© 2022 IJRTI | Volume 7, Issue 12 | ISSN: 2456-3315

Bioremediation Process and Techniques a Strategy to Restore Agricultural Soil Productivity: A Review

A.M Tahir[1]; M.L. Bubarai[1]., and U. Bapetel[1].

[1]Department of Soil Science and Agricultural Chemistry
Modibbo Adama University Yola, Adamawa State, Nigeria

Abstract

There are various ways in which agricultural soil become polluted with hazardous compounds some of which are through the use of farm inputs such as herbicides and pesticides which may persist for a very long period in the soil or through the disposal of industrial waste as effluent discharge or through house hold discharge arising from the use of detergent and other wastes which causes tremendous consequences on the soils. It's therefore necessary to remove these dangerous compounds that accumulate in the soil. The techniques nowadays employ to detoxify the soil of toxic waste is by the application of microorganism, which is known as bioremediation. The microbes use this toxic substrate as their energy source thereby degrading it into a harmless substance and restoring the soil to its original form. Some of the microorganisms are genetically modified to enhance their performance effectively. The process adopted in bioremediation technology is divided into two aspects namely ex situ and In situ bioremediation. In ex situ the techniques involves excavation of the contaminated soil and treating it elsewhere, while In situ bioremediation the contaminated soil is treated on site without transporting it to another place. The systems make use of microbes inhabiting that area of the contaminated site or they may be brought to the environment elsewhere for the remediation. For remediating pesticides contaminated soils the methods adopted are biostimulation and bioaugmentation. The techniques of In situ bioremediation include bioventing, Airsparging, Bioslurping, pump and treat, percolation and permeable reaction barriers and phytoremidiation. Ex situ bioremediation consist of Land farming, biopiling, windrow and bioreactor. Some of the factors affecting bioremediation are Microbial population, availability of contaminant, temperature, pH nutrients availability, water activity and osmotic pressure among others. Another aspect of remediation is composting **which are rich sources of xenobiotic-degrading microorganisms including bacteria, actinomycetes and lignolytic fungi, which can degrade pollutants to harmless compounds such as carbon dioxide and water.**

KEY WORDS, Bioremediation, bioventing, Airsparging, Bioslurping, pump and treat and composting

INTRODUCTION

The contamination of Agricultural Soils as a result of indiscriminate use of farming inputs such as pesticides and herbicides and dumping of other industrial toxic substances on the soil and the impact of oil spillage is hindering the productivity of crops as a result of the accumulation of non degradable substances which tend to persist for a longer period in the soil. After utilization some of these agricultural compounds enter into the soil, water and plant tissue (Mcguiness *et al*.,2009). Some of these compounds like dichloro diphenyl trichloro ethane (DDT),dieldrin,benzene,polyaromatic hydrocarbon (PAHs) and many others persist very long in soils (Diez, 2010). Their persistent in soil, water and plant affect human and animal (Kanann *et al*., 1999).Therefore there is an urgent need to eliminate them. The best method adopted nowadays is bioremediation which employ microbial strain to achieve the desire objective. The introduction of bioremediation techniques is a well come development in clearing and detoxifying xenobiotics compounds in our soils thereby returning it to its original nature making it viable for production. Bioremediation is the process of using living organisms to absorb nutrients in order to restore an ecosystem to its natural condition. The process involves the use of organism obtained from the environment of interest or imported from other system or specially modified genetically in the laboratory and exposing it to a target contaminant so as to reduce or remove the toxic component (Srinivasan *et al*., 2014). Ruchita, *et al*., (2015) observed that "bioremediation technology has limitations; several microorganisms cannot break toxic metals into harmless metabolites, and these have inhibitory effects on microbial activity. Modification in the outer membrane proteins of bacteria with potential bioremediation properties for improving metal binding abilities is the likely way to enhance their capacity for biotransformation of toxic metals. Some genetically modified microorganism which are capable of enhanced degradation of chemicals contaminants are shown on (Table 1).

In Nigeria the activities of oil exploration and spillage have destroy agricultural land and fishing activities in the region. The negative impacts on Agricultural practices by oil extraction activities have contributed to the abject poverty of the inhabitant of that community (Effiong, *et al*., 2012). Nnabuenyi (2012) observed the effects of oil spill on agriculture and lamented that most of the destroyed farm land and polluted rivers have contributed to the frustration and lack of livelihood for farmers and fisher men. Dighal *et al*., (2017) reported concentration of some heavy metals and Total hydrocarbon content (THC) at hazardous levels as a result of oil spillage and the activities of illegal oil bunkering in some area of river state southern Nigeria, (Table 2 and3). They adopted Descriptive statistics to explain the presents of heavy metals and THC in surface and subsurface soils of the study area, They went further to demonstrate that the THC as recorded during their investigation was above the standard limit for soil quality as recommended by petroleum industries in Nigeria (EGASPIN), the outcome of their work clearly shows that the soil is heavily loaded with THC and heavy metals especially the subsurface soil (Table 3 and 4).They proffer a quick intervention scheme to reclaim the contaminated soil, hence the need for urgent bio remediation.

Table 1 Genetically Engineered Bacterium for Remediation of Heavy Metals

Heavy Metal	**Initial Conc. (ppm)**	**Removal Efficiency (%)**	**Genetically Engineered Bacteria**	**Expressed Gene**
As	0.05	100	*E. coli* strain	Metalloregulatory protein ArsR
Cd^{2+}	-	-	*E .coli* strain	SpPCS
Cr^{6+}	1.4–1000	100	*Methylococcus capsulatus*	CrR
Cr	-	-	*P. putida* strain	Chromate reductase (ChrR)
Cd^{2+},Hg	-	-	*Ralstonia eutropha* CH34, *Deinococcus radiodurans*	merA
Hg	-	-	*E. coli* strain	Organomurcurial lyase
Hg	7.4	96	*E. coli* JM109	Hg2+ transporter
Hg	-	-	*Pseudomonas* K-62	Organomercurial lyase
Hg	-	-	*Achromobacter* sp AO22	Mer
Ni	145	80	*P. fluorescens* 4F39	Phytochelatin synthase (PCS)

(Source Ruchita, *et al* 2015)

Table 2 Concentration of heavy metals on oil spilled soils southern Nigeria

Location	**Depth**	Cr	Fe	Zn	Mn
Kpoi	0-15cm 15-30cm	5.20 5.10	636 524	59.73 60.19	37.65 37.80
Kdere	0-15cm 15-30cm	4.40 4.40	636 644	58.89 58.82	26.35 36.95
Biara	0-15cm 15-30	5.20 5.10	636 644	62.53 62.77	26.35 36.95
Bdere	0-15cm 15-30cm	4.0 4.10	652 605	60.20 60.19	26.30 27.60

(Source Digha *et al.*, 2017)

Table 3: Descriptive statistics of heavy metals in surface and sub-surface oil spilled oil

Heavy metals	**Depth**	X (Mean)	**S.D**	**C.V (%)**
Chromium (cr)	Surface Sub-surface	4.68 4.68	0.53 0.44	11.32 9.40
Iron (Fe)	Surface Sub-surface	635.75 547.75	27.02 83.54	4.25 15.20
Manganese	Surface Sub-surface	29.21 32.20	4.87 5.20	16.67 16.15
Zinc (Zn)	Surface Sub-surface	60.34 60.49	1.35 1.43	2.24 2.36

(Source Digha *et al.*, 2017)

Table 4: Total hydrocarbon content (THC) in oil spilled soils

Location	**Depth**	**THC**
Kpoi	0-15cm 15-30cm	85512 40541
Kdere	0-15cm 15-30cm	69515 40275
Biara	0-15cm 15-30cm	68217 35192
Bdere	0-15cm 15-30cm	48764 18576

(Source Digha et al., 2017)

Table 5 shows the summary of the laboratory result for total hydrocarbon content

Variable	Depth	X – value	S.D (X-X)2	C.V (%)
T.H.C	Surface	68002.0	425.80	0.63
	Sub-surface	33645.5	7575.83	22.5

