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Remedies for soil and groundwater pollution: An overview

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ABSTRACT: Most urban cities are experiencing population growth and increased industrial activities. This has brought most urban soil and groundwater environments under stress. There are reports of soil and groundwater pollution through landfills, gas and oil pipelines, industrial spills and leakages from underground storage tanks (USTs). Pollutants range from heavy metals to volatile organic compounds (VOCs), light non-aqueous phase liquids (LNAPL) (floaters) and dense non-aqueous phase liquids (DNAPL) (sinkers).

Remediation methods depend on such factors as type, mobility and extent of contamination, pollutant spread, pedology, physiography, geology and hydrogeology of the area. Furthermore, remediation method would depend on available technology, economic, institutional and environmental laws. Field oriented methods are described with documentations that must accompany them. Finally, this overview concludes with a discussion of the problems of follow-up monitoring and future challenges of remediation methods.

Key Words: Groundwater quality; Industrial pollution; Landfills; Remediation.

Introduction

Groundwater quality is attracting attention in modern civilization. Water naturally contains a number of different dissolved solutes, gases, inorganic, organic and biological constituents which, at the end, determine its quality. Groundwater quality is a consequence of the natural, physical and chemical interaction of the water with its host rocks and other natural environment.

The natural water quality has been shown to be prone to alteration. If the alteration occurs such that the water quality that is previously suitable and fit for a particular use and purpose is altered through human activities such that it is no longer fit for the same purpose, the water is said to be contaminated or degraded. The degradation may impair the usefulness of water but may not necessarily be harmful to health. Walker (1969) defined pollution of groundwater as the impairment of water quality by chemicals, heat or bacteria to a degree that creates an actual public health hazard and adversely affect such waters for normal domestic, municipal, industrial or agricultural use. It is referred to as pollution when health hazard is caused through poisoning or spread of disease. If soil or groundwater is polluted, it is often asked whether the quality can be restored or at least be remedied to an acceptable level.

The artificial processes to remove the contaminants totally or partially to a tolerable level is referred to as remediation.

Aims of remediation

The main objective of site remediation is to restore soil and groundwater quality to pre-contamination conditions or to restore the site to its natural conditions. In this case, all objectionable substances and contaminants are removed, thus bringing the aquifer back to a state in which the groundwater content is suitable for all uses. This implies that every contaminant molecule must be removed.

Absolute removal of these molecules for achieving a clean status is almost impossible to attain. Thus, clean up standards and groundwater protection standards are usually stipulated by state or government agencies or relevant environmental protection agencies charged with the responsibility of groundwater protection. Such agency would normally fix the maximum allowable contaminant concentration left on site which would not adversely affect soil and groundwater quality or human health.

Materials and Methods

Remediation Methods

There are six basic remediation methods:

1. Removal of the contaminated water by pumping and then treating to an appropriate quality. The water can then be re-injected into the aquifer and pumped into circulation for use.
2. Excavation of polluted rocks, soil and sediments.
3. Use of hydrogeological barriers. This is a containment method. The spread of pollutants is prevented by using physical barriers such as sheet plies, cement grouts, impermeable membranes and permeable reactive barriers (PRB).
4. Bioventing. This is the removal of volatile fraction of pollutants from soil and unsaturated zone by vacuum pumping from a borehole. The principle is to circulate air which volatilizes and promotes the degradation of organic pollutants within the soil or unsaturated zone.
5. Bioremediation. Bacteria are grown in the polluted zone to deal with the pollutants.
6. Phytoremediation. This is the use of plants that can utilize contaminations. Pollutants are got rid of or reduced to a minimum by the growth of such plants in the contaminated soils or sediments.

Procedures and processes of aquifer and groundwater assessment

Aquifer and groundwater assessment follow a sequence of hydrogeologic studies aimed at obtaining vital information about the site such that each stage is a prerequisite for the other towards attaining almost a pre-impact level or zero contamination. The field method must achieve the following prerequisites:

(i) Define the site geology and stratigraphy.

(ii) Define the hydrogeology and establish groundwater occurrence, its disposition and flow direction.

(iii) Delineate vertical and spatial contaminant spread in the vadoze zone and in the aquifer through soil/sediment sampling and groundwater sampling for grain size studies and chemical analysis.

Reconnaissance site investigation reporting

This is a quick appraisal of the site to understand the site geology, the groundwater condition including the flow direction, the nature of contamination, the types of risks and hazards to health.

