Remediation and Reclaimation

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Remediation of a contaminated site

Environmental pollution is a serious problem to the public health. Soil, water and air are main components of the environment where human, animals, plants and microorganisms are the main inhabitants on the earth. Contamination of a site (water and/or soil) with hazardous or toxic materials requires cleaning it to become usable and have no serious impact on the environment. There are a number of terms are associated with this subject.

What is remediation?

Remediation: Cleanup of a site to levels determined to be health-protective for its intended use or public health.

Mitigation: Actions taken to improve site conditions by limiting, reducing or controlling hazards and contamination sources.

Decontamination: The removal hazardous material from a site so as to prevent or minimize any adverse effects on the environment.

Biodegradation: The process of destruction or mineralization of either natural or synthetic materials by the microorganisms of soils, waters, or wastewater treatment systems.

Bioremediation**:** A process that uses microorganisms to change toxic compounds into non-toxic ones.

Vitrification: is the transformation of a substance into a glassy material.

Containment: Enclosing or containing hazardous substances in a structure to prevent the migration of contaminants into the environment.

Remedial Action Plan (RAP): A plan that outlines a specific program leading to the remediation of a contaminated site.

Work plan: The site work plan describes the technical activities to be conducted during the various phases of a remediation project.

Monitoring wells: are specially-constructed wells used exclusively for testing water quality.

Hazardous waste: Waste substances which can pose a substantial or potential hazard to human health or the environment when improperly managed.

Dichlorobenzene (DCB): A volatile organic compound often used as a deodorizer, and as a moth, mold and mildew killer. It is a white solid with a strong odor of mothballs. It is toxic and cancer-causing agent.

Dioxins: A group of toxic organic compounds that may be formed as a result of incomplete combustion. They are rapidly absorbed through the skin and gastrointestinal tract and are listed as cancer-causing chemicals

Polychlorinated biphenyls (PCBs): A group of toxic chemicals used for a variety of purposes including electrical applications (transformers), carbonless copy paper, adhesives, hydraulic fluids, and caulking compounds. It is considered as carcinogenic chemical.

Polyvinyl chloride (PVC): A plastic made from the gaseous chemical vinyl chloride. PVC is used to make pipes, records, raincoats and floor tiles. It produces hydrochloric acid when burned. Health risks from high concentrations of vinyl chloride include liver cancer and lung cancer, as well as cancer of the lymphatic and nervous systems.

Tetrachloroethylene (TCE): Volatile organic compound that is commonly used as an industrial degreasing solvent. TCE affects the central nervous system and is listed as a cancer-causing chemical.

Aeration (soil): The process by which air in the soil is replaced by air from the atmosphere.

Reasons for Remediation:

1. Keeping environment clean and healthy

2. Removing sources of contamination to other sites.

3. Changing the contaminated site from harmful into usable site

a- Land development (residential, commercial, industrial)

b- Using the site for agricultural production

c- Maintaining historical and archeological sites

d. Creating recreational, social and educational centres

4. Adding value to the site after remediation

5. Maintaining the biodiversity

Types of Pollutants:

There are several types of pollution, and while they may come from different sources and have different consequences, understanding the basics about pollution can help environmentally conscious individuals minimize their contribution to these dangers. In total, there are nine recognized sources of pollution in the modern world. These sources of pollution don't simply have a negative impact on the natural world, but they can have a measurable effect on the health of human beings as well.

Air Pollution

Air pollution is defined as any contamination of the atmosphere that disturbs the natural composition and chemistry of the air. This can be in the form of particulate matter such as dust or excessive gases like carbon dioxide or other vapors that cannot be effectively removed through natural cycles, such as the carbon cycle or the nitrogen cycle.

Air pollution comes from a wide variety of sources. Some of the most excessive sources include:

- Vehicle or manufacturing exhaust

- Forest fires, volcanic eruptions, dry soil erosion, and other natural sources
- Building construction or demolition

Depending on the concentration of air pollutants, several effects can be noticed. Smog increases, higher rain acidity, crop depletion from inadequate oxygen, and higher rates of asthma. Many scientists believe that global warming is also related to increased air pollution.

Water Pollution

Water pollution involves any contaminated water, whether from chemical, particulate, or bacterial matter that degrades the water's quality and purity. Water pollution can occur in oceans, rivers, lakes, and underground reservoirs, and as different water sources flow together the pollution can spread.

Causes of water pollution include:

- Increased sediment from soil erosion
- Improper waste disposal and littering
- Leaching of soil pollution into water supplies
- Organic material decay in water supplies

Impact: The effects of water pollution include decreasing the quantity of drinkable water available, lowering water supplies for crop irrigation, and impacting fish and wildlife populations that require water of a certain purity for survival.

Soil Pollution

Soil, or land pollution, is contamination of the soil that prevents natural growth and balance in the land whether it is used for cultivation, habitation, or a wildlife preserve. Some soil pollution, such as the creation of landfills, is deliberate, while much more is accidental and can have widespread effects.

Soil pollution sources include:

- Hazardous waste and sewage spills
- Non-sustainable farming practices, such as the heavy use of inorganic pesticides
- Strip mining, deforestation, and other destructive practices
- Household dumping and littering

Impact: Soil contamination can lead to poor growth and reduced crop yields, loss of wildlife habitat, water and visual pollution, soil erosion, and desertification.