(Source Digha et al., 2017)

In India the rapid industrial development is causing the release of toxic chemical in the soil and water. Nagajyoti (2010) lamented that large areas of land can be contaminated by heavy metals released from smelters, waste incinerators, industrial wastewater, and from the application of sludge or municipal compost, pesticides, and fertilizers. Saha and Panwar(2013) noted that waste water for irrigation has resulted in buildup of heavy metals in soils of agricultural land near cities and towns of India. Irrespective of their sources in the soil, accumulation of heavy metals can degrade soil quality, reduce crop yield and the quality of agricultural products, and thus negatively impact the health of human, animals, and the ecosystem. According to estimate of CSSRI (Central Soil Salinity Research Institute) Karnal (2010-11) 6.73 m ha of soil in India is salt affected. Not only fertilizers, pesticides which are soil drenched or applied as aerial sprays also remain to be active for a long time which ultimately affects soil microclimate and animals too for a long time. Yoshizawa *et al*.,(2004) lamented that annually Asia generated 4.4 billion tones of solid waste and MSW comprises 790 millions tones of which about 48 (6%) million tones is generated in India. All these constraint needs an urgent urge of amendments of the soil and the only promising solution appears to be bioremediation (Anupam *et al*., 2015)
Microorganism plays a significant role in detoxification of toxic chemicals in the soil. The process of using microorganism to remove toxic contaminants especially heavy metals is known as bioremediation. It is an innovative and promising technology available for removal of heavy metals and recovery of the heavy metals in polluted water and lands. It uses naturally occurring bacteria and fungi or plants to degrade or detoxify substances hazardous to human health and the environment. The microorganisms may be indigenous to a contaminated area or they may be isolated from elsewhere and brought to the contaminated site. Contaminant compounds are transformed by living organisms through reactions that take place as a part of their metabolic processes (Vidali, 2001) The process of bioremediation involves converting the toxic materials into harmless substances specifically water and carbon dioxide. This can be carried out on site or offsite by taking advantage of indigenous microorganisms or introduction of bacteria or fungal strains to achieve the desire aim of detoxification of hazardous compound (Gibson and Saylor 1992). Microorganisms are distributed in large numbers everywhere and their systems are capable of utilizing toxic substances as source of energy for growth via aerobic and anaerobic respiration or fermentation. They have enzymes that are capable of degrading toxic compounds, (Ahlet and Peters 2001).Since microorganisms have developed various strategies for their survival in heavy metal-polluted habitats, these organisms are known to develop and adopt different detoxifying mechanisms such as biosorption, bioaccumulation, biotransformation and biomineralization, which can be exploited for bioremediation either ex situ or in situ (Lin and Lin, 2005).

Microorganisms uptake heavy metals actively (bioaccumulation) or passively (Hussein *et al.*, 2001). The microbial cell walls, which mainly consist of polysaccharides, lipids and proteins, offer many functional groups that can bind heavy metal ions, and these include carboxylate, hydroxyl, amino and phosphate groups (Scott and Karanjkar, 1992). Fungi of the genera *Penicillium*, *Aspergillus* and *Rhizopus* have been studied extensively as potential microbial agents for the removal of heavy metals from aqueous solutions (Volesky,and Holan 1995 ; Huang, and Huang 1996). Biodegradation can be enhanced by use of contaminated adapted microorganism or genetically impaired bacteria at contaminated sites, this is referred to as bioaugmentation (Quan *et al*., 2004). Bioremediation can also be enhance by adding essential nutrients to stimulate growth of indigenous bacteria, this techniques is known as biostimulation (Trindade *et al*., 2005).

BIOREMIDATION TECHNIQUES

Basically bioremediation techniques are classified into two viz: (1) in situ and (2) ex situ (Vidali, 2000). In situ remediation techniques involve leaving the soil in its original place and bringing the biological mechanisms to the soil. Ex *situ* remediation techniques involve removing the soil from the subsurface to treat it (Vidali, 2000).In situ remediation includes techniques such as bioventing, Airparging, bioslurping , Pump and treat , Percolation and Permeable reactive barriers. In sit*u* remediation is less costly due to the lack of excavation and transportation costs, but these remediation techniques are less controllable and less effective. (Koning, *et al.*, 2000).

1.0 INSITU BIOREMEDIATION

1.1 Bioventing: These techniques involve controlled stimulation of airflow by delivering oxygen to unsaturated zone in order to increase bioremediation, by increasing activities of indigenous microbes. In bioventing, amendments are made by adding nutrients and moisture to enhance bioremediation with the ultimate goal being to achieve microbial transformation of pollutants to a harmless state (Philp and Atlas 2005 ; Ho¨hener and Ponsin 2014). The development and application of venting and bioventing for in situ removal of petroleum from soil have been shown to remediate approximately 800 kg of hydrocarbons by venting, and approximately 572 kg by biodegradation (Saadoun *et al*., 2005)

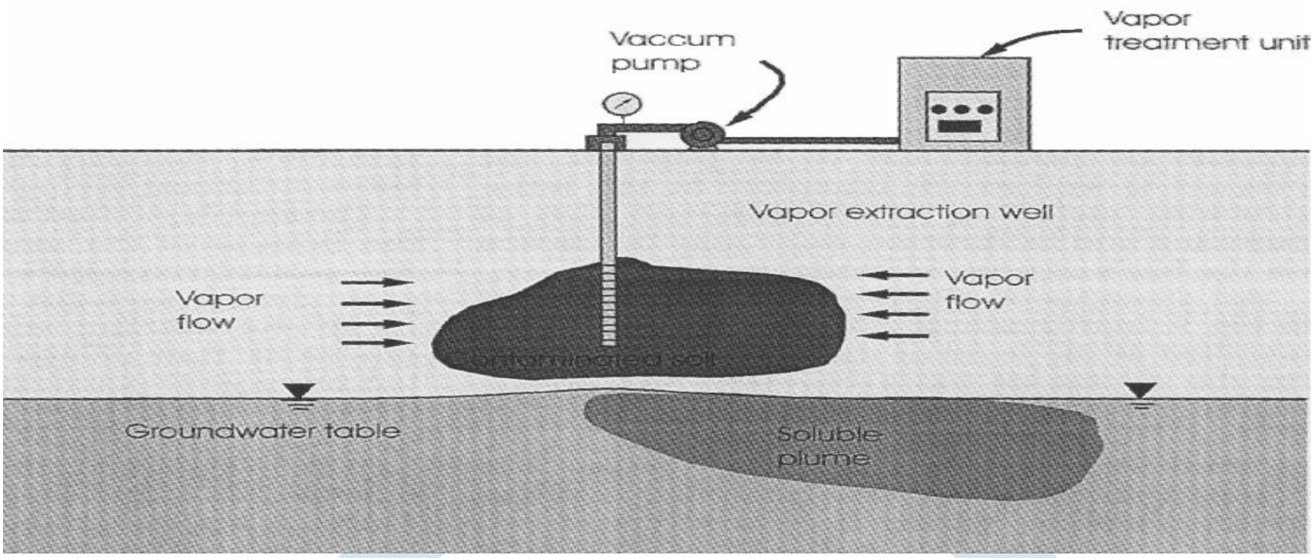


Figure 1 Illustration of bioventing system. (Source: Held and Dörr, 2000).

1.2 Airparging or biosparging: It involves the injection of air into the saturated zone of a contaminated soil, at low flow rates (<5 m^3/h per point) to transfer volatiles compounds to the unsaturated zones for biodegredation (Fingerman and Nagabhushanam, 2005).The air injected below the water table increases oxygen concentration and enhances the rate of biological degradation of organic contaminants by microorganism. The addition of bioremediation process makes application of air sparging more favourable for the remediation of less volatile contaminants like diesel fuel wastes oil (Anderson and Ward, 1995).