It involves quick sampling of soil, sediments and groundwater and, in some cases, surface water for chemical analysis. Sediment and water samples could be taken from surface, trenches, shallow or deep pits, wells and boreholes. Use is made of hoes, shovels, augers or motorized drilling machines.

Areas of suspected contamination are sampled first. Soil or sediment sampling is concentrated in the vadoze (unsaturated) zone, through test pits, showing pits and borings. Volatile organic carbons (VOC) and volatile hydrocarbons and other organic volatile gases are also tested for by using gas detection equipments. Areas that show signs of contamination by the presence of volatile hydrocarbons must be quickly secluded as they pose direct health hazards to the reconnaissance site workers. Some examples of volatile organic carbons include trichloroethylene, tetrachloroethylene, carbon tetrachloride 1,1,1-trichloro-ethene 1,2-dichloroethene, vinyl chloride, benzene, methylene chloride, chlorobenzene. While volatile organic carbons (VOC) are the most frequently reported contaminants, heavy metals and inorganic compounds are the second and third most frequently reported categories of hazardous substances. Examples include arsenics, barium, cadmium, chromium, lead, mercury, selenium, nickel, zinc, nitrates and phosphates. The most common inorganic constituents of concern are the thirteen priority pollutant metals such as silver, arsenic, barium, cadmium, nickel, mercury, lead, selenium, thallium, antimony, copper and zinc.

A reconnaissance investigation analysis should be carried out for all substances known or suspected of being used on site or spilled, dumped on site in such quantities that could cause pollution.

Samples are collected, packaged and stored for onward transportation to the laboratory for analysis. It must be assured that samples are very carefully handled to ensure quality.

Reports should contain maps and sketches of area and details of metabolic or ionic concentrations in tables, bar charts and in contours. Vertical and spatial distribution of specific metals and ions should be illustrated. This would indicate or isolate the source of pollution, the spread or plume migration and rate of migration. Such plume, exposure routes or contaminant pathways are compared with existing targets such as sites workers, water table, groundwater flow directions, water wells, springs, underground systems, railroads, roads, galleries, bunkers, residential areas, surface water bodies like lakes, rivers, streams and agricultural farmlands.

Detailed site investigation: Hydrogeologic approach

The primary aim of detailed site investigations is to identify the problems or etsblish the plumes to measure the spatial and vertical movement or spread of plume of the contaminants. This could be achieved by siting pits, wells or boreholes at hydrogeologically significant points or areas relative to the judgment and consideration of the plumes and groundwater movement direction.

Samples are collected from such wells or pits for analysis. They include groundwater and soil/aquifer sediment samples. Periodic sampling could be conducted for time variant ionic concentration variation studies.

A check for floating products should be conducted by installation of special wells. If floating products are detected, it is worthy to note that due to capillary forces, floating products often accumulate in wells to thicker layers than in areas outside the well environment.

Soil samples and aquifer sediments should be analyzed for grain size distribution, textural studies, porosity and permeability measurements. These measurements would help in understanding the hydraulic properties of the formations, and to determine the configuration of the contaminant plume, and its movement rate and direction. The basic transporting processes of contaminant plume are by advection and diffusion as given by Fetters (1988).

$$V = \frac{K_i}{n}$$

where V = Linear velocity
K = Hydraulic conductivity
n = Effective porosity
i = Hydraulic gradient

Advection, therefore, is the rate of following water given by Darcy's law. Diffusion is the process by which both ionic and molecular species dissolved in water move from areas of higher concentration to areas of lower concentrations. Under steady state conditions, Fetters (1988) used Fick's laws to explain solute flux as

$$F = -\frac{Ddc}{dx}$$

where F = Mass flux of solute per unit area per unit time
D = Coefficients of diffusion (area/time)
C = Solute concentration (mass/volume)
$\frac{dc}{dx}$ = Concentration gradient (mass/volume/distance)

Aquifer remediation

From the reports of the detailed site investigation, if the site still poses a threat to human health and the environment, remediation scope is determined guided by maps and cross-sections showing the plume spread with the geological and hydrogeological background of the site.

There are several remediation techniques in use for groundwater as well as aquifer and soil restoration (USEPA, 1985).

Excavation

Contaminated rocks and soil are physically excavated and removed to other hazardous waste or disposal landfill sites. Purer, uncontaminated rock fills are stored and used for back fills and compaction. This is followed up by post excavation, refill, compaction, sampling and testing to determine effectiveness. However, serious factors to be considered in these techniques are:

i. Volume of materials to be removed: If too voluminous and deep, it becomes non-economical and risky.

ii. Equipment to be used: They must be readily available and affordable. If not, then viability is reduced.

iii. Source and type: Distance of source must be considerate and not too remote. Materials must be preferably of similar lithlogy.

