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THE USE OF PHYTOREMEDIATION TECHNOLOGY FOR ABATEMENT SOIL AND GROUNDWATER POLLUTION IN TANZANIA: OPPORTUNITIES AND CHALLENGES

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Abstract

Contamination of soil and groundwater from anthropogenic sources is a major concern in many developing countries including Tanzania. Improper handling of Municipal Solid Wastes (MSW) in many urban centers in Tanzania has often resulted into gas emissions and generation of leachate, which pose threat to the environment. Additionally, the use of pesticides for agricultural purposes is on the increase because of the need to improve crop production and control of pests, weed infestation and insect outbreaks. As a consequence, pesticide use has caused adverse contamination in soils and waters. The potentially negative impacts of these pesticide stocks on humans and the environment are of major concern. To make the situation more challenging, the country has experienced a substantially fast growth of the mining sector in many parts of the country over the past ten years, which has resulted in reported soil and water pollution from acid mine drainage with elevated concentrations of heavy metals. It is estimated that more than 30% of the Tanzanians depend on groundwater as their source of water. Most of the conventional methods for environmental remediation of these sites are expensive and often poorly implemented or not implemented at all. Thus there is a clear need to develop new cost effective and environmentally friendly clean-up methods to remediate the contaminated areas in Tanzania. Phytoremediation is a relatively new and promising technology that uses plants to degrade, stabilize, metabolize or sequester potentially toxic compounds from the environment. This paper is aimed at assessing the potential of phytoremediation as a low cost alternative, but which has yet to be studied and used in Tanzania.

Introduction

The extent of anthropogenic environmental pollution in the developing world is well documented (Mattina et. al., 2003). Section 11 of the Tanzania's National Environmental Policy (1997) has identified environmental pollution as one of the key problems that call for urgent attention. Like many developing countries, Tanzania is facing environmental problems of diverse nature and some of which are growing day by day (Mato, 2002). For instance, the Food and Agriculture Organization of the United Nations has estimated that at a minimum 105 t of unwanted pesticides are in "storage" in developing countries, with at least 2 x104 t in African countries (Chaudhry et al., 2002). Urban centers in Tanzania have experienced alarming population growth with increasing number of industries which generate humongous amounts of wastes. Municipal solid wastes (MSW) are dumped in an uncontrolled manner without any provision to deal with leachate generations, consequently posing threat to environment. Inadequate or no waste disposal facilities in the urban areas has often resulted into pollution transport to water sources, jeopardizing groundwater quality.

There has been a tremendous growth of mining industry in Tanzania over the last ten years. However, environmental pollution resulting from mining activities in various places in the country is a problem that is not adequately addressed. Tailings generated during mining operation and extraction processes often contain heavy metals such as Arsenic, Cadmium, Cobalt, Lead, Zinc and Sulfides. Elements/compounds such as mercury and cyanide may be introduced during extraction process. During wet season, acidic leachate which contains heavy metals finds its way to groundwater sources as point pollution source.

Despite all the pollution potential in groundwater resulting from human activities, yet there is a growing demand for groundwater since it is the most readily available low cost source of water supplies to low income populations in towns and cities in the country which is currently experiencing an unprecedented average population growth rate of 6.8% (Mato, 2002). Thus, the problem of groundwater contamination in Tanzania is constantly growing due to the fact that there are limited financial and technological resources to remediate polluted soils and water sources. Contaminants of most concern are metals, polyaromatic hydrocarbons (PAHs) and mineral oil. The current practice of remediating heavy metal contamination elsewhere relies heavily on dig-and-dump or encapsulation, neither of which addresses the issue of decontamination of the soil. Immobilization or extraction by physicochemical techniques can be expensive and applicable only for small areas where rapid, complete decontamination is required. This practice may not be feasible for a developing country like Tanzania.

Plants used in phytoremediation have the capability to self engineer or exert some control over the rhizosphere, local biogeochemistry (soil and water pH, organic content, redox conditions), availability of water and nutrients, creating hydraulic barrier to capture contaminant plumes and the local microclimate. Natural or planted vegetation on polluted sites such as landfills, mine areas and dumpsites play an important role in controlling erosion and removing contaminants such as leachate, besides imparting aesthetic value (Nagendran et al., 2006). Nevertheless, despite the availability of literature on the potentials of phytoremediation in achieving in situ treatment of a wide range contaminants found in municipal solid waste dumpsites and mining areas, there is little to no awareness about this technology in Tanzania.