A case study performed in the Damodar Valley in Eastern India showed that biosparging was effective at removing 75% of contaminants present within a one year time period. The first results were obtained in the field, but these results were enumerated using a laboratory tests and computer programs. The results from the study were used to set the optimum conditions for remediation including: proper moisture content, pH, temperature, nutrients, and carbon sources. The field tests used six separate tests sites. Different parameters were tested in each site in order to investigate the optimum conditions. (Gogoi *et al*.,2002). Bioslurping is a unique *in situ* treatment technique in that it also treats free product phases floating on top of the groundwater. This technique applies a vacuum to extract, soil vapor, water, and free product from the subsurface. Each of those products is separated and then treated. This technique is cost effective because only a small amount of groundwater and soil vapor are pumped at a time, therefore the treatment plant used to treat the vapor and free product can be small (Held and Dörr, 2000). (Figure 2).

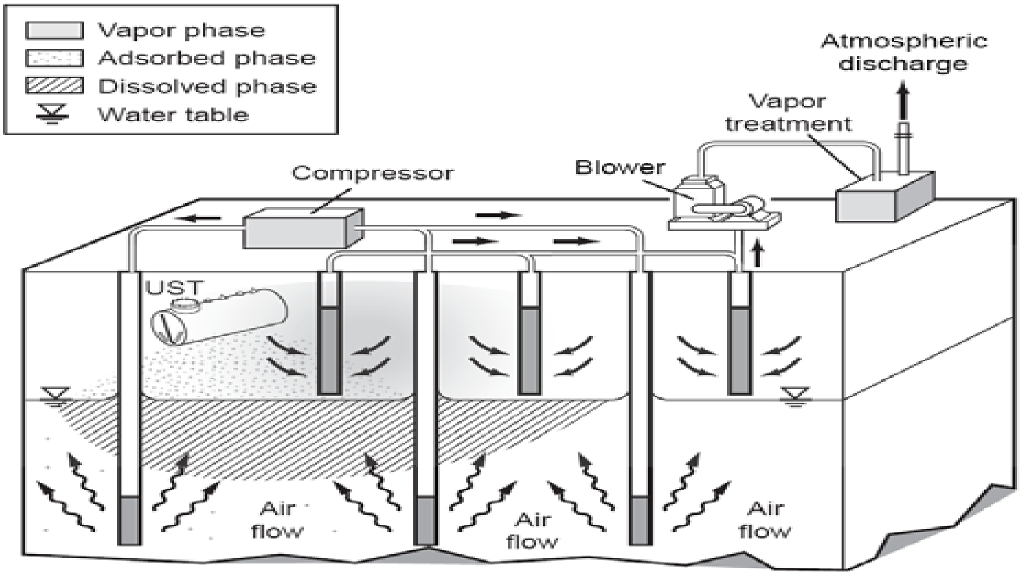


Figure 2 Biosparging system used with soil vapor extraction (EPA, 2006)

1.3 Bioslurping: This is an in situ technology that combines vacuum-enhanced free-product recovery with bioventing of subsurface soils to simultaneously remediate petroleum hydrocarbon-contaminated groundwater and soils. Vacuum-enhanced recovery utilizes negative pressure to create a partial vacuum that extracts free product and water from the subsurface. The technology is portable and uses a single pump to extract free product, groundwater, and soil gas from multiple wells. Groundwater and soil gas may require treatment before being discharged. Bioslurping is used at petroleum spill sites and has proven most effective in fine-to-medium textured soils or fractured rock in areas with a low water table (Lehr *et al.*, 2004 and Lehr, 2004) Figure 3.

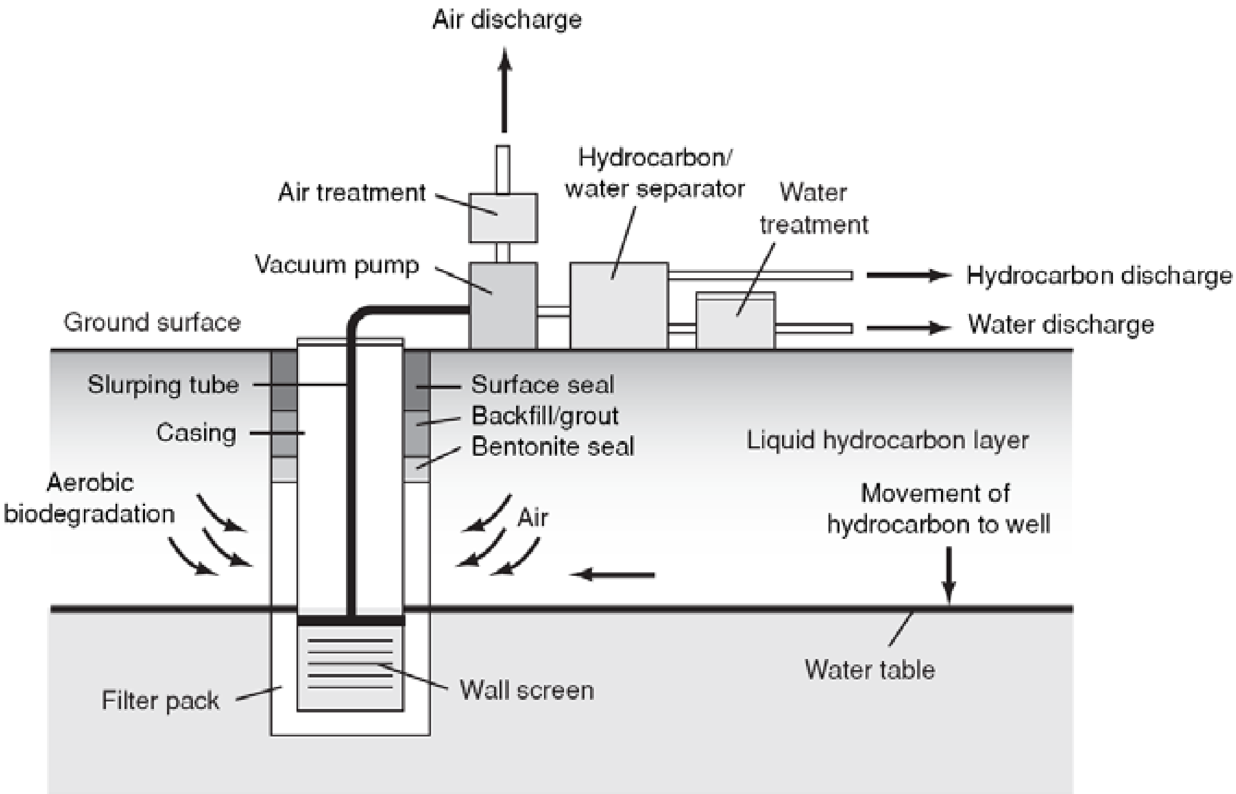


Figure 3. Bioslurping technology (EPA, 2006)

1.4 Pump-and-treat systems Pump-and-treat systems are applied to saturated-zone remediation the removal of any contaminated water from the ground, treatment either at an on-site or offsite plant and return it back to the contaminated soil zone, (Figure 3) (MacKay and Cherry 1989; EPA 2007 Lehr *et al*., 2004). This is one of the most traditional methods of remediation, but it is not the most effective method for all contaminants because it is costly in investment maintenance and very time consuming (Lehr *et al*., 2004). However, the advantage of this method is that the contaminant is actually removed entirely from this system if it is water soluble. For example in the cases of methyl tertiary-butyl ether (MTBE), which is a fuel additive very soluble in water, chlorinated solvents and hydrocarbons in groundwater, the pump and treat method combined with carbon adsorption and air stripping is very effective (Singh and Stapleton 2002; Lehr *et al*., 2004). However, for contaminants that bind very closely to the soil, such as polycyclic aromatic hydrocarbon (PAHs), desorption of the contaminant from the soil to the groundwater is very slow.

