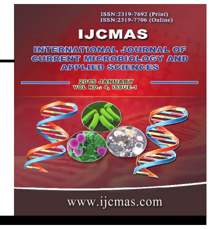

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Review Article

Sustainable management of mining area through phytoremediation: an overview

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A B S T R A C T

Keywords

Phytoremediation, heavy metals, hyperaccumulation, phytoextraction, phytodegradation.

One of the greatest challenges facing the world today is integrating economic activity with environmental integrity and social concerns. The goal of that integration can be seen as “sustainable development”. Sustainable development is development that meets the needs of the present without compromising the ability of future generation to meet their own. Sustainable development is one of a range of ideas about how human should best interact with each other and the biosphere. The mining sector is part of this web of issue. Many countries and communities depend on minerals production as a source of income and a means of development. Minerals development can create many opportunities, including jobs, a transfer of skills and technology and the development of local infrastructure and services. The mining industry has generated wealth in direct and indirect ways but, it is alleged, there is a mismatch of opportunities and problems - the health often being enjoyed for from the communities and environments that feel the adverse impacts. Mining area has polluted with aerodynamic particulate matters (mostly heavy metals) and oxides of sulphates, nitrogen, carbon and hydrocarbons. Mining affects fresh water, streams, rivers, lakes and oceans. Mining operation covers extensive areas which deteriorate both soil topography and biodiversity. Mining industry is the maximum contributor of heavy metals to environment. Forests are effective sink for biodiversity and removing pollutant and maintain ecological balance through bio-geo-chemical cycles. Phytoremediation is an emerging technology that employees the use of microbes and plants for the clean of contaminated environments. Heavy metals are natural constituent of the lithosphere, whose geochemical cycles and biochemical balances have been drastically altered by human activity. Pollution due to heavy metals place human health at risk and it is responsible for several environmental problems including the decrease of microbial activity, soil fertility and crop yields. Microbes play key geo-active roles in the biosphere, particularly in the area of element bio-transformations and biogeochemical cycling, metal and mineral transformations, decomposition, bio weathering and soil and sediment formation. Microbes have a variety of properties that can effect changes in metal speciation, toxicity and mobility, as well as mineral formation or mineral dissolution or deterioration. Such mechanisms are important components of natural bio-chemical cycles for metals as well as associated elements in biomass, soil rocks and minerals. Some plant species have developed tolerance or resistance to heavy metals. Such evolution of ecotypes is a classic example of local adaptation and micro-evolution, restricted to species with appropriate genetic variability. Phytoremediator plant species with (i) high biomass production, (ii) a deep root system, (iii) high growth rate (iv)high capacity to allocate metals in the trunk, can be an alternative for the recovery of degraded soil due to excess of metallic elements. Phytoremediation of heavy metals through microbes and plant species presents advantageous characteristics as an economic and ecologically viable system, making it an appropriate, practical and successful technology.