This paper is an attempt to bridge the existing gap of knowledge on phytoremediation, by reporting major research findings elsewhere and highlighting the potential applicability those findings to a developing country in tropical environment like Tanzania. According to Morikawa and Erkin (2003) , the advantages of phytoremediation are (1) it is an aesthetically pleasing, solar-energy driven cleanup technology; (2) there is minimal environmental disruption and in situ treatment preserves topsoil; (3) it is most useful at sites with shallow, low levels of contamination; (4) it is useful for treating a broad range of environmental contaminants; and (5) it is inexpensive (60-80% or even less costly) than conventional physico-chemical methods (Schnoor, 1997). On the other hand, phytoremediation has its limitations. It is a time consuming process, and it may take at least several growing seasons to cleanup a site. Plants that absorb toxic heavy metals or persistent chemicals may pose a risk to wildlife and contaminate the food chain. In addition, intermediates formed from those organic and inorganic contaminants may be cytotoxic to plants and animals including humans. Understanding mass balance analyses and the metabolic fate of pollutants in plants are the keys to proving the applicability of phytoremediation.

Phytoremediation processes

Phytoremediation is generally referred to as the use of vegetation for in situ treatment of contaminated soils, sediments, and water. The phytoremediation processes work sequentially or simultaneously, depending on the type of contaminants and treatment goals. Different processes may act on different contaminants or at different exposure concentrations (Table 1) (Schnoor, 2002; McCutcheon and Schnoor, 2003). Hence, phytoremediation is best applied at sites with shallow contamination of organic, nutrient, or metal pollutants that are amenable to the following processes (Aken and Schnoor, 2002; McCutcheon and Schnoor, 2003):

Degradation (destruction or alteration of contaminants)

Degradation of contaminants includes phytostimulation/rhizodegradation process, whereby plant exudation, root necrosis and other processes provide organic carbon and nutrients to spur soil bacteria growth by 2 or more orders of magnitude in number (Mwegoha, 2006). These processes also stimulate enzyme induction and co-metabolic degradation by mycorrhizal fungi, rhizo-microbial consortium; provide diverse root zone habitat, alternate chemical movements and concentrations. Live roots pump oxygen; dead roots support anaerobes and leave aeration channels. Additionally, degradation includes phytodegradation process which involves biochemical transformation or degradation of contaminants to harmless byproducts, which may be utilized in production of new biomass, products that are further broken down by other processes to less harmful compounds. Growth and senescence enzymes are sometimes involved in the plant metabolism.

Phytoaccumulation

Phytoaccumulation (plant uptake and accumulation of organic and/or metal contaminants) entails two processes namely phytoextraction (contaminant uptake and accumulation for removal through harvesting, incineration or landfilling) and rhizofiltration (contaminant adsorption or precipitation on roots for containment and/or removal).

Dissipation/Phytovolatilization

Volatile metals and organics are taken up by plants, re-speciated and transpired. Some recalcitrant organic compounds are more easily degraded in the atmosphere.

Phytocontainment/Immobilization

This process involves hydraulic control, defined as containment of shallow groundwater and contaminate, and soil leaching plumes through high transpiration rates by plants and by reversing the aquifer hydraulic gradient. It entails the phytostabilization process, which is prevention of sorbed pollutant transport by pH and redox control that cause speciation, precipitation and sorption to form stable mineral deposits; humification, lignification and covalent or irreversible binding of some organic compounds.

Feasibility of phytoremediation technology in groundwater pollution abatement

In past decade, phytoremediation has attracted an increasing attention to scientists, industry and governmental agencies that are facing the challenge of remediation and restoration of hazardous waste sites in many developed countries, particularly in the USA (Pepper et al., 1995, Mwegoha et. at., 2007). Phytoremediation is a cost-effective and non-intrusive means of remediation for soils, sediments, surface and groundwater environments contaminated by toxic metals, organics, metalloids, radionuclides and excess nutrients (Bollag et al., 1994; Chappell, 1997; Wiltse et at., 1998 and Ouyang, 2002; Susarla et al., 1999; McCutcheon and Schnoor, 2003). Therefore, it has been utilized at a number of pilot and full-scale field demonstration tests (Nzengung and Wang, 2000). It is an emerging technology that should be considered for remediation of contaminated sites because of its aesthetic advantages, and long-term applicability (Pivertz, 2001). Tanzania has experienced a substantially fast growth of the mining sector in many parts of the country over the past ten years, which has resulted in reported soil and water pollution from acid mine drainage with elevated concentrations of heavy metals. The use of hyper-accumulators elsewhere (plants that can accumulate high concentration of heavy metals) has been a success in removing heavy metals from contaminated sites. Futhermore, phytoremediation is well suited for use at very large field sites where other methods of remediation are not cost effective or practicable; at sites with low concentrations of contaminants where only "polishing treatment" is required over long periods of time; and in conjunction with other technologies where vegetation is used as a final cap and closure of the site (Schnoor, 1997; 2002).