Noise Pollution

Noise pollution refers to undesirable levels of noises caused by human activity that disrupt the standard of living in the affected area. Noise pollution can come from:

- Traffic (cars)
- Airports (aiplanes)
- Railroads
- Manufacturing plants
- Construction or demolition
- Concerts
- Electrical generators

Impact: Some noise pollution may be temporary while other sources are more permanent. Effects may include:

- hearing loss,
- wildlife disturbances, and a
- general degradation of lifestyle.

Radioactive Pollution

Although Radioactive pollution is rare but extremely detrimental, and even deadly, when it occurs. Because of its intensity and the difficulty of reversing damage, there are strict government regulations to control radioactive pollution.

Sources of radioactive contamination include:

- Nuclear power plant accidents or leakage
- Improper nuclear waste disposal
- Uranium mining operations

Impact: Radiation pollution can cause birth defects, cancer, sterilization, and other health problems for human and wildlife populations. It can also sterilize the soil and contribute to water and air pollution.

Thermal Pollution

Thermal pollution is excess heat that creates undesirable effects over long periods of time. The earth has a natural thermal cycle, but excessive temperature increases can be considered a rare type of pollution with long term effects. Many types of thermal pollution are confined to areas near their source, but multiple sources can have wider impacts over a greater geographic area.

Thermal pollution may be caused by:

- Power plants
- Urban sprawl
- Air pollution particulates that trap heat
- Deforestation
- Loss of temperature moderating water supplies

Impact: As temperatures increase, mild climatic changes may be observed, and wildlife populations may be unable to recover from swift changes.

Light Pollution

Light pollution is the over illumination of an area that is considered obtrusive. Sources include:

- Billboards and advertising
- Nighttime sporting events and other nighttime entertainment

Impact: Light pollution makes it impossible to see stars, therefore interfering with astronomical observation and personal enjoyment. If it is near residential areas, light pollution can also degrade the quality of life for residents.

Visual Pollution

Visual pollution - eyesores - can be caused by other pollution or just by undesirable, unattractive views. It may lower the quality of life in certain areas, or could impact property values and personal enjoyment.

Sources of visual pollution include:

- Power lines
- Construction areas
- Billboards and advertising

- Neglected areas or objects such as polluted vacant fields or abandoned buildings

Impact: While visual pollution has few immediate health or environmental effects, what's causing the eyesore can have detrimental affects.

Personal Pollution

Smoking is personal pollution.

Personal pollution is the contamination of one's body and lifestyle with detrimental actions. This may include:

- Excessive smoking, drinking or drug abuse
- Emotional or physical abuse
- Poor living conditions and habits
- Poor personal attitudes

Impact: In some cases, personal pollution may be inflicted by caregivers, while in other cases it is caused by voluntary actions. Taking positive steps in your life can help eliminate this and other sources of pollution so you can lead a more productive, satisfying life.

Fighting Pollution

All types of pollution are interconnected. For example, light pollution requires energy to be made, which means the electric plant needs to burn more fossil fuels to supply the electricity. Those fossil fuels contribute to air pollution, which returns to the earth as acid rain and increases water pollution. The cycle of pollution can go on indefinitely, but once you understand the different pollution types, how they are created, and the effects they can have, you can make personal lifestyle changes to combat poor conditions for yourself and others around you.

Grouping of Remediation Methods Based on Environment and Technologies:

Number of remediation methods and technologies: **371**

Environment: 68 % soil, **32 % water**

Technologies:

39 % biological

21 % physical

21 % thermal

19 % chemical

Differences between In-Situ and Ex-Situ Remediation:

All methods of remediation can be carried out with respect to the contaminated sites in two methods:

1. In Situ: A method of treating contaminated soils, sludges and waters "in place" in a manner that does not require the contaminated material to be physically removed or excavated from where it originates)
2. Ex Situ: A method of treatment and/or disposal for contaminated soils, sludges, and waters (generated as a result of decontamination activities) once they have been physically removed or excavated from where they originate to another place.

General Remediation Methods:

1. Physical Methods:

2. Chemical Methods

3. Biological methods

4. Physico-Chemical methods

Physical Methods:

The methods which do not change the phsico-chemical properties of the pollutants accumulated in the soil to be cleaned.

The advantages

- The possibility of removal or disposal of a broad spectrum of pollutants

The disadvantages:

- They produce a considerable amount of wastes that need future management or utilization

- The management may need high costs in case of large scale pollution.

Types of conducting Physical Methods:

1. Ex-situ: the methods require the transportation of polluted soil to the place of cleaning:

    a. Mechanical separation

    b. Extraction and storage

2. In-situ: the methods which is applied on-site without removal of the soil from polluted site.

This is can be achieved in the following physical methods or technologies:

a. Electrokinetic cleaning methods

b. Cofferdam system

c. Soil covering

d. Fracturing, In Situ

e. Soil Flushing, In Situ

f. Soil Vapor Extraction, In Situ

g. Solidification/Stabilization, In Situ

Ex-situ techniques:

A. Mechanical separation

The mechanical separation of soil is a physico-chemical process in which the contaminated parts of soil are separated. This process leads to a decrease in volume of contaminated soil.

The techniques most often used for separation are: gravitational separation (based on differences in density between fractions) or in cyclones (based on the Coriolis effect), sieve analysis (different grain size of elements) or magnetic separation (based on magnetic induction). The separated fraction containing the pollutants must be cleaned up or neutralized in another process.

Method’s advantages:

- Significant volume reduction of contaminated soil.

- For many years, this technique has been applied in municipal waste management.

Method’s disadvantages:

- This technique could not be applied in the case of homogenous distribution of pollutants in soil. In that case, there is not a satisfactory decrease in volume.