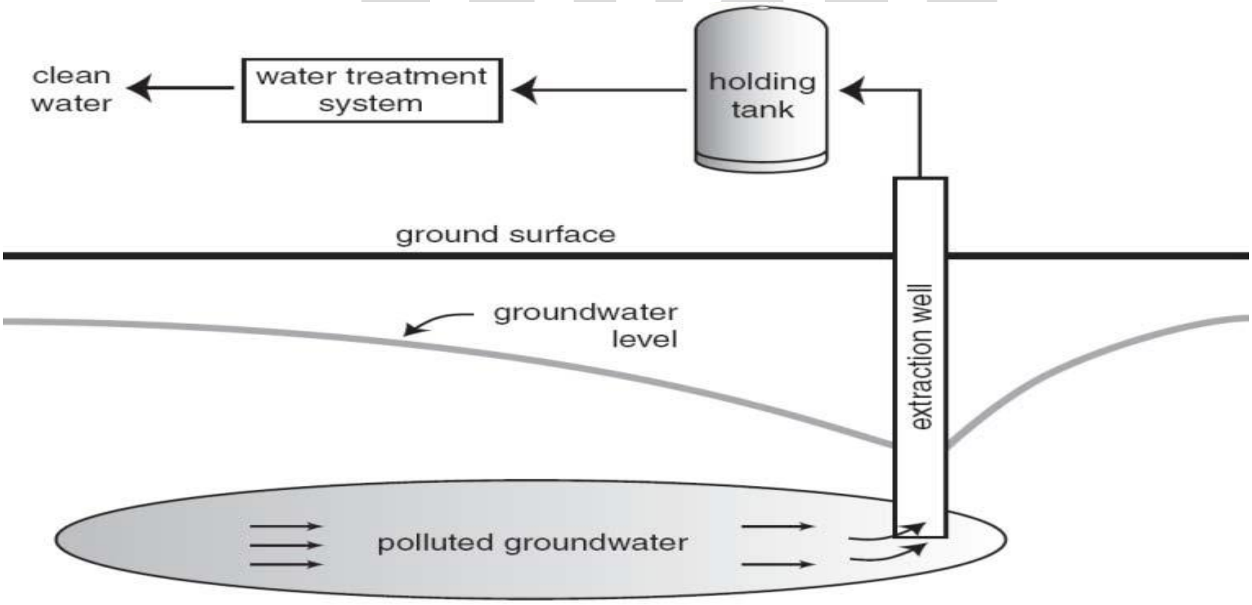


Figure 4. A simplified pump and treat scheme. Treated water is usually returned back in the ground water.(EPA,2001)

When the groundwater is pumped out of the system, the contaminant present in the aqueous phase is also removed, but a significant portion of the contaminant still remains present in the ground. In order for pump and treat to be effective, it must be done over a long period, in order to give the contaminant sufficient time to desorbs from the soil. However, this option becomes much more cost efficient and timely with the addition of mobility agents such as cosolvents (e.g. alcohols), surfactants (e.g. amphiphilic polyurethane nanoparticles, extracellular polymers, and cyclodetrins) and steam that will loosen the bond of the contaminant to the soil particles and increase the apparent solubility of the contaminant (Tungittiplakorn *et al*., 2004 and Talley, 2005).

1.5 Percolation Percolation consists of applying water, containing nutrients and possibly a microbial inoculum, to the surface of a contaminated area and allowing it to filter into the soil and mix with the ground water (Blackburn and Hafker 1993).

1.6 Permeable reactive barrier (PRB) .This is a physical method for remediating contaminated groundwater, due to its design and mechanism of pollutant removal. Researchers (Thiruvenkatachari *et al*., 2008; Obiri-Nyarko *et al*., 2014) reported that biological reaction is one of the several mechanisms (degradation, precipitation and sorption) of pollutant removal in PRB technique. Although alternative terms such as biological PRB, passive bio reactive barrier, bio-enhanced PRB have been proposed to accommodate the bioremediation or biotechnology aspect of the technique, the role of microorganisms have been reported to be mostly enhancement rather than an independent biotechnology (Philp and Atlas 2005). PRB is an in situ technique used for remediating groundwater polluted with different types of pollutants including heavy metals and chlorinated compounds. In this technique, a permanent or semi-permanent reactive barrier (medium) mostly made up of a zero-valent iron (Garcı´a *et al*., 2014; Zhou *et al*. 2014) is submerged in the trajectory of polluted groundwater. As polluted water flows through the barrier under its natural gradient, pollutants become trapped and undergo series of reactions resulting in clean water in the flow through (Thiruvenkatachari *et al*., 2008; Obiri-Nyarko *et al*., 2014).

1.7 Phytoremediation Phytoremediation is an *in situ* technique that uses plants to remediate contaminated soils. Phytoremediation is most suited for sites where other remediation options are not costs effective, low-level contaminated sites, or in conjunction with other remediation techniques. Deep rooted trees, grasses, legumes, and aquatic plants all have application in the phytoremediation field. Phytoremediation has been used to remove TPH, BTEX, PAH, 2,4,6-trinitrotoluene (TNT), and hexahyro-1,3,5-trinitro-1,3,5 triazine (RDX). (Schnoor, 2000).

Plants are able to remove pollutants from the groundwater and store, metabolize, or volatilize them. Also,roots also help support a wide variety of microorganisms in the subsurface. These microorganisms can then degrade the contaminants. The roots also provide organic carbon sources to promote cometabolism in the rizosphere. The rizosphere is the soil in the area of the vegetative roots. Figure 4 illustrates different phytoremediation techniques.

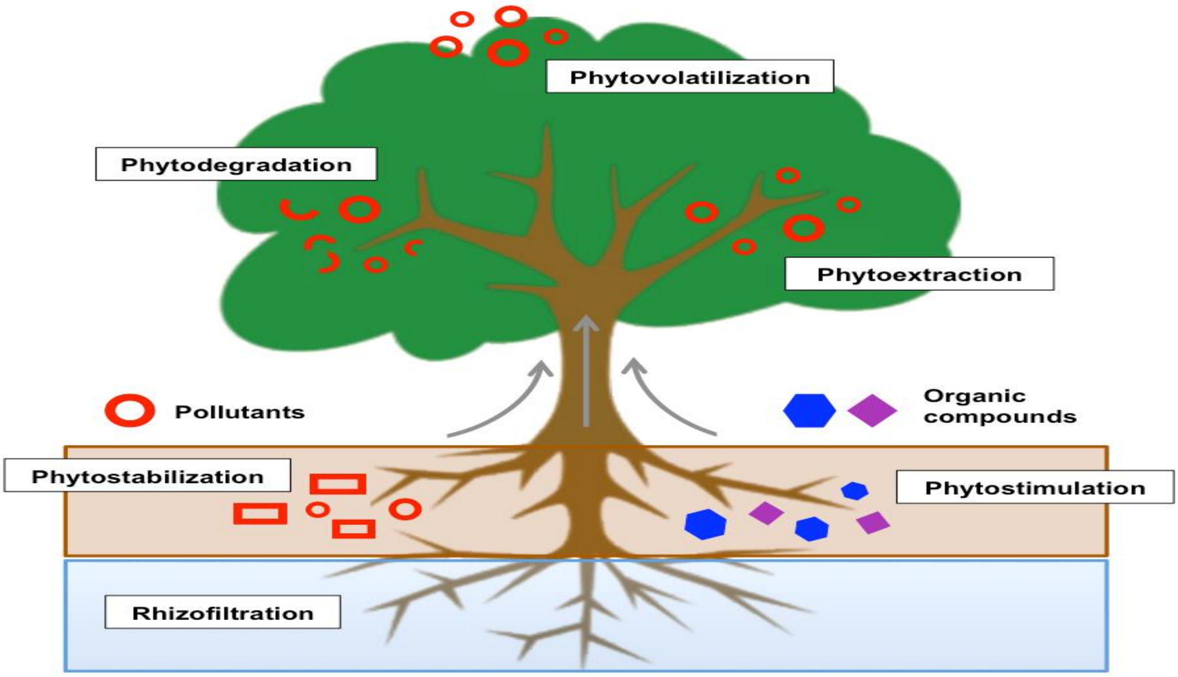
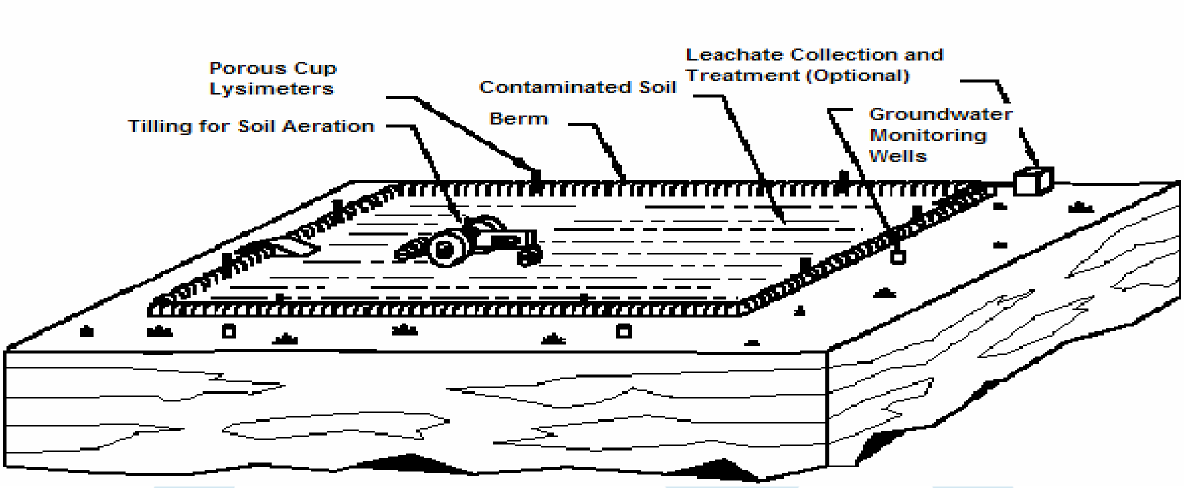