According to Mato (2002), the use of pesticides for agricultural purposes is on the increase because of the need to improve crop production and control of pests, weed infestation and insect outbreaks As a consequence; pesticide use has caused adverse contamination in soils and waters. The use of pesticides for agricultural purposes is on the increase because of the need to improve crop production and control of pests, weed infestation and insect outbreaks. The potentially negative impacts of these pesticide stocks on humans and the environment are of major concern.

The low cost technology, in situ approach of phytoremediation is attractive as it offers site restoration, partial decontamination, maintenance of the biological activity and physical structure of soils, and is potentially cheap, visually unobtrusive, and there is the possibility of biorecovery of metals (Baker et al., 1991, 1994). For developing countries like Tanzania, phytoremediation will assist in conserving natural resources since it has shown great success for on-site and in-situ clean up of large volumes and expansive areas of contaminated soils and/or waters, including groundwater without excavation or other pretreatment trains. Unlike most other bioremediation approaches, phytoremediation can be combined with other technologies intended for source removal and can attenuate contaminant concentrations to nontoxic levels (Schnoor, 2002). The potential of phytoremediation in treating a wide range of contaminants (Table 1), the appeal of phytoremediation to the public, and the nonselective nature of the approach warrant development and application of this technology in Tanzania. According to Schwitzguebel (2000); Ghosh and Singh (2005) the following are the advantages of phytoremediation which would be of relevance under Tanzania situation:

- Amendable to a broad range of organic and inorganic contaminants including many metals with limited alternative options.
- *In Situ / Ex Situ* application possible with effluent/soil substrate respectively; soil can be left at site after contaminants are removed, rather than having to be disposed or isolated.
- *In Situ* applications decrease the amount of soil disturbance compared to conventional methods; it can be performed with minimal environmental disturbance; topsoil is left in a usable condition and may be reclaimed for agricultural use; organic pollutants may be degraded to CO2 and H2O, removing environmental toxicity.
- Reduces the amount of waste to be landfilled (up to 95%), can be further utilized as bio-ore of heavy metals.
- *In Situ* applications decrease spread of contaminant via air and water; possibly less secondary air and/or water wastes are generated than with traditional methods

- Does not require expensive equipment or highly specialized personnel; it is cost-effective for large volumes of water having low concentrations of contaminants; it is cost-effective for large areas having low to moderately contaminated surface soils
- In large scale applications the potential energy stored can be utilized to generate thermal energy; plant uptake of contaminated groundwater can prevent off-site migration.

Plants selection for phytoremediation: a major challenge

Introduction of invasive species for phytoremediation purposes in Tanzania may affect the local biodiversity. Therefore, identification and selection of locally available plant species for phytoremediation research and implementation is one of the challenges that need to be met and a pre-requisite for successful phytoremediation research. Phytoremediation of different types of contaminants requires different general plant characteristics for optimum effectiveness (Table 1). Careful selection of plant and plant variety is critical, first, to ensure that the plant is appropriate for the climatic and soil conditions at the site, and second, for effectiveness of the phytoremediation of the pollutant at hand. Plant species that are long-term competitors and survivors under adverse changing conditions normally have an advantage. Depending on the climatic and soil conditions, the plant may need resistance or tolerance to diseases, heat, cold, insects, drought, chemicals, and stress to maximize its survival rate. The type, amount, and effectiveness of exudates and enzymes produced by a plant's root will vary between species and even within subspecies or varieties of one species. A screening of phytotoxicity and effectiveness of cultivars/varieties might be required on a site-specific basis as an initial step in plant selection (Pivertz, 2001; Schnoor, 2002).

Phytoremediation research studies have examined numerous plants, but interest has focused on a smaller group for reasons such as widespread distribution, ready availability, ease of growth, an existing large knowledge base, or even the plant's commodity value (Pivertz, 2001; Schnoor, 2002). Terrestrial plants are more likely to be effective for phytoremediation than aquatic plants due to their larger root systems. For instance, poplar (or hybrid poplar) and cottonwood trees, such as the willows, Eastern cottonwood (Populus deltoides), have been extensively studied in the United States due to fast-growth rate and a wide geographic distribution that have the ability to take up or degrade various contaminants (Schnoor, 2002). The types of plants that have been used in various phytoremediation applications and their specific treatment goals have been shown in Table1. Although these plants are some of those that have been popular for research to date, further studies in tropical countries like Tanzania, will undoubtedly add many more candidates, some of which may prove to be much more effective for phytoremediation as there is no information on potential locally available plant species that may be used for phytoremediation in Tanzania.