Introduction

Mining is an industry that involves the exploration for and removal of minerals from the earth. Mining industry pollute environment by its pollutants during processing when they are added with primary and secondary factors of environment. Mining pollutant and environmental factors interact with each other and create a stress on environment which impact on biosphere. Mining environment is affect air quality by particulate matter which is released in surface mining. When the soil is removed, vegetation is also removed exposing the soil to the weather, causing particulates to become airborne through wind erosion and road traffic. Mining can cause physical disturbances to the landscape, creating eyesores such as waste stock pits and open pits. Such disturbances may contribute to the decline of biodiversity. Water pollution caused by mining include acid mine drainage, metal contamination and increased sediment level in streams. Acid mine drainage (AMD) is a potentially severe pollution hazard that can contaminate surrounding soil, ground water and surface water. The primary sources for acid generation are sulphide minerals such as pyrite (iron sulphide) which decompose in air and water. Pyrite + oxygen + water → "Yellow body" + sulphuric acid. Yellow body is the name for iron and aluminium compounds that stain streambeds. One of the greatest challenges facing the world today is integrating economic activity with environmental integrity and social concern. The goal of that Integration can be seen as "sustainable development". Sustainable development is development that meets the needs of the present without compromising the ability of future generation to meet their own. Sustainable development is one of a range of ideas about how human should best interact with each other and the biosphere. The technology available during this period was not always able to prevent or control environmental damage. Phytoremediation is a recent technique for environmental management. Mining area has polluted with aerodynamic particulate matters (mostly heavy metals) and oxides of sulphates, nitrogen, carbon and hydrocarbons. Mining industry is the maximum contributor of heavy metals to environment. Heavy metals are natural constituent of the lithosphere, whose geochemical cycle and biochemical balance have been drastically altered by human activity. Man's exposure to heavy metals comes from industrial activities like mining smelting, refining and manufacturing process (Nriagu, 1996). About 90% of the anthropogenic emissions of heavy metals have occurred since 1990 AD; it is now well recognised that human activities leads to a substantial accumulation of heavy metals in soils on a global scale (e.g. 5.6 - 38 x 106 Kg Cd Yr^{-1}). United States Environmental Protection Agency (1997) reported that heavy metals such as Cd, Cu, Pb, Cr, Ni and Zn are important environmental pollutants, particularly in areas with high anthropogenic pressure. Mining for precious metals, coal and other commodities form an important part of many countries economics. Developing countries (Brazil, China, India and Peru) contribute a large proportion of the world's mining products. Mining activities affect health via. Water through; the method of extraction; contamination of local water sources as well as having harmful effects on the environment or by longer term effects on reducing biodiversity (WHO, 2008). Geological and anthropogenic activities are major source of heavy metal contamination (Dembitsky, 2003).

Pollution due to heavy metals place human health at risk and it is responsible for several environmental problems including the decease of microbial activity, soil fertility and crop yields. Forests are effective sink for biodiversity and removing pollutant and maintain ecological balance through biogeochemical cycle. Basing on the above facts, the present paper deals with the effective management of sink potential through phytoremediation.

Mechanism of phytoremediation process

Bioremediation is the process that uses green plants and consortia of microorganisms (fungi, algae and bacteria) or their enzymes to break down relatively non-biodegradable pollutants rendering them safe in the environment. Bioremediation with green plants is often referred to as green-clean or phytoremediation.To grow and complete life cycle plant must acquire essential micronutrients (mostly heavy metals).Plants have evolved highly specific mechanism to take up, translocate and store these nutrients. Metal ions are charged, so they cannot move freely across the cellular membranes which are lipophilic structures. Metal ions transport into cells must be mediated by membrane proteins with transport function, generally known as transporters. Trans-membrane transporters process an extracellular binding domain to which ions attach just before the transport, which connects extra cellular and intracellular media. The trans-membrane structure facilitates the transfer of bound ions from extracellular space through the hydrophobic environment of the membrane to cell. The total amount of ions associated with the root, only a part is absorbed into cells. A significant ion fraction is physically absorbed at the extra cellular negatively charged sites (COO^-) of the root cell walls. The cell wall bound fraction cannot be trans locating to the shoot and therefore, cannot be removed by harvesting shoot biomass (Phytoextraction).Metals can also be complexes and sequestered in cellular structure (e.g. Vacuole) becoming unavailable for translocation to the shoot (Lasat *et al.,* 1998).Movement of metal containing sap from the root to the shoot, termed translocation, primarily controlled by two processes; (i) root pressure and (ii) leaf transpiration. During translocation, metals can be reabsorbed form the sap into leaf cells. Root growth affects the properties of the Rhizospheric soil and stimulates the growth of the microbial consortium. Rhizospheric micro-organisms may interact symbiotically with roots to enhance the potential for metal uptake (Anderson, 1997).Some micro-organism may excrete organic compounds which increase bioavailability and facilitate root absorption of metals (Kanazawa et al., 1995).Soil microorganisms can also directly influence metal solubility by altering their chemical properties. Some plants and grass species can regulate metal solubility in the rhizosphere by exuding a variety of organic compounds (Mugineic, avenic, citric and malic acids) from roots (Pellet *et al.,* 1995 and Larsen *et al.,* 1998).Root exudates complex metal ions keeping them in solution available for Uptake into roots.