Figure 5: Illustration of phytoremediation. (Source: Schnoor, 2000.)

2.0 Ex-situ treatment systems

These techniques involve excavating pollutants from polluted sites and subsequently transporting them to another site for treatment. Ex situ bioremediation techniques are usually considered based on: the cost of treatment, depth of pollution, type of pollutant, degree of pollution, geographical location and geology of the polluted site. Performance criteria, which also determine the choice of ex situ bioremediation techniques, have been described (Philp and Atlas 2005). Examples of ex-situ techniques include land farming, Biopiling, windrow and bio reactor (Blackburn, 1993).

2.1 land farming: Land farming is a process in which the soil is excavated and mechanically separated via sieving. The polluted soil is then place in layers no more than 0.4 meters thick. A synthetic, concrete, or clay membrane is then used to cover the contaminated soil layer. Oxygen is added and mixing occurs via plowing, harrowing, or milling. Nutrients and moisture may also be added to aid the remediation process. The pH of the soil is also regulated (keeping it near 7.0) using crushed limestone or agricultural lime. (Van Deuren, *et al*., 2002). (Nikolopoulou *et al*., 2013). Biodegradation of pollutant is by autochthonous microorganisms (Philp and Atlas 2005; Paudyn *et al*., 2008; Volpe *et al*., 2012; Silva-Castro *et al*., 2015) Figure 5 illustrates the land farming technique.



Figu5: Land farming Technique (Source: United States Environmental Protection Agency, 2004)

2.2 Biopiling Biopiling involves above-ground piling of excavated polluted soil, followed by nutrient amendment, and sometimes aeration to enhance bioremediation by basically increasing microbial activities. The components of this technique are: aeration, irrigation, nutrient and leachate collection systems, and a treatment bed (Whelan *et al*., 2015). The first step in the biopiling process is to perform laboratory tests that will determine the biological degradation capabilities of the soil sample. The next step involves the mechanical separation of the soil, which will homogenize the sample and remove any disruptive material such as plastics, metals, and stones. The stones will then be crushed into smaller pieces and then depending on the degree of contamination will either be added to a pile or sent out for reuse. The soil is then homogenized, meaning that the pollution concentration is averaged out across the entire soil sample. Homogenization allows for biopiling to be more effective. (Schulz-Berendt, 2000). Once the soil is piled, nutrients, microbes, oxygen, and substrate are added to start the biological degradation of the contaminants.; it can also be used effectively to remediate polluted extreme environments such as the very cold regions (Dias *et al*., 2015; Gomez and Sartaj 2014; Whelan *et al*., 2015). Biopiling is most effective in treating pollutants such as BTEX, phenols, PAHs with up to 4 aromatic rings, and explosives such as TNT and RDX. (Schulz-Berendt, 2000, Van Deuren, *et al*., 2002). Once the soil is piled, nutrients, microbes, oxygen, and substrate are added to start the biological degradation of the contaminants. The results of the initial laboratory tests indicate to the operators which substrates such as bark, lime, or composts needs to be added to the soil. Nutrients such as mineral fertilizers may also be added. Additionally, microorganisms such as fungi, bacteria, or enzymes could be added. (Schulz-Berendt, 2000.) A diagram for the heap techniques is shown in Figure 5.

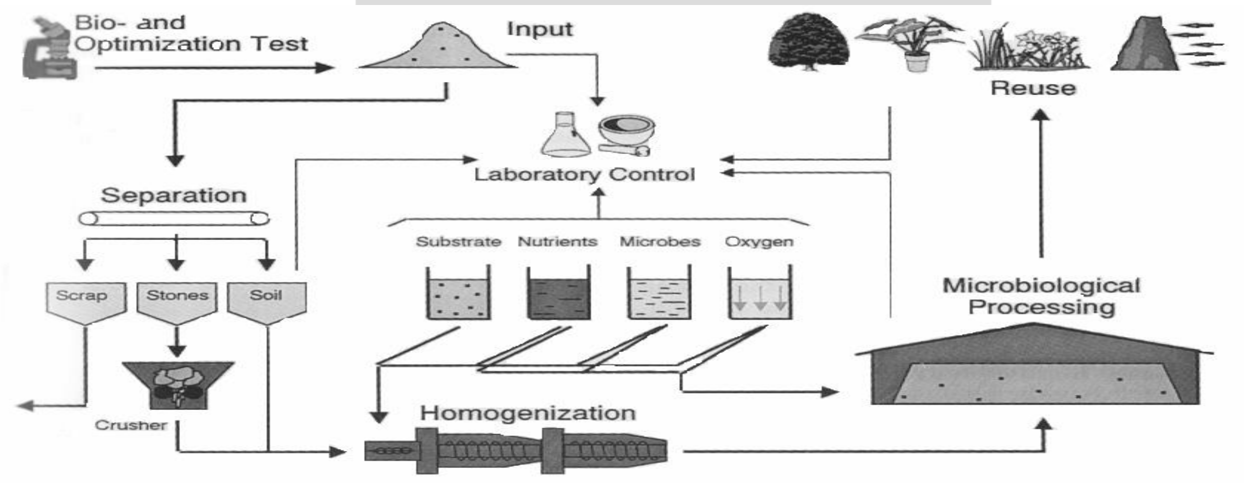


Figure 5: Heap Technique Diagram.

(Source: Schulz-Berendt, 2000).

2.3 Windrow: Windrows rely on periodic turning of piled polluted soil to enhance bioremediation by increasing degradation activities of indigenous and/or transient hydrocarbon oclastic bacteria present in polluted soil. The periodic turning of polluted soil, together with addition of water bring about increase in aeration, uniform distribution of pollutants, nutrients and microbial degradative activities, thus speeding up the rate of bioremediation, which can be accomplished through assimilation, biotransformation and mineralization (Barr, 2002).