Limitations of phytoremediation and opportunities for research

Erakhrumen and Agbontalor (2007) mentioned limitations of the phytoremediation technology as, which constitutes major research challenges that need to be met for successful implementation of the technology in Tanzania:

- Restricted to sites with shallow contamination within rooting zone of remediative plants; ground surface at the site may have to be modified to prevent flooding or erosion
- A long time is often required for remediation; may take up to several years to remediate a contaminated site
- Restricted to sites with low contaminant concentrations; the treatment is generally limited to soils at a meter from the surface and groundwater within a few meters of the surface; soil amendments may be required
- Harvested plant biomass from phytoextraction may be classified as a hazardous waste hence disposal should be proper
- Climatic conditions are a limiting factor; climatic or hydrologic conditions may restrict the rate of growth of plants that can be utilized. Introduction of non-native species may affect biodiversity.
- Consumption/utilization of contaminated plant biomass is a cause of concern; contaminants may still enter the food chain through animals/insects that eat plant material containing contaminants.

Although climatic conditions have been identified in previous research to be a major factor for implementation of phytoremediation research owing to its influence on plant growth, Tanzania has ideal climatic conditions for plant growth all year round, which makes it an ideal environment for phytoremediation research. Nevertheless, the fate of harvested plant biomass from extraction and phytoaccumulation (especially for heavy metals) presents a challenge since the nature of phytoaccumulated contaminants may be classified as hazardous, which calls for proper final disposal. In order to realize the full potential of this technology in Tanzania, it is necessary for plants to grow as large as possible in the presence of various environmental contaminants so that the disposal challenges are minimized. There is a need for well designed and well documented demonstration projects to promote it as a remediation technique. This presents a challenge of establishing greenhouses especially in university and college campuses to facilitate laboratory scale research as a starting point, which will pave way to pilot scale and full scale implementation of phytoremediation potential.

Conclusion

Research related to this relatively new technology needs to be promoted and emphasized and expanded in developing countries like Tanzania since it is a low cost. The focus should be towards attenuation of groundwater pollution by heavy metals, pesticides and rehabilitation of dumpsites. Phytoremediation is predicted to account for approximately 10-15% of the growing environmental remediation market by the year 2010. As regard to Tanzania, remediation of dumpsites and mine areas should aim at minimizing the potential for groundwater contamination resulting from migration of leachate and transmigration of contaminants. In addition, environmental aesthetics should not be ignored.

Phytoremediation offers viable solution to pollution problems as outlined in Table 1. This calls for multi disciplinary collaboration between universities, research institutes and other interested communities to create teams to address questions like agronomic practices needed for successful establishment of vegetation; development or identification of locally available plant species for specific remediation requirements and fate and final disposal of biomass, particularly containing high concentrations of metals.

Table 1: Applications of phytoremediation

Application	Description	Contaminants	Types of plants
Soils			
Phytotransformation	Sorption, uptake and transformation of contaminants	Organics, including Nitroaromatics and Chlorinated aliphatics	Trees and grasses
Rhizosphere biodegradation	Microbial degradation in the rhizosphere stimulated by plants	Organics such as PAHs, petroleum hydrocarbons, TNT, pesticides	Grasses, alfalfa, many other species including trees
Phytostabilization	Stabilization of contaminants by binding, holding soils, and/or decreased leaching	Metals, organics	Various plants with deep or fibrous root systems
Phytoextraction	Uptake of contaminants from soil into roots or harvestable shoots	Metals, inorganics, radionuclides	Variety of natural and selected hyperaccumuators e.g. *Alyssum, Brassica or Thelaspi*
Water/Groundwater			

Rhizofiltration	Sorption of contaminants from aqueous solutions onto or into roots	Metals, radionuclides, Hydrophobic organics	Aquatic plants e.g. duckweed and pennywort; also *Brassica* and sunflower
Hydraulic control/plume capture/phytotrans	Removal of large volumes of water from groundwater and/or aquifers by trees	Inorganics, nutrients, chlorinated solvents	Poplar, willow trees
Phytovolatilization	Uptake and volatilization from soil water and groundwater, conversion of Se and Hg to volatile species	Volatile organic compounds, Se and Hg.	Trees for VOCs in groundwater, brassica, grasses, wetland plants for Se and Hg in soil/ sediments
Vegetative caps	Use of plants to retard leaching of hazardous compounds from landfills	Organics, inorganics, wastewater, landfill leachate	Trees such as poplar, plants such as alfalfa, and grasses
Constructed Wetlands	Use of plants as part of a constructed ecosystem to remediate contaminants from aqueous wastewaters	Metals, acid mine drainage, industrial and municipal wastewater	Free- floating, emergent, or submergent vegetation, reeds, cattail, bamboo

Adopted from Schooner (2002)

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