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Stream	Biology
Faculty	Science
Department/Subject	Zoology
Course	Environmental Monitoring
Course Duration	Annual/Semester
Sub topic	Environmental monitoring
Content	Remedial measures of soil pollutants
Search keywords	Capping, excavation, fine clay, remediation

Contamination of soil, water bodies and sediments with toxic trace elements is the most unfortunate by-product of urbanization, industrialization and mining. The use of contaminated water enhances the chance of occurrences of diseases in plant, animal and human and adversely affects the soil health. In order to restore the natural ecosystem functions, to prevent these from contaminating other components of environment, to improve the quality of human and animal life dependent on the polluted land area, their remediation has been advocated by government organizations, environmentalists, policy makers and land owners. By definition, soil remediation is a set of processes and techniques of reducing the mobile and in consequence, bioavailable fraction of contaminants in soils. The sole objective of soil remediation is to minimize transfer of pollutants into soil organisms, plants, food chains, surface water and groundwater bodies so that expression of toxicity to organisms is either prevented or minimized.

Remediation of large rural areas with marginally polluted soils, and agricultural fields should be approached differently than the remediation of heavily contaminated areas such as those around mining and smelting sites. The selection of remediation technologies depends on:

(a) Size of contaminated area and its topographical location (b) History of contamination process, (c) Soil mineralogical, physical and chemical characteristics (e.g., structure, texture, pH, oxides, carbonates etc.), (d) Physical and chemical properties of the contaminants, (e)

Degree of pollution (i.e., contaminants concentration and their vertical and horizontal spread in the profile), (f) Intended land use after remediation, (g) Technological options and financial support available, (h) Possible impact of remediation technologies on environment, (i) Associated legal and social issues of the region and country.

Isolation and Containment

Under this method, contaminants are isolated and contained to prevent further movement through reducing their permeability and increasing the strength or bearing capacity for the contaminants. Physical barriers (made of steel, concrete, bentonite, clay and tiled-walls) can be used for vertical and horizontal containment as well as for capping of contaminated zone. Capping with synthetic membranes is also advocated to reduce water infiltration and contamination of groundwater. Advantages of containment approach are (i) simple and robust; (ii) generally economical compared to contaminant removal technologies; (iii) eliminates contaminant transport to other areas almost completely. This approach of remediation has also limitations like (i) it may not reduce mass, concentration, or toxicity; (ii) slurry/clay walls (if used for containment) are not impermeable and hence provide containment over a finite period; (iii) long-term monitoring of the containment system is required to ensure that contaminants are not migrating.

Excavation and Landfilling

'Soil excavation and landfilling' is the most common remediation method for metal polluted soils. The process consists of two steps: (i) removal of the contaminated soil from the contaminated site to a special land-fill and (ii) restoration of the site which may include backfilling the excavated space by clean soil with subsequent establishment of vegetation. Soil placed in landfills may also require additional treatment to stabilize metals against their leaching to groundwater. Hazardous waste landfills are specially constructed to contain the contaminant metals in effective manner. However, it is extremely environmentally disruptive to the site and can often be extremely expensive.

'Excavation and landfilling' is simple and is most widely used technique for small, heavily contaminated sites. Site managers often prefer this technique because of its low risk of failure, its predictable time frame for decontamination, and because it leaves the site in a relatively pristine condition. In case of contamination over a large area, this technique is simply not feasible due to high costs involved with excavation of large mass of contaminated soil; its replacement with equal quantity of good quality soil and limited availability of landfill space to contain high volume of contaminated soil.

Vitrification

During vitrification, contaminated soil mass is treated through the processes involving melting and refreezing to create a glass-like solid that entraps inorganic contaminants and thereby isolates these from the environment. It can be applied both in-situ and elsewhere above ground in a treatment unit (ex-situ). The high temperature applied during vitrification process also destroys organic contaminants in soil. Vitrification is thus applicable for treating soil contaminated with both toxic organic chemicals and trace elements. The process involves introduction of electrodes into the wet soil that is capable of carrying current. Heat generated during current flow raises temperature of surrounding soil mass to 1100–1450^{0}C that is sufficient to liquefy siliceous soil particle. After melting is over, contaminated mass is solidified upon cooling. Toxic gases can also be produced during vitrification of soil contaminated with certain contaminants. Full-scale vitrification technologies exist for soils contaminated with arsenic, lead and chromium. Soil mixed with various toxic wastes can also be treated in this manner.

