Treatment Methods for Contaminated Soils - Translating Science into Practice

[1]Rebecca George, [2]Varsha Joy, [3]Aiswarya S, [4]Priya A Jacob
[1,2,3,4]Karunya University, Coimbatore, Tamil Nadu, India

Abstract
With the rise of concrete buildings and roads, one part of the Earth that we rarely see is the soil. The plants that feed us grow in soil and keeping it healthy is essential for maintaining a beautiful planet. However, like all other forms of nature, soil also suffers from pollution. The pollution of soil is a common thing these days, and it happens due to the presence of man made elements. The main reason why the soil becomes contaminated is due to the presence of man made waste. The waste produced from nature itself such as dead plants, carcasses of animals and rotten fruits and vegetables only adds to the fertility of the soil. However, our waste products are full of chemicals that are not originally found in nature and lead to soil pollution. This paper focuses on the various types of soil pollutions that occur commonly. A detailed discussion is made in this paper about the various treatment methods used for the polluted soil. These treatments include thermal treatment, phytoremediation, soil vapor extraction, biosparging and electric resistance heating works. Case studies of these treatment methods used are also discussed in this paper.

Keywords
Soil Pollution, Soil Treatment,Phytoremediation, Biosparging.

I. Introduction

Soil contamination or soil pollution is caused by the presence of xenobiotic (human-made) chemicals or other alteration in the natural soil environment. It is typically caused by industrial activity, agricultural chemicals, or improper disposal of waste. The most common chemicals involved are petroleum hydrocarbons, polynuclear aromatic hydrocarbons (such as naphthalene and benzo (a)pyrene), solvents, pesticides, lead, and other heavy metals. Contamination is correlated with the degree of industrialization and intensity of chemical usage.

The concern over soil contamination stems primarily from health risks, from direct contact with the contaminated soil, vapors from the contaminants, and from secondary contamination of water supplies within and underlying the soil. Mapping of contaminated soil sites and the resulting cleanup are time consuming and expensive tasks, requiring extensive amounts of geology, hydrology, chemistry, computer modeling skills, and GIS in Environmental Contamination, as well as an appreciation of the history of industrial chemistry.

Soil pollution can be caused by:

- Pesticides, herbicides and fertilizers
- Mining
- Oil and fuel dumping
- Disposal of coal ash
- Leaching from landfills
- Drainage of contaminated surface water into the soil
- Discharging urine and feces in the open
- Electronic waste

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Coal ash - Historical deposition of coal ash used for residential, commercial, and industrial heating, as well as for industrial processes such as ore smelting, were a common source of contamination in areas that were industrialized before about 1960. Coal naturally concentrates lead and zinc during its formation, as well as other heavy metals to a lesser degree. When the coal is burned, most of these metals become concentrated in the ash (the principal exception being mercury). Coal ash and slag may contain sufficient lead to qualify as a “characteristic hazardous waste”, defined in the USA as containing more than 5 mg/L of extractable lead using the TCLP procedure. In addition to lead, coal ash typically contains variable but significant concentrations of polynuclear aromatic hydrocarbons(PAHs).These PAHs are known human carcinogens and the acceptable concentrations of them in soil are typically around 1 mg/kg. Coal ash and slag can be recognized by the presence of off-white grains in soil, gray heterogeneous soil, or (coal slag) bubbly, vesicular pebble-sized grains.

Sewage - Treated sewage sludge, known in the industry as biosolids, has become controversial as a fertilizer to the land. As it is the byproduct of sewage treatment, it generally contains more contaminants such as organisms, pesticides, and heavy metals than other soil.

Pesticides and herbicides - A pesticide is a substance or mixture of substances used to kill a pest. A pesticide may be a chemical substance, biological agent (such as a virus or bacteria), antimicrobial, disinfectant or device used against any pest. Pests include insects, plant pathogens, weeds, mollusks, birds, mammals, fish, nematodes (roundworms) and microbes that compete with humans for food, destroy property, spread or are a vector for disease or cause a nuisance. Although there are benefits to the use of pesticides, there are also drawbacks, such as potential toxicity to humans and other organisms.