- This method is not effective for some soils types.

- The separated part of the contaminated soil must be cleaned up using another method.

B. Extraction and storage

This method is the simple extraction of contaminated soil cover, using a digger or bulldozer, and its storage in an appropriate place for further clean-up using another method (e.g. biodegradation, vitrification or other). The storage site has to be sheltered to prevent wind and water erosion.

Method's advantages:

- Short time of excavation of contaminated soil (even one day)

- Does not require highly specialist equipment

- Could be applied in the case of emergency, when other methods are not effective or are too costly.

Method's disadvantages: - Using a simple digger and bulldozer, the excavation is only possible up to a depth of 3 m.

- Not applicable in the case of small, local polluted sites because of high expenses.

In situ Physical Methods:

The Electrokinetic Remediation

The Electrokinetic Remediation (ER) process removes metals and organic contaminants from low permeability soil, mud, sludge, and marine dredging.

- ER uses electrochemical and electrokinetic processes to desorb, and then remove, metals and polar organics.

- This in situ soil processing technology is primarily a separation and removal technique for extracting contaminants from soils.

Advantages:

- This is the only method for in-situ removal of heavy metals from contaminated site.
- It is applicable to different metals.

Disadvantages:

- Its efficiency depends on many features which determines the results
- Any heterogeneity of the soil body decreases accuracy of the results
- Acidification of the remediated soil is a side effect of this method

Applicability for pollutants: heavy metals, anions, and polar organics in soil, mud, sledge, and marine dredging

Duration: Short to medium-term technology. Cleanup ranges from a few weeks to several months.

Coffedram System

In this system, barriers are used which made from different materials placed under soil surface.

The main role of the barriers is protection against spreading of dangerous or toxic substances from the contaminated site.

The main types of barrier construction are:

1. Semi-permeable barriers
2. Non-permeable vertical barriers
3. Non-permeable horizontal barriers
4. Barriers based on redox process (using Fe, FeS, $FeCO_3$)
5. Precipitation barriers using $Ca(OH)_2$ or $CaCO_3$ or $CaPO_4$
6. Biological barriers
7. Sorption barriers

Method's advantages:

- This system of barriers is applicable to every kind of contamination.
- Fast results

Method's disadvantages:

- Non-permeable barriers require continuous monitoring
- Any damage to the barrier decrease the efficiency
- Attention must be given to the underground water flow direction

Soil covering (surface insulation) In Situ:

- Operation of this physical method is based on covering the contaminated soil surface to prevent toxic migration to the environment as a result of rain water or wind erosion.
- The covering layers are made of combined material such as synthetic fiber, clay and concrete.
- Construction of the cover consists of four layers:
    1. Protective layer with growing plants to prevent erosion of the surface cover.
    2. Drainage layer to drain rainfall water percolating through the surface layer
    3. Non-permeable barrier to protect the contaminated area against contact with precipitation water.
    4. Base-layer, made from selected mineral materials with a suitable grain size and mechanical parameters.

Fracturing, In Situ

Cracks are developed by fracturing beneath the surface in low permeability and over-consolidated sediments to open new passageways that increase the effectiveness of many in situ processes and enhance extraction efficiencies.

Applicability: Fracturing is applicable to the complete range of contaminant groups with no particular target group. The technology is used primarily to fracture silts, clays, shale, and bedrock.

Duration: Normal operation employs a two-person crew, making 15 to 25 fractures per day with a fracture radius of 4 to 6 meters to a depth of 15 to 30 meters. For longer remediation programs, refracturing efforts may be required at 6- to 12-month intervals.

Soil Flushing, In Situ

- Water, or water containing an additive to enhance contaminant solubility, is applied to the soil or injected into the ground water to raise the water table into the contaminated soil zone.

- Contaminants are leached into the ground water, which is then extracted and treated.

Applicability: used with pollutants such as inorganics including radioactive contaminants. The technology can be used to treat VOCs, SVOCs, fuels, and pesticides.

Duration: Short to medium-term technology. Cleanup ranges from a few weeks to several months.

Soil Vapor Extraction, In Situ

- Vacuum is applied through extraction wells to create a pressure/concentration gradient that induces gas-phase volatiles to be removed from soil through extraction wells.

- This technology also is known as in situ soil venting, in situ volatilization, enhanced volatilization, or soil vacuum extraction.

Applicability for pollutants: The target contaminant groups for in situ SVE are VOCs and some fuels

Duration: The duration of operation and maintenance for in situ SVE is typically medium- to long-term.

Solidification/Stabilization, In Situ

Contaminants are physically bound or enclosed within a stabilized mass (solidification), or chemical reactions are induced between the stabilizing agent and contaminants to reduce their mobility (stabilization).

Applicability for pollutants: The target contaminant group for in situ S/S is generally inorganics (including radionuclides).

Duration: The timeframe for in situ S/S is short- to medium-term, while in situ ISV process is typically short-term.

Chemical Methods:

These methods are conducted to degrade the contaminant(s) accumulated in the soil to make changes in the physic-chemical properties to reduce their environmental hazard.

Chemical methods are developed according to the following chemical processes:

1. Oxidation and reduction
2. Extraction
3. Precipitation of sparingly soluble chemical compounds
4. pH stabilization

The main advantages of these methods are:

- The broad spectrum of applicability.