2.4 Bioreactor: Bioreactor, as the name implies, is a vessel in which raw materials are converted to specific product(s) following series of biological reactions. There are different operating modes of bioreactor, which include: batch, fed-batch, sequencing batch, continuous and multistage. Conditions in a bioreactor support natural process of cells by mimicking and maintaining their natural environment to provide optimum growth conditions. Polluted samples can be fed into a bioreactor either as dry matter or slurry; in either case, the use of bioreactor in treating polluted soil has several advantages compared to other ex situ bioremediation techniques. Excellent control of bioprocess parameters (temperature, pH, agitation and aeration rates, substrate and inoculum concentrations) is one of the major advantages of bioreactor-based bioremediation. The ability to control and manipulate process parameters in a bioreactor implies that biological reactions within can be enhanced to effectively reduce bioremediation time. It can be used to treat soil or water polluted with volatile organic compounds (VOCs) including benzene, toluene, ethyl benzene and xylenes (BTEX). The applications of different bioreactors for bioremediation process have resulted in removal of wide range of pollutants .The flexible nature of bioreactor designs allows maximum biological degradation while minimizing abiotic losses (Mohan *et al*., 2004)

FACTORS AFFECTING BIOREMEDIATION

The control for bioremediation processes is a complex system of many factors. These factors include the existence of a microbial population capable of degrading the pollutants, the availability of contaminants to the microbial population and the presence of oxygen, others factors are temperature, pH nutrients availability, water activity and osmotic pressure (Madhavi *et al*.,2012). Table 8 summarized factors affecting bioremediation.

8 Major factors affecting Bioremediation (Boopathy, 2000)

Microbial
Growth until critical biomass is reached
Mutation and horizontal gene transfer
Enzyme induction
Enrichment of the capable microbial populations
Production of toxic metabolites
Environmental
Depletion of preferential substrates
Lack of nutrientsnhibitory environmental conditions
Substrate
Too low concentration of contaminants
Chemical structure of contaminants
Toxicity of contaminants Solubility of contaminants
Biological aerobic vs anaerobic process
Oxidation/reduction potential
Availability of electron acceptors
Microbial population present in the site
Growth substrate vs co-metabolism
Type of contaminants
Concentration
Alternate carbon source presence
Microbial interaction (competition, succession, and predation)
Physico-chemical bioavailability of pollutants
Equilibrium sorption
Irreversible sorption
Incorporation into humic matters
Mass transfer limitations
Oxygen diffusion and solubility
Diffusion of nutrients
Solubility/miscibility in/with water

Some Other Bioremediation Processes for Degradation of Pesticides

Bio-Stimulation

This refers to addition of specialized nutrients and suitable physiological conditions for the growth of the indigenous microbial populations. This promotes increased metabolic activity, which then degrades the contaminants (Trindade, *et al.*, 2005). Bio stimulation has been used to remove pesticides contamination in the environment. In this process, the activity of the indigenous microorganisms is stimulated by adding the organic and/or inorganic additives such as N or P, etc. The modifications added would be used by the indigenous microorganisms for cell growth to increase cell number as well as their activities to degrade the pesticides. In addition, the amendments could be necessary as the enzyme-inducers and/or the co-metabolic substrates in the pesticide degradation pathways (Robles-*et al*., 2008).

Bio-Augmentations

Bio-augmentation is the introduction of exogenous microorganisms with specific catabolic abilities into the contaminated environment or into a bioreactor to initiate the bioremediation process. This can be an in situ or ex situ treatment process in which naturally occurring microbes are added to contaminated sites to eliminate toxic contaminants (Head and Oleszkiewicz, 2004; Perelo, 2010). The technique is reported to be an effective bioremediation approach for improving pesticide degradation in contaminated soil and water that lack indigenous microbial activity (Dams *et al.*, 2007; Plangklang and Reungsang, 2010).It has been employed to degrade a wide range of chemical contaminants such as ammonia, hydrogensulphide, insecticides, petroleum compounds, and a growing number of toxic organic chemicals present in soil and water (Hwang and Cutright, 2002; Jianlong, Xiangchun, Libo, Yi and Hegemann, 2002; Quan, *et al*.,2004).

Composting

Semple *et al*., (2001) reported that ``Composting matrices and composts are rich sources of xenobiotic-degrading microorganisms including bacteria, actinomycetes and lignolytic fungi, which can degrade pollutants to innocuous compounds such as carbon dioxide and water. These microorganisms can also biotransform pollutants into less toxic substances and/or lock up pollutants within the organic matrix, thereby reducing pollutant bioavailability." Stegmann, (1991 and Hupe, 1996). documented the effects of mature compost on hydrocarbon degradation in soil-compost mixes in laboratory reactors, best results were achieved by mixing mature, 6-month-old compost with TPH-contaminated soil.They found degradation rates of about 375 mg TPH/kg/day, values much higher than those reported for in situ biodegradation—40 mg/kg/day (Atlas, 1991).

Table 9 Removal of chlorophenols from contaminated soils using different composting regimes

Time week	Total chlorophenol					
	Soil + bark chips remediated soil		Soil + straw compost		Soil+	
	$mgkg^{-1}$soil remaining	% remaining	$mgkg^{-1}$ soil	% remaining	$mgkg^{-1}$	%
0	43	100	45	100	43	100
1	19	44.2	23	51.1	21	48.8
3	16	37.2	21	46.7	18	41.9
5	10	23.3	13	28.9	11	25.6
7	9	20.9	10	22.2	9	20.9
9	7	16.3	10	22.2	7	16.4
Introduction of highly contaminated soil						
0	771	100	683	100	1108	100
4	203	26.3	233	34.1	585	52.8
8	35	4.5	42	6.1	103	9.3
12	33	4.3	44	6.4	53	4.8
16	34	4.4	42	6.1	67	6.0
42	29	3.8	38	5.6	49	4.4

(adapted from Laine and Jùrgensen (1997)

CONCLUSION

Soil and water are being polluted by various organic and inorganic pollutants due to rapid industrialization and use of agrochemicals in imbalanced proportions. There is an urgent need to explore cheaper ways of cleaning up the polluted soils. Bioremediation is a unique and cost-effective technique for cleaning up pollution by intensifying the natural biodegradation processes. Therefore there is an urgent need to intensify research on bioremediation playing more emphasis on the behavior and characteristics of various microorganisms in various habitats.

REFERENCE

1. Ahlet,R.C., and Peters (2001) Treatment of PCB Contaminated soils: .Evaluation of insitu reductive dechlorination of PCBs Environ prog. 20(2), 108-116
2. Anupam ,B., Saurabh, S., Dinesh, C., Pankaj, R., Kumar, P.,Satish ,C. and N.K Singh (2015) Enhanced bioremediation techniques for agricultural soils. *International Journal of Curr Res,Acad.Rev* 3(7): 166-173