The drawbacks of the technique of excavation of hazards waste for disposal are the cost of disposal, transportation and finding appropriate disposal sites.

Use of hydrogeological barriers/containment

This includes a series of measures to keep the contaminant ions within the ground and prevent its circulation. Physical or hydrogeological barriers are constructed. They include the use of slurry walls, sheet piles, grouting and the use of permeable reactive barriers (PRB).

Slurry walls

These are low permeability barriers emplaced by trenching into the subsurface. They confine the contaminant by surrounding the entire spill or by cutting off flow through the surface. An upstream barrier is put in place to cut flow. Slurry wall is made of bentolite slurry to a depth of up to 50m. The slurry wall could be solidified by adding cement or by mixing with excavated material (Fig. 1).

Use of permeable reactive barriers (PRB)

A Permeable Reactive Barrier (PRB) is an artificial medium consisting of reactive materials placed in an aquifer across the flow direction of groundwater. As the contaminated groundwater (plume) flows through it the reactive material passively immobilize the contaminants. The reactive media provide reactive surfaces for reactions such as sorption, oxidation, precipitation and redox reactions that break down the contaminants contained in the plume to produce harmless or insoluble products that are retained in the barrier.

Bioventing

Volatile organic compounds are removed from the unsaturated zone through vacuum pumping. Large volumes of air are let into the spill. Volatilization occurs with biodegradation of the organic pollutions or contaminants. This is also known as soil venting.

Contaminant removal by pumping

The type of contaminant must have been identified and its mobility established. Sims and Sims (1991) distinguished contaminants and their associated products into two phases – solid and fluid – in five compartments, viz. gas, inorganic solids, organic solids, water and oil referred to as Non Aqueous Phase Liquids (NAPLs). The NAPLs are further divided into two, depending on their relative density with water, i.e. those that are lighter than water (LNAPLs) and those with density greater than water (DNAPLs).

The LNAPLs include fuels of hydrocarbon, e.g. petrol or gasoline, aviation fuel, jet fuel, kerosene and heating oil. DNAPLs include chlorinated hydrocarbons like 1,1,1-trichloroethane, carbon tetrachloride, chlorophenols, chlorobenzenes, tetrachloroethylene and plychlorinated biphenyls (PCBs).

Locating the water table is an essential part of characterization of the site because the LNAPLs flow along the water table while the DNAPLs are found along the bedrocks in the subsurface.

By the use of systems of pumping boreholes or wells, the contaminant products can be removed through any of the following methods (Figs. 2, 3 & 4):

1. Use of a single pump. This produces a mixture of hydrocarbons and water which could be separated later. Here, minimal input of drilling and equipment is achieved.
2. Use of a two-well pump system such that one pump causes a water-table slope or gradient, and the other pump recovers the floating contaminants or hydrocarbons.
3. A single well with two pumps in which the upper drains out the floating hydrocarbon and the lower pump induces a water table gradient.
4. Pump and treat system.
5. Two well systems could be installed. One well is installed towards the plume to pump out both contaminated water (e.g. oil and water) for treatment. The other well pumps out fresh water. By such arrangement a hydraulic barrier is created to prevent plume movement or spread through the aquifer.

Bioremediation

The principle of bioremediation is based on the fact that microbial activity uses the contaminant as food source, thus producing a non-toxic, harmless, by product and consequently decontaminating the groundwater aquifer.

In subsurface bioremediation, groundwater is pumped via extraction wells and recycled into groundwater fed with oxygen, such as peroxide and nutrients. This allows biologic action to start on the contaminants. Further biologic respiration and metabolism of the micro-fauna cleanses the aquifer matrix. The bio-remedial process is most suitable to hydrocarbon fuel cleanup and cleansing of other aliphatic compounds. Waste production and nutrient delivery must be controlled and balanced to prevent clogging of the porosity and permeability of the aquifer.

