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REMEDIATION OF HEAVY METAL CONTAMINATED SOIL: A COMPARATIVE STUDY OF REMEDIATION TECHNIQUES

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ABSTRACT: Numerous attempts to decontaminate polluted soils with the use of an array of both in-situ and ex-situ techniques are being made. None of these is a panacea for remediating contaminated soils and often more than one of the techniques may be necessary to optimize the cleanup effort. The complexity of soils and the presence of multiple contaminants also make most remediation efforts arduous and costly. The thermal, chemical, and physical treatment methods have failed to eliminate the pollution problem because those methods only shift the pollution to a new phase such as air pollution. This paper evaluates the benefits and costs of each technique and finds the bioremediation technology, which leads to degradation of pollutants, may be a lucrative and environmentally beneficial alternative.

KEYWORDS: Bioremediation, ex situ remediation, in situ remediation, phytodegredation, phytoremediation.

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1. INTRODUCTION

The ecological effects of toxic metals and their biological magnification through the food chain along with the highly publicized events such as the Minamata disease in Japan due to Mercury pollution have prompted a demand for decontamination of heavy metals. At the microscopic scale, heavy metals may have serious effects on the microbial population which are the key players of the different nutrient turnovers in the soils. Consequently, ecosystems functioning can be seriously perturbed and long term soil fertility may be threatened due to such heavy metal contamination. Therefore, it can be understood, how much necessary it is, to get rid of heavy metal pollution as far as possible also for the betterment of the ecosystems. Metal contamination has led to different types of medical problems like birth defects, cancer, skin lesions, growth retardation leading to disabilities, liver and kidney damage and a host of other maladies.

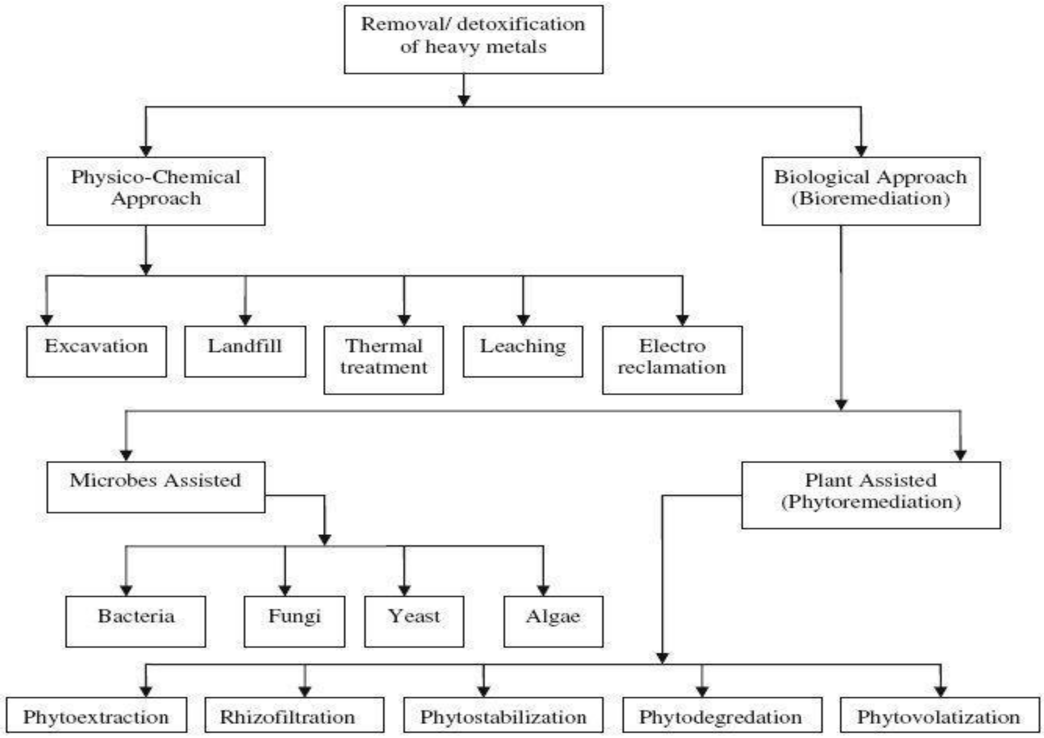

Figure 1: Approaches for the remediation of heavy metals from contaminated soil [2]