Types of phytoremediation

Phytoremediation can be applied to organic and inorganic pollutants presented in soil, liquid and air substracta, mainly in soil contaminated with heavy metals. Phytoremediation can be achieved through several processes. These are as follows:

- Phytoextraction (Phyto-accumulation)
- Phytostabilisation
- Rhizofiltration
- Phytovolatilization
- Phytodegradation (Phyto-transformation)

Phytoextraction

The technology involves the extraction of metals by plant roots and the translocation thereof to shoots. The roots and shoots are subsequently harvested to remove the contaminants from the soil.The costs involved in phytoextraction would be more than ten times less per hectare compared to conventional soil remedial techniques. During the phytoextraction procedure, plants cover the soil and erosion and leaching will thus be reduced. A fern *P. Vittata* is a hyper accumulator to Arsenic (Ma *et al.*, 2001).Sunflower (*H. annus*) have proven effective in the remediation of radionuclides and certain heavy metals (Schnoor, 1997). Several species of salix are explored in programmes for the removal of heavy metals from soil (Unterbrunner *et al.*, 2007).Though production of biomass, a profuse root system, high growth rate, capacity to grow in soil poor in nutrients and associated to metal resistance are important factors for the use of plant species in the method of soil decontamination. Currently about 400 hyperaccumular species of metals, pertaining to the A*steraceae, Brassicaceae, Caryophyllaceae, Cyperaceae, Acanthaceae, Fabacae, Lamiaceae, Poaceae, Violaceae* and *Euphorbiaceae*families have been identified (Prasad & Freitas, 2003).Avicennia marina accumulates metals in the roots in proportion to their concentration in the sediments (Weis & Weis, 2004).After exposure to metals, the leaves excrete significant amount of this metal in conjugation with saline crystals excreted at the adaxial surface of the leaf. Spartina alterniflora and Phragmit esaustralis actively excretes metals in saline crystals released through hydathodes (Burke *et al.,* 2000).

Phytostabilsiaiton

Phytostabilization can occur through the sorption, precipitation, complexion or metal valence reduction. Some of the advantages associated with this technology are that the disposal of hazardous material / biomass is not required and it is very effective whenrapid immobilisation is needed to preserve ground and surface water. Phytostabilisation, by Sorghum (fibrous root) and other grass families are used to remediate soil contaminated with heavy metals and amended vermicompost in contaminated soil as a natural fertilizer (Jadia &Fulekar, 2008).The large surface area of fibrous roots and intensive penetration of roots into the soil reduces leaching via stabilization of soil and capable of immobilizing and concentrating heavy metals in the roots. This prevents seeping or spreading of pollutants to ground water or to the surrounding soil. The process is effective in stabilizing vegetation cover, prevention of soil erosion and also remedial for metal pollution.

Rhizofiltration

It is defined as the use of plants, both terrestrial and aquatic, to absorb, concentrate and precipitate contaminates from polluted aqueous sources in their roots. Sunflower, mustard, tobacco, rye, spinach and corn have been studied for their ability to remove heavy metals. Roots of many hydroponically grown terrestrial plants such as mustard and sunflower effectively removed the potentially toxic elements Cu, Cd, Cr, Ni, Pb, Zn and Fe from aqueous solutions (Dushenkov *et al.*, 1995).The results showed that pistia, duckweed and water hyacinth can be good accumulators of heavy metals in aquatic environment. This method re-stabilizes plant community in polluted landscape, prevents leaking of soil pollutants and promotes recycling of metals for industrial use. This system also removes metals in wetlands and estuarine system.