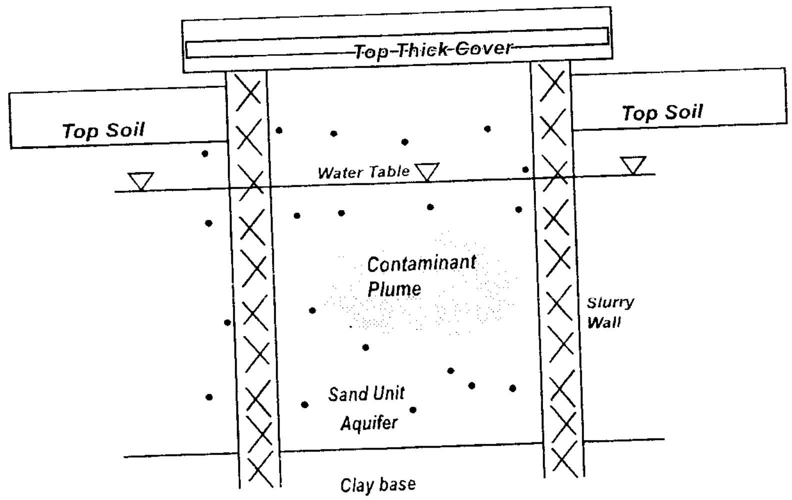

Fig. 1: Typical slurry wall.