Bioremediation is defined as “The use of biological mechanisms to destroy, transform, or immobilize environmental contaminants in order to protect potential sensitive receptors.” [1]. Ex situ remediation techniques involve removing the soil from the subsurface to treat it. In situ remediation techniques involve leaving the soil in its original place and bringing the biological mechanisms to the soil. Ex situ thermal processes involve the transfer of pollutants from the soil to a gas phase. The pollutants are released by vaporization and the burned at high temperatures. Ex situ thermal remediation is completed in 3 steps: soil conditioning, thermal treatment, and exhaust gas purification [3]. Thermal treatment heats the soil in order to transfer volatile pollutants to a gas phase. Heating is done by using a sintering strand, fluid bed, or rotary kiln plants. The soil is usually heated to a low temperature range of 350-550°C. Combustion of the gases occurs over the top of the soil, but the volatile gases are not destroyed. The gases are then burned in an after-burner chamber at approximately 1200°C and dioxins are destroyed [4]. In situ thermal processes are still in the developmental phase. The process involves injecting a steam-air mixture at 60-100 °C into the soil. In order to avoid the transport of pollutants to the groundwater, the steam-air mixture must stay in that temperature range. After the injection, volatile and semi-volatile compounds transport from the soil to the gas phase. The gases are then removed from the subsurface using a soil vapor extraction system and then treated at the surface. In situ thermal remediation is limited for use in only certain soil types, namely homogeneous soils with high permeability and low organic content. In situ thermal processes are only appropriate for removing pollutants, which can be stripped in the lower temperature range (e.g. BTEX) [5]. The ex situ chemical/physical remediation process known as soil scrubbing uses mechanical energy to separate the pollutants from the soil. The soil is crushed and then separated via sieving. This ensures that the soil sample is homogeneous. The soil is then dispersed in liquid. Water, which is sometimes enhanced with an additive, is used to dissolve the pollutant. The additives are used to overcome the bonding forces between the pollutants and the soil particles. The soil is then separated into two categories: low density and high -density solids. Highly polluted fine particles are then separated out and dewatered. The particles are then rinsed with uncontaminated water. The wastewater and exhaust air are then purified. Soil scrubbing is most effective when removing BTEX, TPH, PAH, PCB, heavy metals, and dioxins [6]. In situ chemical/physical processes are sometimes referred to as pump and treat processes. The pump and treat process pumps water into the subsurface in order to draw out the contaminants. Surfactants are sometimes added to the water to increase the solubility of the pollutants. The water is then treated with standard wastewater treatment techniques. The pump and treat process is extremely limited by the permeability of the soil. Chemical oxidation is also employed to destroy contaminants such as PAHs and trychloroethylene (TCE) [7]. Chemicals such as ozone, permanganate, and peroxide have all been injected into the soil and used to accelerate the destruction of toxic organic compounds [8]. Another in situ chemical/physical process used is soil vapor extraction. Vacuum blowers are used to extract volatile pollutants for the soil through perforated pipes. The volatile pollutants are then treated at the site using activated carbon filters or compost filters. The effectiveness of this technique is dependent on soil characteristics such as moisture content, temperature, and permeability. A high percentage of fine soil or a high degree of saturation can also hinder the effectiveness of soil vapor extraction [9]. Leaching the in-place soil with water and often with a surfactant (a surface-active substance that consists of hydrophobic and hydrophilic regions; surfactants lower the surface tension) to remove the contaminants. This method is cumbersome since large quantities of water required to remove the pollutants and, consequently, the waste stream is large and disposal costs can be high. In vitrification the contaminants are solidified with an electric current, resulting in their immobilization. The contaminants can be held in place or can be isolated by installing subsurface physical barriers such as clay liners and slurry walls to minimize lateral migration. Scientists and engineers have also added surfactant to clay minerals (organo-clays) to enhance retention of organic pollutants [10]. Composting consists of excavating the soil and then mixing organics such as wood, hay, manure, and vegetative waste with the contaminated soil [11]. The organics are chosen based on their ability to provide the proper porosity and carbon and nitrogen balances to aid in the breakdown of contaminants. Maintaining thermophilic temperatures 54 to 65°C is an important part of composting. In most cases, the indigenous microorganisms maintain this temperature while degrading the contaminant. Composting is most effective when removing PAH, TNT, and RDX [12]. Landfarming is a process in which the soil is excavated and mechanically separated via sieving. The polluted soil is then place in layers no more than 0.4 meters thick. A synthetic, concrete, or clay membrane is then used to cover the contaminated soil layer. Oxygen is added and mixing occurs via plowing, harrowing, or milling. Nutrients and moisture may also be added to aid the remediation process. The pH of the soil is also regulated (keeping it near 7.0) using crushed limestone or agricultural lime [13]. Biopiling is an process that is also known as the heap technique. The first step in the biopiling process is to perform laboratory tests that will determine the biological degradation capabilities of the soil sample. The next step involves the mechanical separation of the soil, which will homogenize the sample and remove any disruptive material such as plastics, metals, and stones. The stones will then be crushed into smaller pieces and then depending on the degree of contamination will either be added to a pile or sent out for reuse. The soil is then homogenized, meaning that the pollution concentration is averaged out across the entire soil sample. Homogenization allows for biopiling to be more effective. Once the soil is piled, nutrients, microbes, oxygen, and substrate are added to start the biological degradation of the contaminants. The results of the initial laboratory tests indicate to the operators which substrates such as bark, lime, or composts needs to be added to the