Limitations Efficiency of vitrification process is reduced by higher contents of clay, moisture and debris. Applicability of solidification/stabilization processes is generally limited to shallow depth and smaller volume of contamination. Vitrification can not be used where soil is contaminated with large amounts of flammable or explosive materials. Heating the soil may cause movement of contaminants into clean areas in the subsurface region. Also, the solidified material may prevent future use of the site.

In-Place Stabilization/Immobilization

Contaminated soils may be stabilized by mixing with solidifying materials such as cement or other pozzolanic materials (siliceous or alumino-siliceous material possessing cementing properties), thermoplastics, or other suitable agents. Stabilization/immobilization techniques may be applied in situ at the site of contamination or ex situ on excavated soil. The stabilized matrix may be a solid impermeable mass or a more friable solidified matrix. The solidified soil matrix reduces exposed surface area, resulting in reduced contaminant contact with the surrounding environment and reduced loss by leaching. Cement is the most commonly used solidifying material because of it’s low cost, readily available, and is relatively easy to handle.

Cement has a high pH at which many metals form insoluble compounds; thereby it also stabilizes the contaminants chemically. The resulting pH of the matrix stabilized with cement, may be more than ten and therefore, the cement stabilized soil mass cannot support plant growth. In some cases, the chemical form of the contaminants, particularly halides and soluble salts, may retard cement setting time or reduce the strength of the soil-cement mixture. Stabilization/immobilization is most effective in low to moderately contaminated soils, especially where contamination is near the surface where excavation or in situ mixing is easiest.

<u>Soil Washing</u>

Contaminated soils can also be remediated by soil washing. Two types of soil washing are followed:

(i) Particle Separation Techniques (ii) Leaching Technique

(i) Particle Separation Techniques

In this case, soil contaminants are associated with one particular range of size fractions of the soil which are subsequently segregated out and disposed separately. Most of the insoluble organic and inorganic toxic contaminants have the affinity to be attached with clay, silt, and organic soil particles through either chemical bonding or physical forces. This verity is utilized for reducing soil contamination through particle size separation. The silt and clay particles are attached to sand and gravels by physical forces like compaction and adhesion.

Contaminated organic matter particles, fine clay (along with associated humus fraction) and silt particles are separated from the coarser sand and gravel soil particles by washing processes and thereby contaminants are concentrated effectively into a smaller soil volume for subsequent treatment or disposal. This technique is more suitable for removing high specific gravity particles such as heavy metal-containing compounds (lead, radium oxide, etc.).

(ii) Leaching Technique

In this case, contaminants are chemically solubilized and removed from the soil system. Soil washing as a decontamination technique removes contaminants solubilized using chemical extractants and may be conducted in situ or ex-situ on excavated soil. Chemical extractants used to enhance heavy metal solubility include inorganic acids , organic acids , complexing agents (detergents, EDTA), or combinations of these chemicals. During this process, suitable extracting solution is percolated through the soil. The solution is recovered and treated to remove the contaminants; and extractants are often re-used. This process continues until the remediation goal is achieved or further solubilization/extraction of contaminants is not possible.

Thermal Treatment

Thermal treatment is rarely used on soils contaminated with heavy metals. It is commonly used for removing organic contaminants through chemical degradation and volatilization by heating the soil to high temperatures. The vaporized contaminants are subsequently collected and treated. Different types of soil heating techniques are available like; electrical resistance heating, radio frequency/electromagnetic heating, hot air/steam injection.

Electro-Reclamation

Electro-reclamation is based on an electrokinetic process which occurs during flow of direct current between a cathode and an anode inserted in the soil. The electric current results in the flow of small electrically charged particles and soil-pore water where cations and anions travel to the cathode and anode respectively. In most soils with a predominance of negatively charged surfaces, uncharged molecules migrate with the bulk flow of liquids towards the cathode. The technique is most successfully applied in high clay soils containing organic or relatively mobile contaminants and is applicable to a relatively few metal ions. During the remediation process, electrodes must be equipped with a purge system that helps to maintain pH around the electrodes and removes the contaminants. The effectiveness of electroreclamation is mostly dependent on the chemical composition of soil pore-water and groundwater.

References:

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