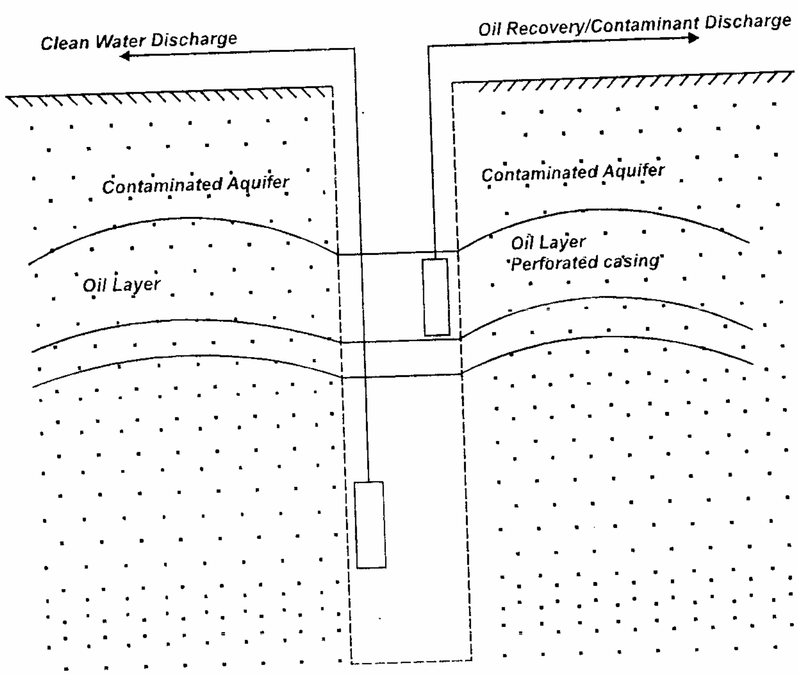

Fig 2: Using Two Pumps to Remove Contaminant or oil leaks From Aquifer

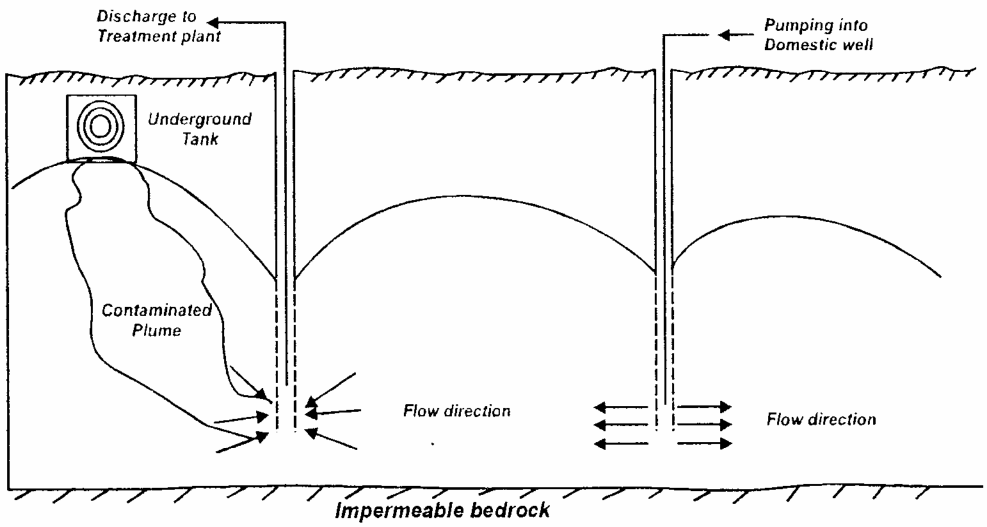

Fig 3: Pump and Treat System

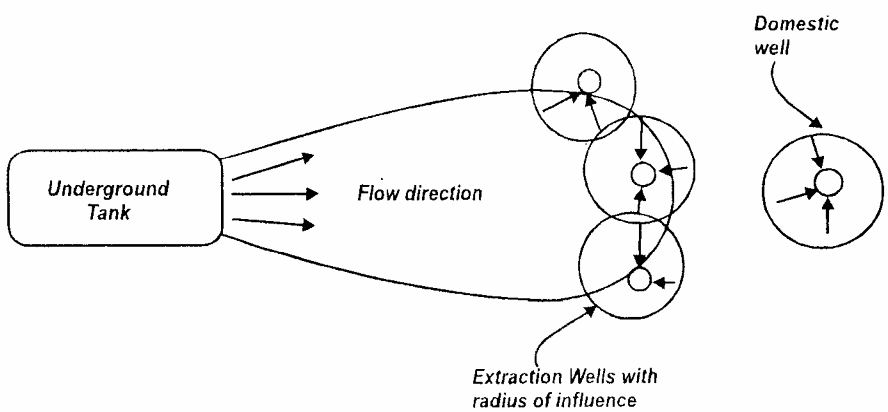

Fig 4: Plan view of Pump-and-treat System (from U.S. EPA, 1995).

Phytoremediation

This is the use of plants to clean up polluted soil, sediments and water. Phytoremediation utilizes plants that have natural attributes for the removal of contaminants from soil, rocks and water. With their root systems, enormous surface areas are created or provided for the absorption and accumulation of such contaminants in water and nutrients including heavy metals and other ions for growth. These plants termed hyper-accumulators accumulate and tolerate 10 – 100 times higher metal concentrations than normal crops. These plants offer the ability to remove much higher quantities of metals from soil than normal crops and thus could support a method of farming to decontaminate soil, sediments or rock materials.

Hyperaccumulator plant species are known to accumulate levels at least as high as 1% Zn, Ni, Se, Cu, Co, Mn, As, >0.1% Cd, and radionuclides as ^{137}Cs, ^{60}Co, ^{96}Sr, U and Pu (Chaney et al., 1995).

Phytoremediation can, therefore, be combined with the earlier mentioned excavation of contaminated aquifer rock sediments or soil material.

Conclusion and Recommendations

Groundwater remediation is of great importance. This is because of the critical importance of groundwater resources to the economic life of our civilization. For sustainability of such a scarce resource which is becoming threatened by pollution due to industrialization adequate remedial methods must be devised. Remedial action must be followed up by well planned monitoring. This would establish the overall performance of the remedial action. Critical parameters should be monitored. Some of the problems that can militate against groundwater remediation include:

1. Lack of documentation of field performance of methods and their effects on groundwater system.
2. Poor access to and potential commercialization of such documents.
3. Cost of project, especially for large impact areas. Documentations of a remediation programme must include the following:
    i. Map of sites showing locations of monitoring wells, pits, cores, geology, geographic and physiographic landmarks, structures and buildings.
    ii. Geologic cross-sections of site stratigraphy, aquifer disposition.
    iii. Groundwater level contour maps showing flow direction.
    iv. Groundwater contamination contour maps showing ionic distribution in groundwater.
    v. Soil contamination contour maps showing ionic distribution in soil.
    vi. Cost effectiveness of remediation options.

A well conducted remediation must conform to established environmental standard orders. There must be an evaluation of well delineated zero contamination line and alternative remediation methods and post remediation monitoring design.

References

Chaney, R,; Brown, S.; Yin-Ming, L.; Scott Angle, J.; Homer, F. and Green, C. (1995) Potential use of metal hyperaccumulators. J. Mining Environ. Manag. 3(3)

Fetters C. W. Jr. (1988) Applied Hydrology. C. E. Merril Publishing Co., New York.

Sims, C. R. and Sims, L. J. (1991) Site characterization for sub-surface remediation. Centre for Environmental Research Information, U. S. Environmental Protection Agency (EPA/625/4-91026.

USEPA (1985) RCRA Groundwater Monitoring Compliance Order Guidance. EPA Office of Solid Waste and Emergency Response (NTIS PB 87-193710).

Walker, W. H. (1969) Illinois groundwater pollution. J. Amer. Water Works Assoc. 61(1), 31 – 48.