3. Anderson,W.C., and C.H. Ward. (1995). Innovative site Remediation Technology, Vol 1 Bioremediation , American Academy of Environmenta Engineering, WATECH.
4. Atlas, R.M. (1991) "Bioremediation of Fossil Fuel Contaminated Soils." In In Situ Bioreclamation, by R.E. Hinchee and R.F. Olfenbuttel, 15. Boston: Butterworth-Heinemann,.
5. Bucher, M (2007) Functional biology of plant phosphate uptake at root and mycorrhiza interfaces. New Phytologist 173: 11-26
6. Boopathy, R,(2000). Factors limiting bioremediation technologies Bioresource Technology 74 (2000) 63-67
7. Burd,G, Dixon, D.G, Glick, B.R, (2000). Plant growth promoting bacteria that decrease heavy metal toxicity in plants. Can J Microbiol46:237–245
8. Barr, D, (2002). Biological methods for assessment and remediation of contaminated land: case studies., Construction Industry Research and Information Association, London
9. Blackburn, J.W., and Hafker, W.R. (1993) TIBITECH, 11, 328
10. Digha opaminola N., Ambah b. & Jacob, esther .N. (2017).The Effects of Crude Oil Spillage on Farmland in Gokana local Government Area of Rivers State *European Journal of Basic and Applied Sciences* Vol. 4 No. 1, *ISSN 2059-3058*
11. Dias, R.L., Ruberto, L., Calabro, A., Balbo, A.L., Del Panno, M.T., Mac Cormack, W.P., (2015). Hydrocarbon removal and bacterial community structure in on-site biostimulated biopile systems designed for bioremediation of diesel-contaminated Antarctic soil. Polar Biol 38:677–687. doi:10.1007/s00300-014-1630-7
12. Diez,M.C, (2010). Biological Aspects involved in the degradation of organic pollutants.*J.Soil,Plant, Nutri*. 10: 224- 367
13. Dams, R. I., Paton, G. I., & Killham, K. (2007). Rhizo-remediation of pentachlorophenol by *Sphingobiumchlorophenolicum*, ATCC 39723. *Chemosphere*, *68*(5), 864–870.doi:10.1016/j. chemosphere.2007.02.014 PMID: 17376504
14. Effiong, S.A. and Etowa, U.E. (2012). Oil Spillage Cost, Gas Flaring Cost and Life Expectancy Rate of the Niger Delta people of Nigeria, *Advances in Management & Applied Economics*, 2 (2), pp. 211-
15. 228.
16. EPA (2007), Treatment Technologies for Site Cleanup: Annual Status Report (Twelfth Edition),
17. EPA-542-R-07-012.
18. Epa, (2006). Insitu and Exsitu Biodegradation Technologies for Remediation of contaminated Sites, USEPA
19. Fingerman, M., and Nagabhushanam, R.(2005).Bioremediation f aquatic and terrestrial ecosystem, Science Publishers Inc.
20. EPA,(2001).A citizens guide to pump and treat EPA,542-F-01-025
21. Garcı´a Y, Ruiz, C., Mena, E., Villasen˜or ,J., Can˜izares ,P., Rodrigo, M.A., (2014). Removal of nitrates from spiked clay soils by coupling electrokinetic and permeable reactive barrier technologies. *J Chem Technol Biotechnol* 90:1719–1726. doi:10.1002/jctb. 4488
22. Gomez, F., Sartaj, M, (2014). Optimization of field scale biopiles for bioremediation of petroleum hydrocarbon contaminated soil at low temperature conditions by response surface methodology (RSM). Int Biodeterior Biodegradation 89:103–109. doi:10. 1016/j.ibiod.2014.01.010
23. Gogoi, B.K., Dutta, N.N., Goswami, P., Krishna Mohen, T.R., (2002). A Case Study of Petroleum hydrocarbon Contaminated Soil at a Crude Oil Site, *Advances in Environmental Research*, 7(4) 767- 782.
24. Gogoi, B.K., Dutta, N.N., Goswami, P., Krishna Mohen, T.R., (2002). A Case Study of Petroleum hydrocarbon Contaminated Soil at a Crude Oil Site, *Advances in Environmental Research*, 7(4) 767- 782.
25. Gibson,D.T., and Sayler,G.S, (1992). Scientific foundation of bioremediation, Currnt Status and future needs, American Society for Microbiology, Washing .D.C
26. Ho¨hener, P., Ponsin, V. (2014). In situ vadose zone bioremediation. Curr Opin Biotechnol 27:1–7. doi:10.1016/j.copbio.2013.08.018
27. Head, M. A., & Oleszkiewicz, J. A. (2004). Bio-augmentation for nitrification at cold temperatures. *Water Research*, *38*(3), 523–530. doi:10.1016/j.watres.2003.11.003 PMID:14723920
28. Hwang, S., & Cutright, T. J. (2002). Biodegradability of Aged Pyrene and Phenenthrene in a Natural Soil. *Chemosphere*, *47*(9), 891–899. doi:10.1016/S0045-6535(02)00016-4 PMID:12108695
29. Hussein, H., Krull, R., Abou El-Ela, S.I., Hempel, (2001). D.C. Interaction of the different heavy metal ions with immobilized bacterial culture degrading xenobiotic wastewater compounds. In Proceedings of the Second International Water Association World Water Conference, Berlin, Germany,; pp. 15–19.
30. Held, T., and Dörr, H. (2000). *In Situ* Remediation, *Biotechnology*, 11b, 350-370.
31. Huang, C., Huang, C.P. (1996). Application of *Aspergillus oryzae* and *Rhizopus oryzae* for Cu (II) removal. *Water Res.*, *30*, 1985–1990.
32. Hupe, K., J.C. Luth, J. Heerenklage, and R. Stegmann. (1996). "Enhancement of the BiologicalDegradation of Contaminated Soils by Compost Addition." In The Science of Composting, by M. de Bertoldi, P. Bert, and P. Tiziano, 913-923. London: Blackie Academic and Professional,
33. Jianlong, W., Xiangchun, Q., Libo, W., Yi, Q., & Hegemann, W. (2002). Bioaugmentation as a Tool to Enhance the Removal of Refractory Compound in Coke Plant Wastewater. *Process Biochem, Oxford,UK*, *38*(5), 777–781. doi:10.1016/S0032-9592(02)00227-3
34. Koning, M., Hupe, K., and Stegmann, R. (2000). Thermal Processes, Scrubbing/Extraction, Bioremediation and Disposal. *Biotechnology*, 11b, 306-317.

35. Kannan,K., S.Tats ukawa, (1994). Persistent organo chlorine residues in food stuffs from Australia, papua New Guinea and the Solomon Islands: Contamination level and Dietary exposure Sci, Total Env. 153: 29-49
36. Lin, C.C.; Lin, H.L. (2005) Remediation of soil contaminated with the heavy metal (Cd^{2+}). *J.Hazard. Mater.*, 122, 7–15
37. Lehr, J.H. (2004).Wiley's Remediation Technologies Handbook. Major Contaminant Chemicals and Chemical Groups, John Wiley & Sons, Inc.
38. Landfarming.(2004) How to Evaluate Alternative Cleanup Technologies for Underground Storage Tank Sites: a Guide for Corrective Action Plan Reviewers. Environmental Protection Agency. 1 Oct. 2006<http://www.epa.gov/OUST/pubs/tum_ch5.pdf>.
39. Lehr, J., Hyman, M., Gass, T., and Seevers, W. (2004). Handbook of Complex Environmental Remediation Problems, McGraw-Hi
40. Laine, M.M., Jùrgensen, K.S., (1997) Effective and safe composting of chlorophenol-contaminated soil in pilot scale. Environmental Sci- ence and Technology 31, 371±378.
41. Madhavi, M.S.,Gaonkar, N., and M.S.,Mohini dilip duraphe, (2012). Review paper onParameters affecting Bioremediation *Interntional Journal of life Science and Pharm. Res*. Vol 2.(3)L 77-80
42. Mcguinness,M., and D. Dowling, (2009). Plant Associated Bacterial Degradation of Toxic organic compounds in soils *Int,J Environ Res.Public Health*. 6: 2226-2247
43. Mohan, S.V., Sirisha, K., Rao, N.C., Sarma, P.N., Reddy, S.J., (2004). Degradation of Chlorpyrifos contaminated soil by bioslurry reactor operated in sequencing batch mode: bioprocess monitoring. *J Hazard Mater* 116:39–48. doi:10.1016/j.jhazmat.2004.05.037
44. MacKay, D.M., and Cherry, J.A. (1989,) Environ. Sci. Technol., 23, 630
45. Nikolopoulou, M., Pasadakis, N., Norf H., Kalogerakis, N, (2013). Enhanced ex situ bioremediation of crude oil contaminated beach sand by supplementation with nutrients and rhamnolipids. Mar Pollut Bull 77:37–44. doi:10.1016/j.marpolbul.2013.10.038
46. Nnabuenyi, U.M. (2012). Impact of Oil Exploration and Exploitation on the Niger Delta Region: Environmental
47. Nagajyoti, P.C (2010). Heavy metals, occurrence and toxicity for plants: a review. Environ Chem Lett 8(3):199-216
48. Robles-Gonzalez, I. V., Fava, F., & Poggi-Varaldo, H. M. (2008). A review on slurry bioreactors for bioremediation of soils and sediments. *Microbial Cell Factories*, *7*(1), 1–16. doi:10.1186/1475-2859-7-5 PMID:18312630
49. Obiri-Nyarko, F., Grajales-Mesa, S.J., Malina, G., (2014). An overview of permeable reactive barriers for in situ sustainable groundwater remediation. Chemosphere 111:243–259. doi:10.1016/j.chemo sphere.2014.03.112
50. Plangklang, P., & Reungsang, A. (2010). Bio-augmentation of carbo furan by *Burkholderia cepacia* PCL3 in a bio slurry phase sequencing batch reactor. *Process Biochemistry*, *45*(2), 230–238. doi:10.1016/j. procbio.2009.09.013
51. Perelo, L. W. (2010). Review: In situ and bioremediation of organic pollutants in aquatic sediments. *Journal of Hazardous Materials*, *177* (1-3), 81–89. doi:10.1016/j.jhazmat.2009.12.090 PMID: 20138425
52. Paudyn, K., Rutter, A., Rowe, R.K., Poland, J.S., (2008). Remediation of hydrocarbon contaminated soils in the Canadian Arctic by landfarming. Cold Reg Sci Technol 53:102–114. doi:10.1016/j. cold regions. 2007.07.006