Herbicides are used to kill weeds, especially on pavements and railways. They are similar to auxins and most are biodegradable by soil bacteria. However, one group derived from trinitrotoluene(2:4 D and 2:4:5 T) have the impurity dioxin, which is very toxic and causes fatality even in low concentrations.

Another herbicide is Paraquat(dipyridylium).

It is highly toxic but it rapidly degrades in soil due to the action of bacteria and does not kill soil fauna. Insecticides are used to rid farms of pests which damage crops. The insects damage not only standing crops but also stored ones and in the tropics it is reckoned that one third of the total production is lost during food storage. As with fungicides, the first insecticides used in the nineteenth century were inorganic e.g. Paris Green and other compounds of arsenic. Nicotine has also been used since the late eighteenth century.

A. Types of Soil Pollution

1. Agricultural Soil Pollution - Usage of Pesticides and Fertilizers

Many farming activities engage in the application of fertilizers, pesticides and insecticides for higher crop yield. This is good because we get more food, but can you think of what happens to the chemicals that end up on the crops and soils? Sometimes, insects and small animals are killed and bigger animals that eat

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tiny animals (as in food chains) are also harmed. Finally, the chemicals may be washed down as it rains and over time, they end up in the water table below .Above all these, the major amount of pesticides and fertilizers added go to the underground soil thus polluting it to a great extent.

2. Soil Pollution by Industrial Effluents and Solid Wastes

Chemical and nuclear power plants produce waste materials that have to be stored somewhere. Pharmaceuticals manufacturers also produce lots of solid and liquid waste. In many cases they are stored in an environmentally safe way, but there are some that find their way into landfills and other less safe storage facilities. Sometimes they also find their way into leaking pipes and gutters. They end up polluting soils and making crops harmful to our health.

3. Pollution Due to Urban Activities

Humans depend on trees for many things including life. Trees absorb carbon dioxide (a green house gas) from the air and enrich the air with Oxygen, which is needed for life. Trees provide wood for humans and a habitat to many land animals, insects and birds. Trees also, help replenish soils and help retain nutrients being washed away. Unfortunately, we have cut down millions of acres of tree for wood, construction, farming and mining purposes, and never planted new trees back. This is a type of land pollution.

II. Treatment Methods

A. Phytoremediation

Phytoremediation is a process that uses plants to stabilize or destroy soil contaminants. A number of different mechanisms exist for this process, including phyto-stabilization and phyto-accumulation. In the former, chemical compounds produced by plants are used to immobilize contaminants. The latter process uses plant shoots and leaves to store contaminants that usually contain metals. The plants are specifically chosen for their abilities to absorb large quantities of lead. Many plants such as mustard plants, alpine pennycress, hemp, and pigweed have proven to be successful at hyper accumulating contaminants at toxic waste sites. Poplar trees are among the most widely chosen plants for phytoremediation and require a large surface area of land. In addition to metals, phytoremediation may also be used against pesticides, explosives, fuels and volatile or semi-volatile organic compounds.

Over the past 20 years, this technology has become increasingly popular and has been employed at sites with soils contaminated with lead, uranium, and arsenic. While it has the advantage that environmental concerns may be treated in situ; one major disadvantage of phytoremediation is that it requires a long-term commitment, as the process is dependent on a plant's ability to grow and thrive in an environment that is not ideal for normal plant growth. Phytoremediation may be applied wherever the soil or static water environment has become polluted or is suffering ongoing chronic pollution. Examples where phytoremediation has been used successfully include the restoration of abandoned metal-mine workings, reducing the impact of sites where polychlorinated biphenyls have been dumped during manufacture and mitigation of on-going coal mine discharges.