soil. Nutrients such as mineral fertilizers may also be added. Additionally, microorganisms such as fungi, bacteria, or enzymes could be added [14]. Bioreactors treat contaminated soils in both solid and liquid (slurry) phases. The solid phase treatment process mechanically decomposes the soil by attrition and mixing in a closed container. An acid or alkalinity may also be added to control the pH [15]. In fixed bed reactors, composts is added and significantly increases the degradation rate. In rotating drum reactors, the drum has a screw like mechanism in the middle of it that rotates to mix and transport the soil. The liquid phase treatment process uses suspension bioreactors and treats soils as slurry. The slurry feed enters the system and is rinsed through a vibrating screen to remove debris. Sand is then removed using a sieve or hydrocyclone. If a hydrocyclone is used to remove the sand, the sand falls to the bottom of the cyclone and the fines remain on top. The fines are then treated in a bioreactor. After the treatment, the slurry must be dewatered and the water is then treated with standard wastewater techniques [16]. Bioventing is the only in situ bioremediation technique that allows for the treatment of unsaturated soil. Bioventing is not effective if the water table is within several feet of the surface. Van Deuren et al, 2002 uses a vacuum enhanced soil vapor extraction system. Due to the pressure gradient in the soil, atmospheric oxygen flows into the subsurface. This oxygen starts an aerobic contaminant decomposition process. In many cases it is necessary to add nitrogen salts as an additive by sprinkling a nutrient solution on top of the soil or by injecting them into the soil above the contaminated soil zone [17]. Biosparging is the injection of atmospheric air into the aquifer. It is used in both saturated and unsaturated soil zones. The technique was developed to reduce the consumption of energy. The injection of air into the aquifer results in small channels for the air to move to the unsaturated soil zone. In order to form the necessary numerous branches in these channels, the air must be pulsed into these soil. Biosparging results in volatile contaminants being transported to the unsaturated zone, therefore soil vapor extraction is usually used to extract the volatile vapors and then treat them at the surface [18]. Phytoremediation, the use of plants to remediate soils and water can be quite effective. There are hundreds of plant species that can detoxify pollutants. For example, sunflowers can absorb uranium, certain ferns have high affinity for As, alpine herbs absorb Zn, mustards can absorb Pb, clovers take up oil, and poplar trees destroy dry-cleaning solvents. Recently the brake fern (*Pteris vittata*) was found to be an As hyper-accumulator [19] and very effective in remediation of a Central Florida soil contaminated with chromated copper arsenate [20]. Phytoextraction is a subprocess of phytoremediation in which plants remove dangerous elements or compounds from soil or water, most usually heavy metals, metals that have a high density and may be toxic to organisms even at relatively low concentrations. The heavy metals that plants extract are toxic to the plants as well, and the plants used for phytoextraction are known hyperaccumulators that sequester extremely large amounts of heavy metals in their tissues. Phytoextraction can also be performed by plants that uptake lower levels of pollutants, but due to their high growth rate and biomass production, may remove a considerable amount of contaminants from the soil [21]. Phytostabilization involves the reduction of the mobility of heavy metals in soil. Immobilization of metals can be accomplished by decreasing wind-blown dust, minimizing soil erosion, and reducing contaminant solubility or bioavailability to the food chain. The addition of soil amendments, such as organic matter, phosphates, alkalizing agents, and biosolids can decrease solubility of metals in soil and minimize leaching to groundwater. The mobility of contaminants is reduced by the accumulation of contaminants by plant roots, absorption onto roots, or precipitation within the root zone. In some instances, hydraulic control to prevent leachate migration can be achieved because of the large quantity of water transpired by plants [22]. Phytodegradation which is also known as phyto-transformation is the breakdown of contaminants taken up by plants through metabolic processes within the plant, or the breakdown of contaminants surrounding the plant through the effect of enzymes produced by the plants. Plants are able to produce enzymes that catalyze and accelerate degradation. Hence, organic pollutants are broken down into simpler molecular forms and are incorporated into plant tissues to aid plant growth [23]. Bioremediation is a sustainable strategy that utilizes the metabolic potential of microorganisms and plants to clean-up contaminated environments. It achieves contaminant decomposition or immobilization by exploiting the existing metabolic potential of microorganisms with novel catabolic functions derived from selection or by introduction of genes encoding such functions. Bioremediation techniques can also be divided into two categories – in situ and ex situ bioremediation. The in situ technique involves treatment of soil and associated ground water in its original place without displacing the material. In the ex situ process, excavation of the entire contaminated material is needed for treatment at some other treatment place where the activity of microbes and other parameters can be controlled. But which method has to be applied depends on three basic principles – (i) the amenability of the pollutant to biological transformation, (ii) the accessibility of the contaminant to microorganisms (bioavailability) and (iii) the opportunity for optimization of biological activity (bioactivity). This technology may be applied in the removal of xenobiotic compounds from agrochemical and petrochemical industries, oil spills, heavy metals in sewage, sludge and marine sediments etc. Bioremediation is a multidisciplinary approach, however, the most important aspect is the microbiological aspect. The microbiological aspect involves biostimulation (stimulating viable native microbial population), Bioaugmentation (artificial introduction of viable population), bioaccumulation (sequestration and accumulation of heavy metals by microbes) and biosorption (adsorption by living or dead microbes). For instance, microorganisms can transform heavy metals from one oxidative state or organic complex to another. Mainly, microorganism-based remediation depends on the resistance of the utilized microbe to the heavy metal that is either activated independently or through metal stress [24].