- High efficiency

- High specifity for individual contaminant

The disadvantages are:

- Usually high costs of application

- Production of a large amount of wastes including hazardous wastes

- Problems of process control especially in situ techniques

A. Chemical Extraction, Ex Situ

- Oxidation chemically converts hazardous contaminants to non-hazardous or less toxic compounds that are more stable, less mobile, and/or inert.

- The oxidizing agents most commonly used are ozone, hydrogen peroxide,hypochlorites, chlorine, and chlorine dioxide.

- The method includes waste contaminated soil and solvent (extractant) are mixed in an extractor, thereby dissolving the contaminants.

The extracted solution is then placed in a separator, where the contaminants and solvent are separated for treatment and further use.

Two main types of extraction are:

1. **Acid Extraction and**
2. **Solvent Extraction**

Applicability for pollutants: primarily organic contaminants such as PCBs, VOCs, halogenated solvents (Fluorine, chlorine, bromine, iodine), and petroleum wastes.

Duration: The duration of operations and maintenance for chemical extraction is medium-term.

B. Chemical Reduction/Oxidation, Ex Situ

Reduction/oxidation chemically converts hazardous contaminants to non-hazardous or less toxic compounds that are more stable, less mobile, and/or inert.

The oxidizing agents most commonly used are ozone, hydrogen peroxide, hypochlorites, chlorine, and chlorine dioxide.

Applicability for pollutants: Mainly for inorganics, but also effect against nonhalogenated VOCs and SVOCs, fuel hydrocarbons, and pesticides.

Duration: a short- to medium-term technology.

B. Chemical Oxidation, In Situ

- Oxidation chemically converts hazardous contaminants to non-hazardous or less toxic compounds that are more stable, less mobile, and/or inert.

- The oxidizing agents most commonly used are ozone, hydrogen peroxide, hypochlorites, chlorine, and chlorine dioxide.

- Applicability for pollutants: many toxic organic chemicals, unsaturated aliphatic (e.g., trichloroethylene,TCE) and aromatic compounds (e.g., benzene)

Duration: Medium to long-term technology. Cleanup ranges from a few months to several years.

C. Dehalogenation, Ex Situ

Reagents like H2CO3 are added to soils contaminated with halogenated organics.

The dehalogenation process is achieved by:

a. Either the replacement of the halogen molecules or
b. The decomposition and partial volatilization of the contaminants.

Applicability for pollutants: halogenated SVOCs and pesticides

Duration: a short- to medium-term process.

D. Chemical Oxidation, In Situ

Oxidation chemically converts hazardous contaminants to non-hazardous or less toxic compounds that are more stable, less mobile, and/or inert.

The oxidizing agents most commonly used are ozone, hydrogen peroxide, hypochlorites, chlorine, and chlorine dioxide.

Applicability for pollutants: many toxic organic chemicals, unsaturated aliphatic (e.g., trichloroethylene,TCE) and aromatic compounds (e.g., benzene)

Duration: Medium to long-term technology. Cleanup ranges from a few months to several years.

Physical-Chemical Methods

- Separation Ex Situ

- Soil Washing Ex Situ
- Solidification/Stabilization Ex Situ

Separation Ex Situ

Separation techniques concentrate contaminated soil through physical and chemical means.

These processes seek to detach contaminants from their medium (i.e., the soil, sand, and/or binding material that contains them).

Applicability for pollutants: SVOCs, fuels, and inorganics (including radionuclides)

Duration: a short-term process

Soil Washing Ex Situ

Contaminants adsorbed onto fine soil particles are separated from bulk soil in an aqueous-based system on the basis of particle size.

The wash water may be augmented with a basic leaching agent, surfactant, pH adjustment, or chelating agent to help remove organics and heavy metals.

Applicability for pollutants: SVOCs, fuels, and heavy metals

Duration: typically short- to medium-term

Solidification/Stabilization Ex Situ

Contaminants are physically bound or enclosed within a stabilized mass (solidification), or chemical reactions are induced between the stabilizing agent and contaminants to reduce their mobility (stabilization).

Applicability for pollutants: The target contaminant group for ex situ S/S is inorganics, including radionuclides

Duration: Typical ex situ Solid/Stabilization is a short- to medium-term technology

Heat/Thermal Treatments Methods:

These treatment methods applied with Soil, Sediment, Bedrock and Sludge. It includes the following technologies:

- **Thermal Treatment, In Situ**
- **Hot Gas Decontamination, Ex Situ**
- **Incineration, Ex Situ**
- **Pyrolysis, Ex Situ**
- **Thermal Desorption, Ex Situ**

Thermal Treatment In Situe

Steam/hot air injection or electrical resistance/electromagnetic/fiber optic/radio frequency heating is used to increase the volatilization rate of semi-volatiles and facilitate extraction.

Applicability for pollutants: SVOCs and VOCs

Duration: Thermally enhanced SVE is normally a short- to medium-term technology.

Hot Gas Decontamination Ex Situ

The process involves raising the temperature of the contaminated equipment or material for a specified period of time.

The gas effluent from the material is treated in an afterburner system to destroy all volatilized contaminants.

Applicability for pollutants: explosive items, such as mines and shells, being demilitarized (after removal of explosives) or scrap material contaminated with explosives.

Duration: a short-term technology

Incineration:

High temperatures, 870-1,200 °C, are used to combust (in the presence of oxygen) organic constituents in hazardous wastes.

Different types of combustion processes such as:

- Circulating Bed Combustor (CBC)
- Fluidized Bed
- Infrared Combustion
- Rotary Kilns

Applicability for pollutants: explosives and hazardous wastes, particularly chlorinated hydrocarbons, PCBs, and dioxins.