B. Soil Vapor Extraction

Soil Vapor Extraction (SVE) is an in situ remediation technology that leaves the soil as-is, without moving or digging. The technique uses a vacuum to emit a controlled flow of air through the soil. Volatile and some semi-volatile contaminants are then removed. Ground water pumps may be used during the procedure to mitigate water upwelling caused by the vacuums. After contaminants are removed, other remediation measures may be necessary if soil cleaning objectives have not been met. SVE projects typically require one to three years for completion, and field pilot studies are necessary prior to the procedure for determining feasibility and system configuration.

1. SVE Effectiveness

The effectiveness of SVE, that is, the rate and degree of mass removal, depends on a number of factors that influence the transfer of contaminant mass into the gas phase. The effectiveness of SVE is a function of the contaminant properties (e.g., Henry's Law constant, vapor pressure, boiling point, adsorption coefficient), temperature in the subsurface, vadose zone soil properties (e.g., soil grain size, soil moisture content, permeability, carbon content), subsurface heterogeneity, and the air flow driving force (applied pressure gradient). SVE effectiveness issues include tailing and rebound, which result from contaminated zones with lower air flow (i.e., low permeability zones or zones of high moisture content) and/or lower volatility (or higher adsorption). Recent work at U.S. Department of Energy sites has investigated layering and low permeability zones in the subsurface and how they affect SVE operations. Enhancements for improving the effectiveness of SVE can include directional drilling, pneumatic and hydraulic fracturing, and thermal enhancement (e.g., hot air or steam injection) .Directional drilling and fracturing enhancements are generally intended to improve the gas flow through the subsurface, especially in lower permeability zones. Thermal enhancements such as hot air or steam injection increase the subsurface soil temperature, thereby improving the volatility of the contamination. In addition, injection of hot (dry) air can remove soil moisture and thus improve the gas permeability of the soil.

C. Biosparging

Biosparging is a treatment technique using natural microorganisms, like yeast or fungi, to decompose hazardous soil substances. Some microorganisms can ingest dangerous chemicals without harm. In turn, those pollutants are rendered into less toxic or nontoxic substances, usually in the form of carbon dioxide and water. To be successful, biosparging requires active and healthy microorganisms. This is encouraged via increased bacterial growth in the soil, which creates optimal living conditions. After the contaminants are regulated, the microorganisms reduce in number because their food source is gone. Biosparging (fig. 1) can occur under aerobic and anaerobic conditions.

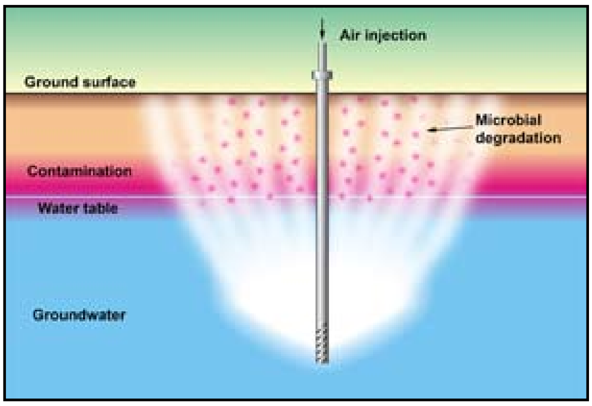

Fig. 1: Biosparging

It is an efficient process that is typically more economical than SVE or conventional air sparging. Since flow rates are low, blowers and associated operating costs are less, and there is no need to treat collected contaminant-laden soil gas that has been stripped (like in air sparging).

Injection of oxygen or ozone at low flow rates is also commonly used for chemical oxidation, and even propane has been injected to provide a carbon source for biological treatment. All of these treatment methods work by treating the contaminants in situ, rather than stripping them out for removal and ex situtreatment. This methodology is rapidly gaining favor for sites where risk-based assessments have determined that there is little threat of exposure via normal pathways, but that some remediation is needed. It is also useful to create a barrier against migration of contaminants off-site—a horizontal well installed across a migrating contaminant plume effectively treats all of the water that crosses it, eliminating the need for expensive and ineffective pump-and-treat systems.