2. CONCLUSION

Bioremediation really does work to remove many different pollutants for soils. One of the greatest obstacles to overcome is the need for an engineering and scientific knowledge base. For bioremediation to be successful, researches, regulators, design engineers, and contractors need to understand the basic science behind these techniques and how that science can be applied to specific contaminated sites [25]. In situ techniques have the advantage that the soil does not have to be removed or transported, but the techniques lack contaminant removal efficiency, these remediation techniques are less controllable and less effective. Ex situ techniques are more effectively remove the contaminants, but sacrifice economic feasibility due to the costs involved with excavating and transporting the soil.

Table 1: Methods of remediation and involved costs [26]

Treatment	**Costs ($/ ton)**	**Additional factors/¥expenses**
Vitrification	75 – 425	Long term monitoring
Land filling	100 – 500	Transport/excavation/monitoring
Chemical treatment	100 – 500	Recycling of contaminants
Electrokinetics	20 – 200	Monitoring
Phytoremediation	5 – 40	Monitoring

Because of the high cost, there is need for the less expensive cleanup technologies. Bioremediation is a cost effective eco-friendly means of healing nature with nature. One of the less expensive clean up technology is the bioremediation. Because, in addition it remediate the soil in-situ and avoids dramatic landscape disruption, and preserves the ecosystem. The elimination of heavy metals requires their concentration and containment as they cannot be degraded by any biological, physical, or chemical processes. Therefore, employing microorganisms in heavy metal elimination and environmental cleaning is an effective approach due to their varied ability of interacting with heavy metals.

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4. CONFLICT OF INTEREST

There is no conflict of interest.

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