Duration: incineration technology ranges from short- to long-term

Pyrolysis, Ex Situ

Chemical decomposition is induced in organic materials by heat in the absence of oxygen.

Organic materials are transformed into gaseous components and a solid residue (coke) containing fixed carbon and ash.

Applicability for pollutants: SVOCs and pesticides

Duration: incineration technology ranges from short- to long-term

Thermal Desorption Ex Situ

Wastes are heated to volatilize water and organic contaminants.

A carrier gas or vacuum system transports volatilized water and organics to the gas treatment system.

- High Temperature Thermal Desorption (HTTD)

  320 – 560 °C

- Low Temperature Thermal Desorption (LTTD)

  90 – 320 °C

Applicability for pollutants: SVOCs, PAHs, PCBs, and pesticides

Duration: short-term technology

Water Remediation Treatment

1. Physical Treatment Methods
2. Physical-Chemical Treatment Methods

Physical Treatment

1. Monitored Natural Attenuation In Situ
2. Constructed Wetland, Ex Situ

Monitored Natural Attenuation, In Situ

Natural subsurface processes—such as dilution, volatilization, biodegradation, adsorption, and chemical reactions with subsurface materials—are allowed to reduce contaminant concentrations to acceptable levels.

Applicability for pollutants: VOCs and SVOCs and fuel hydrocarbons, maybe also halogenated VOCs

Duration: long-term technologies, which may take several years

Constructed Wetland, Ex Situ

- The constructed wetlands-based treatment technology uses natural geochemical and biological processes inherent in an artificial wetland ecosystem to accumulate and remove metals, explosives, and other contaminants from influent waters.

This method can be used as a filtration or degradation process.

Applicability for pollutants: organic matter; nutrients, such as nitrogen and phosphorus; and suspended sediments

Duration: This treatment is a long-term technology intended to operate continuously for years.

Physical-Chemical Treatment Methods:

This method can be used with the Ground Water, Surface Water, and Leachate using the following types of treatments:

1. Air Sparging, In Situ
2. Bioslurping, In Situ
3. Chemical Oxidation, In Situ
4. Directional Wells, In Situ
5. Dual Phase Extraction, In Situ
6. Thermal Treatment, In Situ
7. Hydrofracturing, In Situ
8. In-Well Air Stripping, In Situ
9. Passive/Reactive Treatment Walls, In Situ
10. Containment

Air Sparging, In Situ

Air is injected into saturated matrices to remove contaminants through volatilization.

Applicability for pollutants: VOCs and fuels

Duration: a medium to long duration which may last, generally, up to a few years

Bioslurping, In Situ

Deep well injection is a liquid waste disposal technology.

This alternative method uses injection wells to place treated or untreated liquid waste into geologic formations that have no potential to allow migration of contaminants into potential potable water aquifers.

Applicability for pollutants: VOCs, SVOCs, fuels, explosives, and pesticides

Duration: no data

Chemical Oxidation, In Situ
Oxidation chemically converts hazardous contaminants to non-hazardous or less toxic compounds that are more stable, less mobile, and/or inert.

The oxidizing agents most commonly used are ozone, hydrogen peroxide, hypochlorites, chlorine, and chlorine dioxide.

Applicability for pollutants: many toxic organic chemicals, unsaturated aliphatic (e.g., trichloroethylene,TCE) and aromatic compounds (e.g., benzene)

Duration: Medium to long-term technology. Cleanup ranges from a few months to several years.

Directional Wells, In Situ
Drilling techniques are used to position wells horizontally, or at an angle, to reach contaminants not accessible by direct vertical drilling.

Directional drilling may be used to enhance other in-situ or in-well technologies such as ground water pumping, bioventing, SVE, soil flushing, and in-well air stripping.

Applicability for pollutants: no particular target group

Duration: no data

Dual Phase Extraction, In Situ
A high vacuum system is applied to simultaneously remove various combinations of contaminated ground water, separate-phase petroleum product, and hydrocarbon vapor from the subsurface.

Applicability for pollutants: VOCs and fuels (e.g., LNAPLs)

Duration: Medium to long-term technology.

Thermal Treatment, In Situ

Steam is forced into an aquifer through injection wells to vaporize volatile and semi-volatile contaminants.

Vaporized components rise to the unsaturated zone where they are removed by vacuum extraction and then treated.

Applicability for pollutants: SVOCs and fuels

Duration: typically short to medium duration

Hydrofracturing, In Situ

Injection of pressurized water through wells cracks low permeability and over-consolidated sediments.

Cracks are filled with porous media that serve as substrates for bioremediation or to improve pumping efficiency.

Applicability for pollutants: several contaminants with no particular group.

Duration: no data.

In-Well Air Stripping, In Situ

Air is injected into a double screened well, lifting the water in the well and forcing it out the upper screen.

Simultaneously, additional water is drawn in the lower screen.

Once in the well, some of the VOCs in the contaminated ground water are transferred from the dissolved phase to the vapor phase by air bubbles.

The contaminated air rises in the well to the water surface where vapors are drawn off and treated by a soil vapor extraction system.

Applicability for pollutants: halogenated VOCs, SVOCs, and fuels

Duration: no data.

Passive/Reactive Treatment Walls, In Situ

These walls (barriers) allow the passage of water while causing the degradation or removal of contaminants.

Different types of walls:

- Funnel and Gate
- Iron Treatment Wall

Applicability for pollutants: VOCs, SVOCs, and inorganics

Duration: generally intended for long-term operation to control migration of contaminants in ground water.