D. Electric Resistance Heating

Electric resistance heating works by sending an electrical current into soil through multiple electrodes. Those electrodes are strategically placed to ensure an entire area is reached. As the electrical current passes through the subsurface, it encounters resistance that heats the soil. The soil turns gradually hotter until contaminant compounds reach boiling temperatures. They then evaporate, and vapor extraction techniques are used to remove fumes. Once the vapors are removed, treatment can begin at the soil's surface level. Benefits of this technique include low levels of disruption, and cleanup that typically occurs within six to 10 months.

Electrode spacing and operating time can be adjusted to balance the overall remediation cost with the desired cleanup time. A typical remediation may consist of electrodes spaced 15 to 20 feet apart with operating times usually less than a year. The design and cost of an ERH remediation system depends on a number of factors, primarily the volume of soil/groundwater to be treated, the type of contamination, and the treatment goals. The physical and chemical properties of the target compounds are governed by laws that make heated remediations advantageous over most conventional methods. The electrical energy usage required for heating the subsurface and volatilizing the contaminants can account for 5 to 40% of the overall remediation cost. There are several laws that govern an ERH remediation. Dalton's law governs the boiling point of a relatively insoluble contaminant. Raoult's law governs the boiling point of mutually soluble co-contaminants and Henry's law governs the ratio of the contaminant in the vapor phase to the contaminant in the liquid phase.

E. Thermal Treatment

Thermal treatment is a solution for treating nonrecyclable and nonreusable waste in an environmental and economical friendly way. Thermal treatment reduces the volume and mass of the waste and inerts the hazardous components, while at the same time generating thermal and/or electrical energy and minimizing pollutant emissions to air and water.

Thermal treatment methods generally heat and destroy pollutants through soil. The heat can also destroy or evaporate some chemicals. In turn, evaporated pollutants move more easily than those in solid form. Once treatment begins, pollutants are steered into and contained within underground wells before getting pumped to the surface. Above-ground treatment techniques can then purify the contaminants. Thermal treatment, which has proven particularly successful with non-aqueous phase liquids (NAPLs), often keeps soil in place and is thus called in situ. Examples of thermal treatment techniques include steam injection, hot water injection and radio frequency heating,waste incineration, pyrolysis and gasification .In modern European waste management waste incineration plays the absolute dominant role. The processes result in residual products from the waste as well as products resulting from flue gas cleaning additives, which afterwards have to be deposited at a controlled site such as a landfill or a mine. After thermal treatment ferrous and non-ferrous metals can be recovered and recycled. Also the grate ash or slag can be recovered for building purposes. Nutrients and organic matter are destroyed and cannot be recovered after thermal treatment.

III. Conclusion

The following conclusions are made from the discussions made in this paper.

1. Soil pollution is caused by the presence of human-made chemicals or other alteration in the natural soil environment.
2. Various treatment methods have evolved in order to treat these polluted soils.
3. Phytoremediation is an in situ process that uses plants to stabilize or destroy soil contaminants and is employed at sites with soils contaminated with lead, uranium, and arsenic.
4. Soil vapour extraction is an in situ process which uses a vacuum to emit a controlled flow of air through the soil.
5. Biosparging is a treatment technique using natural microorganisms, like yeast or fungi, to decompose hazardous soil substances and is an efficient process that is typically more economical than SVE or conventional air sparging.
6. Electric resistance heating is a technique that has low levels of disruption, and cleanup.
7. Thermal treatment is an in situ solution for treating nonrecyclable and nonreusable waste in an environmental and economical friendly way. This treatment reduces the volume and mass of the waste and inerts the hazardous components.
8. There is a great need to realize the importance of soil treatment, so that we save our environment for our future generations.

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