53. Philp, J.C., Atlas, R.M., (2005). Bioremediation of contaminated soils and aquifers. In: Atlas RM, Philp JC (eds) Bioremediation: applied microbial solutions for real-world environmental cleanup. American Society for Microbiology (ASM) Press, Washington, pp 139–236

54. Quan, X., Shi, H., Liu, H., Wang, J., & Qian, Y. (2004). Removal of 2,4-dichlorophenol in a conventional
55. activated sludge system through bioaugmentation. *Process Biochem, Oxford, UK*, *39*(11), 1701–1707.
56. doi:10.1016/S0032-9592(03)00307-8

57. Silva-Castro ,G.A., Uad, I, Rodrı´guez-Calvo, A., Gonza´lez-Lo´pez, J., Calvo, C., (2015). Response of autochthonous microbiota of diesel polluted soils to land- farming treatments. Environ Res 137: 49-58. doi: 10.1016/j.envres.2014.11.009

58. Srinivasan, V., Bhavan, P. S. and Krishnakumar, J.(2014).*Bioremediation of Textile Dye Effluent by Bacillus and Pseudomonas Spp. International Journal of Science, Environment and Technology, Vol. 3(6)*, , 2215-2224
59. Saha,J.K, Panwar, N.R. (2013). Environmental pollution in the country in relation to soil quality and human health. In Kundu S, Manna MC, Biswas AK, Chaudhary RS, Lakaria BL, & Rao AS (Eds.), IISS Contribution in Frontier Areas of Soil Research (281-306). Bhopal, India: Indian Institute of Soil Science
60. Saadoun, I.M.K., and Al-Ghzawi, Z.D. (2005). Bioremediation of aquatic and terrestrial ecosystem, Fingerman, M., and Nagabhushanam, R. (Eds.), Science Publishers Inc.

61. Smith, S.E., Smith, F.A., Jakobsen, I, (2003). Mycorrhizal fungi can dominate phosphate supply to plants irrespective of growth responses. Plant Physiology 133: 16-20
62. Singh, V.P., and Stapleton, R.D. (2002). Biotransformations: Bioremediation Technology for Health and Environmental Protection, Elsevier.

63. Schulz-Berendt, V. (2000). Bioremediation with Heap Technique. *Biotechnology*, 11b, 320-328.
64. Schnoor, J.L.,(2000). Degradation by Plants-Phytoremediation, *Biotechnology*, 11b, 372-384.

65. Semple K.T., Reid B.J. Fermor T.R.(2001) Impact of composting strategies on the treatment of soils contaminated with organic pollutants Environmental Pollution 112 (2001) 269±283 www.elsevier.com/locate/envpol
66. Schlesinger ,W.H (1997). Biogeochemistry: An Analysis of Global Change, 2nd edition. Academic Press, San Diego, 588 pp
67. Scott, J.A., Karanjkar, A.M., (1992), Repeated cadmium biosorption by regenerated *Enterobacter aerogenes*biofilm attached to activated carbon. *Biotechnol. Lett.*, *14*, 737–740.
68. Stegmann, R., S. Lotter, and J. Heerenklage (1991).“Biological Treatment of Oil-contaminated Soils in Bioreactors.” In On-Site Bioreclamation, edited by R.E. Hinchee and R.F. Olfenbuttel, 188-208. Boston: Butterworth-Heinemann
69. Thiruvenkatachari, R., Vigneswaran, S., Naidu, R., (2008). Permeable reactive barrier for groundwater remediation. J Ind Eng Chem14:145–156. doi:10.1016/j.jiec.2007.10.001
70. Trindade, P. V. O., Sobral, L. G., Rizzo, A., C. L., Leite, S. G. F., & Soriano, A. U. (2005). Bioremediation of a weathered and recently oil-contaminated soil from Brazil: A comparison study. *Chemosphere*, *58*(4), 515–522. doi:10.1016/j.chemosphere.2004.09.021 PMID: 15620743
71. Talley, J.W.(2005), Bioremediation of recalcitrant compounds, Talley, J. (Ed.), Taylor & Francis.
72. Tungittiplakorn, W., Lion, L.W., Cohen, C., and Kim, J.Y.(2004). Environ. Sci. Technol., 38, 1605.
73. Tugel, A.J., A.M. Lewandowski, eds. (February 2001 -- last update). *Soil Biology Primer* [online]. Available: www.statlab.iastate.edu/survey/SQI/soil_biology_primer.htm November 4, 2010.
74. United, S. Environmental Protection Agency (2000). Introduction to Phytoremediation,” National Risk Management Research Laboratory, EPA/600/R-99/107, 2000, http://www.clu-in.org/ download/remed/introphyto.pdf.
75. Volpe A, D’Arpa S, Del Moro G, Rossetti S, Tandoi V, Uricchio VF (2012). Fingerprinting hydrocarbons in a contaminated soil from an Italian natural reserve and assessment of the performance of a low-impact bioremediation approach. Water Air Soil Pollut 223:1773–1782. doi:10.1007/s11270-011-0982-7
76. Van Deuren, J., Lloyd, T., Chhetry, S., Raycharn, L., Peck, J., (2002). Remediation Technologies ScreeningMatrix and Reference Guide, *Federal Remediation Technologies Roundtable*, 4.
77. Vidali, M. Bioremediation. (2001). An overview. Pure Appl. Chem. 73 (7), 1163–1172
78. Volesky, B., Holan, Z.R. (1995). Biosorption of heavy metals. *Biotechnol. Prog.*, *11*, 235–250

79. Whelan, M.J., Coulon, F., Hince, G., Rayner, J., McWatters, R., Spedding T., Snape, I. (2015). Fate and transport of petroleum hydrocarbons in engineered biopiles in polar regions. Chemosphere 131:232–240. doi:10.1016/j.chemosphere.2014.10.088
80. Yoshizawa, S., Tanaka, M., & Shekdar, A. V. (2004). Global trends in waste generation. In Recycling
81. waste treatment and clean technology. TMS Mineral, Metals and Materials Publishers.
82. Zhou, D., Li, Y., Zhang ,Y., Zhang, C., Li, X., Chen, Z., Huang, J., Li, X., Flores, G., Kamon, M., (2014). Column test-based optimization of the permeable reactive barrier (PRB) technique for remediating groundwater contaminated by landfill leachates. J Contam Hydrol 168:1–16. doi:10.1016/j.jconhyd.2014.09.003
83. Zaidi, S., Usmani. S., Singh, B.R,, Musarrat, J. (2008). Significance of Bacillus subtilis strains SJ-101 as a bioinoculant for concurrent plant growth promotion and nickel accumulation in Brassica Juncea. Chemosphere 64:991–997
84. Zhuang, X.L., Chen, J., Shim, H., Bai, Z. (2007).New advances in plant growth-promoting rhizobacteria for bioremediation. Environ Int 33:406–413 598