Containment:

In this method, contaminants are restricted in limited area to avoid movement to another clean area using one of the following methods:

1. Physical Barriers
2. Deep Well Injection

Physical Barriers:

These subsurface barriers consist of vertically excavated trenches filled with slurry.

The slurry, usually a mixture of bentonite and water, hydraulically shores the trench to prevent collapse and retards ground water flow.

Applicability for pollutants: Slurry walls contain the ground water itself, thus treating no particular target group of contaminants

Duration: no data

Deep Well Injection

Deep well injection is a liquid waste disposal technology.

This alternative uses injection wells to place treated or untreated liquid waste into geologic formations that have no potential to allow migration of contaminants into potential potable water aquifers.

Applicability for pollutants: VOCs, SVOCs, fuels, explosives, and pesticides

Duration: no data

Biological Methods:

These methods are based on the biological activity of microorganisms and higher plants. These have the ability to degrade pollutants accumulated in the soil, including their mineralization and immobilization or removal of them.

What is bioremediation?

Bioremediation is defined as the process whereby organic wastes are biologically degraded under controlled conditions to an innocuous (not harmful) state, or to levels below concentration limits established by regulatory authorities.

It uses naturally occurring microorganisms like bacteria and fungi or plants to degrade or detoxify substances hazardous to human health and/or the environment.

History of Bioremediation

1. •~1900 Advent of biological processes to treat organics derived from human or animal wastes
2. •~1950 Approaches to extend wastewater treatment to industrial wastes
3. •~1960 Investigations into the bioremediation of synthetic chemicals in wastewaters

4. •~1970 Application in hydrocarbon contamination such as oil spills and petroleum in groundwater (more pollution than the natural microbial processes could degrade the pollutants)
5. •~1980 Investigations of bioremediation applications for substituted organics
6. Natural Attenuation (slow process, not complete enough, not frequently occurring enough to be broadly used for some compounds, especially very difficult or recalcitrant substances)
   •~1990 Natural Attenuation of ’70 and ’90
7. •~2000 Development of *in situ bioremediation; source zone reduction; bioaugmentation*
8. •~2003 Genomics era of Bioremediation (Cleaning up with genomics

Fundamentals of biodegradation reactions

1. Aerobic bioremediation

•Microbes use O2in their metabolism to degrade contaminants

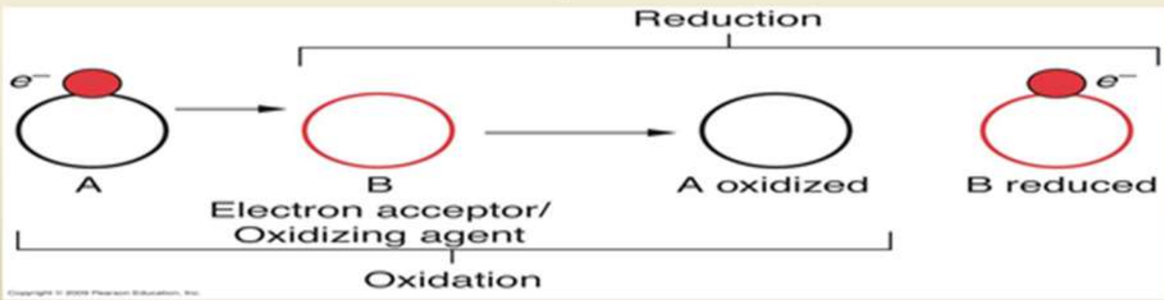
2. Anaerobic bioremediation

•Microbes substitute another chemical for O2 to degrade contaminants

•Nitrate, iron, sulfate, carbon dioxide, uranium, technicium, perchlorate

3.Cometabolic bioremediation

microbes do not gain energy or carbon from degrading a contaminant. Instead, the contaminant is degraded via a side Reaction



Bioremediation involves the production of energy in a redox reaction within microbial cells: an energy source (electron donor), an electron acceptor, and nutrients

What is a redox reaction?

- Redox – reduction + oxidation
- Both processes occur simultaneously
- Hence, one species is oxidised, another is reduced
- So, what is oxidation, and what is reduction?
- 3 different versions of the definition:

Redox

Oxidation	Reduction
gain in oxygen	loss of oxygen
loss of hydrogen	gain in hydrogen
loss of electrons	gain of electrons

Basic Requirements for Bioremediation:

There are three basic requirements or agents required in the bioremediation process which is called triple-corner process:

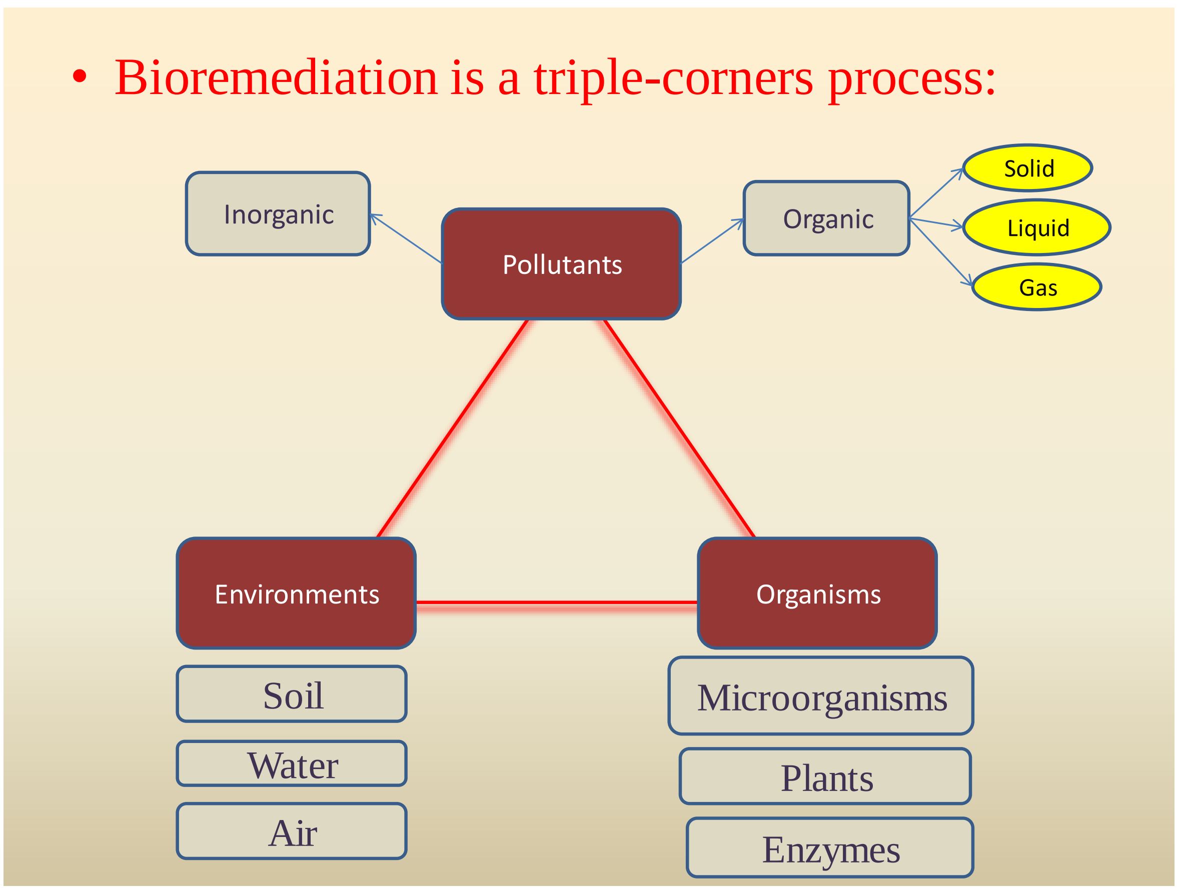
1. Pollutant(s):
   a. Inorganic
      - Heavy metals
      - Attached groups (such as Halogens).
   b. Organic:
      - Solid
      - Liquid
      - Gas

2. Environment components:

    - Soil
    - Water
    - Air

3. Organisms:

    - Prokaryotes: Microorganisms bacteria
    - Eukaryotes: Plant and Fungi



There are two types of biological remediation or reclamation methods:

1. Bioremediation (microbial-remediation) methods: the methods are based on microorganisms activity commonly used for the

reclamation of soil polluted by organic compound and may be used to degrade inorganic materials like metals.

2. Phytoremediation methods: the methods are based on using higher organisms or plants for degradation and removal of different contaminants (both organic and inorganic) from the contaminated soil. The most known phytoremediation methods are:
    a. Phytostabilization.
    b. Phytoextraction/degradation

The advantages of biological methods for soil remediation or reclamation are:

- Wide range of applications
- High efficiency but at limited concentration ranges of contaminant (tolerance to the organisms)
- Cost-efficiency and simplicity during the initiation and processing.

The disadvantages or limitations are:

- Dependency of process efficiency on bioavailability and contents of removing contaminants.
- Longer time required to get the remediation results.
- Sometimes, production of highly toxic wastes.

<u>Ex situ Biological Methods:</u>

Composting: degradation of organic and nonhalogenic and some halogenic contaminated soil by aerobic organisms to mineralize organic compounds to simple compounds such as CO2, H2O and others.

Advantages and disadvantages are described p.11 of (Safemanmin)

- Simple and cheap method
- Some of groups of contaminants can be totally removed
- High level of community acceptance

Methods disadvantages:

- Not applicable for some organic or inorganic pollutants
- Not effective for strongly contaminated soils
- A considerable large area for storage area is required
- Relatively long-lasting process
- Necessity for effluents (liquid wastes) collection and control

Biological Filter and bioreactor: see page 12 of (Safemanmin)

These methods are based on the biological activity of microorganisms.

The stages for this method include the following processes:

- First stage: the contaminated soil is mixed with water to make suspension
- Second stage: after moving the suspension in a reaction chamber microorganisms are added to biodegrade the contaminants by sorption or transformation process.
- Third stage: the remediated soil is completely functional after drying.

Method's advantages:

- Effective and relatively fast remediation technique
- Useful for the removal of both organic and inorganic contaminants
- Wide range of applicability
- Soil retains its properties
- High level of community acceptance

Method's disadvantages:

- Construction of a special installation is required.
- Large amounts of wastes (solid and liquids) are generated.
- Efficiency strongly depends on soil properties
- Relatively high costs

<u>In Situ Biological methods:</u>

Bioremediation: see page 13 of (Safemanmin):

This method is based on the physiological activity of microorganisms to clean up onsite soil contaminated by organic compounds.

There is a particular kind of bioremediation is called biodegradation or rhizodegradation in the rhizosphere (the zone that surrounds the roots), where the roots colonized by the microorganisms ‘ zone of higher plants to increase the efficiency of the remediation process.

