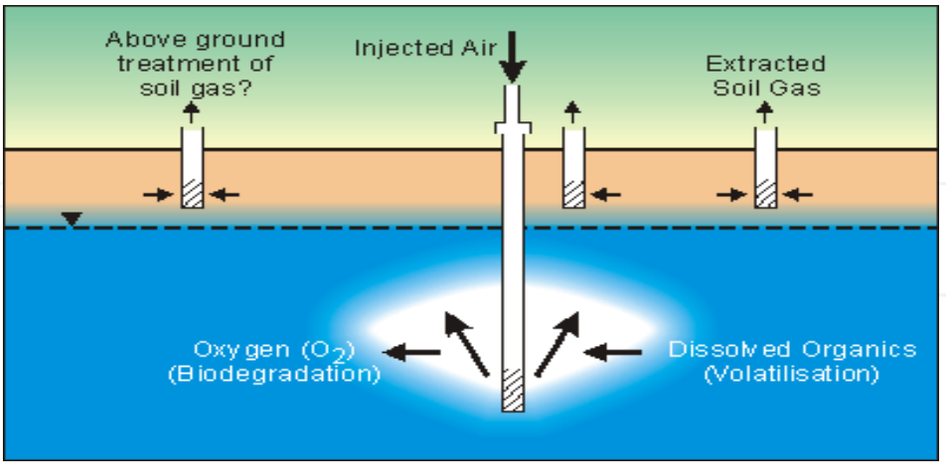


Figure 4. A schematic diagram illustrating method of air sparging.

Air-sparing can cost less than $1 per 1,000 l in favorable situations and tends to be among the cheapest remedial alternatives when applicable. The technology uses simple, inexpensive, low-maintenance equipment that can be left unattended for long periods of time. Also, the technology tends to enjoy good public acceptance. The technology requires

the presence of indigenous organisms capable of degrading the contaminants of interest, as well as nutrients necessary for growth. Also, it is necessary that the contaminants be available to the organisms, and not tightly sorbed to soil particles. Air sparing is not applicable in sites where high concentrations of inorganic salts, heavy metals, or organic compounds are present, as hinder microbial growth.

Excavation (and removal) is a fundamental remediation method involving the removal of contaminated soil/media, which can be shipped off-site for treatment and/or disposal, or treated on-site when contaminants are amenable to reliable remediation techniques.

Excavation is generally utilized for localized contamination and point source and is also used for the removal of underground structures that are out of compliance or have been identified as a potential or actual point source of contamination. The limiting factor for the use of excavation is often represented by the high unit cost for transportation and final offsite disposal. EPA (1991) further stated some limiting factors that may limit the applicability and effectiveness of the process to include:

i. Generation of fugitive emissions may be a problem during operations.
ii. The distance from the contaminated site to the nearest disposal facility will affect cost.
iii. Depth and composition of the media requiring excavation must be considered.
iv. Transportation of the soil through populated areas may affect community acceptability.

In this respect, the on-site removal and treatment can often yield significant savings and, in addition, the treated soil may have beneficial secondary use (e.g. as construction fill or road base material) at the same site.

2.4. Thermal treatment

2.4.1. Thermal desorption

Thermal desorption technology is based on a physical separation system. The process desorbs (physically separates) organics from the soil without decomposition. Volatile and semi-volatile organics are removed from contaminated soil in thermal desorbers at 95-315°C for low-temperature thermal desorption (also called soil roasting), or at 315-340°C for high-temperature thermal desorption. To transport the volatilized organics and water to the gas treatment system, the process uses an inert carrier gas. The gas treatment units can be condensers or carbon adsorption units, which will trap organic compounds for subsequent treatment or disposal. The units can also be afterburners or catalytic oxidizers that destroy the organic constituents. The bed temperatures and residence times of the desorbers are designed to volatilize selected contaminants, not to oxidize them. Certain less volatile compounds may not be volatilized at low temperatures [62-63].

2.4.2. Incineration

For the remediation of soils polluted with organic compounds, incineration is the most widely used method. This method is very expensive and generates problems with air

emissions and noise [64]. Incineration technology is intended to permanently destroy organic contaminants. Incineration is a complex system of interacting pieces of equipment and is not just a simple furnace. It is an integrated system of components for waste preparation, feeding, combustion, and emissions control. Central to the system is the combustion chamber, or the incinerator. There are four major types of incinerator: rotary kiln, fluidized bed, liquid injection, and infrared.

2.5. Novel remediation techniques

2.5.1. Nanotechnology and remediation

Nanotechnology has contributed to the development of a great diversity of materials as those used in electronic, optoelectronic, biomedical, pharmaceutical, cosmetic, energy, catalytic, and materials applications. As a general definition, nanotechnology is involved with objects on the nano scale, or materials measuring between 1 and 100 nm [65]. In future, modification and adaptation of nanotechnology will extend the quality and length of life [66]. The social benefits are significant from nanomaterials and the new products are applicable to information technology, medicine, energy, and environment. The emergence of nanotechnology presents a number of potential environmental benefits.

2.5.2. Steam stripping

The steam stripping method is based on a mass transfer concept, which is used to move volatile contaminants from water to air. Steam is injected through an injection well into the soil to vaporize volatile and semi-volatile contaminants [67]. The contaminated vapour steam is removed by vacuum extraction, and the contaminants are then captured through condensation and phased separation processes [68].

2.5.3. Dehalogenation

Dehalogenation of organic compounds is chemical displacement of a chlorine molecule and resulting reduction of toxicity.

2.5.4. Chemical reduction/oxidation

Chemical reduction/oxidation is a chemical conversion of hazardous contaminants to non-hazardous or less toxic compounds. The result is a more stable, less mobile and/or inert material [69].

2.5.5. Ultraviolet (UV) oxidation

Ultraviolet (UV) oxidation technology uses UV radiation, ozone, or hydrogen peroxide to destroy or detoxify organic contaminants as water flows into a treatment tank. The reaction products are dechlorinated materials and chlorine gas [70-71].

2.5.6. Supercritical fluids extraction

Supercritical fluids are materials at elevated temperature and pressure that have properties between those of a gas and a liquid. Under these conditions, the organic contaminant readily dissolves in the supercritical fluid. Supercritical fluids processes represent emerging technologies in the site remediation field. Few full-scale applications of Supercritical fluids are currently in existence [72-73].

3. Conclusion

A number of organic pollutants, such as PAHs, PCBs and pesticides, and inorganic pollutants are resistant to degradation and represent an ongoing toxicological threat to both wildlife and human beings. Bioremediation has grown into a green, attractive and promising alternative to traditional physico-chemical techniques for the remediation of hydrocarbons at a contaminated site, as it can be more cost-effective and it can selectively degrade the pollutants without damaging the site or its indigenous flora and fauna. However, bioremediation technologies have had limited applications due to the constraints imposed by substrate and environmental variability, and the limited biodegradative potential and viability of naturally occurring microorganisms. For the development of remediation processes to succeed commercially, it is essential to link different disciplines such as microbial ecology, biochemistry and microbial physiology, together with biochemical and bioprocess engineering.

In short, the key to successful remediation resides in continuing to develop the scientific and engineering work that provides the real bases for both the technology and its evaluation; and simultaneously in explaining and justifying the valid reasons which allow scientists and engineeres to actually use these technologies for the welfare and safety of a public which is more and more concerned about the environment and its protection.

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