Method’s advantages:

- It is simple to apply and no equipment are required
- Low cost method
- Almost non-invasive to the environment
- High efficiency with organic pollutants
- High level of community acceptance

Method’s disadvantages:

- Not applicable for highly contaminated soil
- Method’s efficiency is highly dependent on weather conditions
- It depends on access to feed substances (macro and microelements)

Phytostabilization:

This method is based on the ability of roots to immobilize pollutants.

The process takes place on the root surface due to adsorption effect where contaminants are absorbed into roots and precipitated in the root area.

Before application of this method, the soil needs special chemical treatment using compounds causing pollutant stabilization. Only soil prepared in such way could be grown by stabilizing plants.

Method’s advantages:

- Low cost method

- Positive effect on the environment
- It has no side effect

Method's disadvantages:

- Contaminants are not removed from the soil but only immobilized
- Plants and soil require long term monitoring
- The applied plants require intensive fertilization
- The applied plants species could pick up minimal amounts of metals and transport them overground parts.

Table: Most frequently used additives in the phytostabilization of heavy metals

Kind of additives	**Heavy metal stabilized**
Phosphate compounds	Pb
Hydrated Iron	As, Cd, Cu, Ni, Pb, Zn
Organic matter	As, Cd, Cu, Pb
Clay mineral	As, Cd, Cu, Mn, Ni, Pb, Zn

Plant species most suitable for metal stabilization:

- Poplar trees are useful for arsenic stabilization and it tolerates Arsenic (As) concentration in the soil up to 1250 mg/kg and Cd concentration up to 160 mg/kg
- Mustard plants can reduce Cr^{6+} and Cr^{3}-
- Some grasses can be used to minimize contamination with Cu, Pb and Zn

Phytoextraction:

This method is based on picking up the contaminants by the roots of plants and transported to their over ground parts and then removed together with the crops.

There are 2 types of phytoextraction method:

1. Continuous phytoextraction using hyperaccumulators (plants with high ability to accumulate metals in shoots with a few % of dry mass.)
2. Induced phytoextraction used in the case of non-hyper accumulators when special substances are inserted into the soil to increase their accumulation properties.

This method affected by the following factors:

- Soil pH
- Oxidize-reduction conditions
- Microbiological activity

Method's advantages

- Relatively low costs
- It is friendly to the environment
- Low technical equipment requirements
- High level of community acceptance

Method's disadvantages

- Contaminated biomass must be cleaned with proper management
- It is difficult to conduct in soil heavily contaminated with heavy metal
- There is a risk of animal bringing contaminants into the food chain.

Plant Cover:

This is a long term method based on self-standing systems of cultivated plants that are introduced to the danger surface area.

Plant cover can reduce the danger to an acceptable level and requires minimum conservation.

There are two types of plant cover:

1. Evapotranspiration cover: the plant cover which has enough thickness consisting of plants growing in the soil. This method applied to reduce the evaporation and transpiration processes of plants and the infiltration of water.
2. Phytoremediation cover: this is consisting of soil and plant. This method applied to:
   a. Decrease the water infiltration
   b. Assist the process of degradation of the contaminants
   c. Protect the environment

The main functions of plant cover are:

1. Prevention of direct contact of people and animal with the contaminants.
2. Decrease of water percolation (infilteration)
3. Long term functioning without a big conservation effort.
4. Control of effluent (fast stream of water) to decrease soil erosion.
5. Prevention of the contaminants migration
6. Prevention of releasing large amount of gases in the environment

Method advantages:

- Prevention and minimizing of surface erosion
- Low cost method
- Plants can stimulate the activity of O2 microorganisms due to the of the decomposition of toxic fumes.
- Supports the biodegradation of contaminants in the soil.

Method disadvantages

- Necessity for long term monitoring and maintenance of plant cover
- Surface waters can infiltrate deeper horizons of the soil due to decomposed roots.
- Contaminants can be passed into the food chain through plants.
- The majority of this type of cover is effective only in specific conditions.

Other innovative methods and technologies:

- Lasagna process: is a physic-chemical process based on electroosmosis phenomenon.

Ddescription, Figure 6, advantages and disadvantages are on page 18

- Stabilization of contaminant based on using polymer of microbial origin. Details on page 18 of (Safemanmin)
- Virtification: is a physico-chemical method, in which soil material is smeltedon.

Biodegradation of Aromatics:

Several microbes are now well recognized as aromatic degrading organism. Sometime they acts individually or acts together called consortium. A wide variety of bacteria and fungi can carry out aromatic transformation, both partial and complete, under a variety of environmental conditions. The bacteria Pseudomonous putida or fungi like Phanesochaete chrysosporium are well known for arotic compound biotransformation reactions. Under aerobic conditions the most common initial transformation is a hydroxylation that involves the incorporation of molecular oxygen. The enzymes involved in these initial transformations are either monooxygenases or dioxygenases.

Fundamentals of Biodegradation reactions:

According to the following diagram, there are reactions with details in the next diagram:

1. Aerobic reaction
2. Anaerobic reaction
3. Cometabolic reaction

Limitations to biodegradation

• Adequate bacterial concentrations (although populations

generally increase if there is food present)

• Electron acceptors

• Nutrients (e.g., nitrogen and phosphorus)

• Non-toxic conditions (NAPL pools are likely to be toxic)

• Minimum carbon source (which may exceed regulatory

limits for toxic chemicals)

Reference:

Safemanmin: Description of soil reclamation and remediation methods, D3: pages 1-19