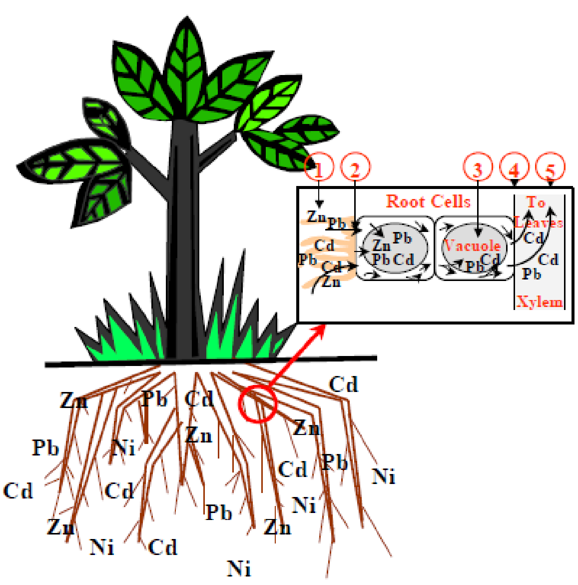
Phytovolatilization

Phytovolatilization involves the use of plants to take up contaminants from the soil, transforming theminto volatile forms and transpiring into the atmosphere. In laboratory experiment, tobacco (N. tabacum) and a small model plant (*Arobidopsis thaliana*) that had been genetically modified and include a gene for mercuric reductase converted ionic mercury Hg(II)to the less toxic metallic mercury Hg (O) and volatilized it (Meagher *et al.*, 2000).Transformed yellow poplar (*Liriodendron tulipifera*) plantlets had resistance to and grew well in, normally toxic concentrations of ionic mercury. The transformed plantlets volatilized about ten times more elemental mercury than did untransformed plantlets (Rugh *et al.*, 1998).Indian mustard and canola (*Brassica rapus*) may be effective for phytovolatilization of selenium and other heavy metals. These occur mostly in growing plants and trees.

Phytodegradation

Heavy metals and organic pollutants from soil and water are degraded metabolically by plants or enzymatically by microbes. These pollutants are broken down, transformed and finally taken up by plants as nutrients. This process reduces soil and ground water pollution and enhances micro-degradation in the rhizosphere.

Figure.1 Metal uptake and accumulation in plants



1. A metal fraction is sorbed at root surface
2. Bioavailable metal moves across cellular membrane into root cells
3. A fraction of the metal absorbed into roots is immobilized in the vacuole
4. Intracellular mobile metal crosses cellular membranes into root vascular tissue (xylem)
5. Metal is translocated from the root to aerial tissues (stems and leaves)

Source : Lasat, Mitch M. "The Use of Plants for the Removal of Toxic Metals from Contaminated Soil". American Association for the Advancement of ScienceEnvironmental Science and Engineering Fellow. (2000):5-24

Pseudomonas multophila was shown to reduce the mobile and toxic Cr^{6+} to nontoxic and immobile Cr^{3+} (Park *et al.*, 1999).Other heavy metals Hg^{2+}, Pb^{+2}, Cd^{2+}, Fe^{3+}, Zn^{2+} and etc are toxic to environment due to their motility, oxidation state. Environmental mobility of these metals are minimised and transformed to less toxic and environment friendly form of metals by microbes.

Plant species show different allocation patterns for heavy metals, whose translocation from roots to the aerial part and their release from foliar tissue can be an important step for metal flow in ecosystems. Some stress tolerant plants that accumulate pollutants in excess are known as hyper accumulators or natural scavengers. *Eichhornia crassipes* (water hyacinth), *Hydrocotyl umbellate* (Pennyworth), *Lemna minor* (Duck Weed) take up lead copper, cadmium, mercury. Spirodela removes chromium, lead and arsenic. *Azolla pinnata* (water velvets) are hyper accumulators of lead, copper, cadmium, iron and silver.Pistia (water lettuce) the free floating is a well-known arsenic scavenger. Typha (Cuttail) is employed for removing copper, nickel even calcium and magnesium salts. Ipomea (water spinach) accumulates lead and chromium. is tolerance to zinc. Azolla (ferns) aquatic mosses and liverworts are efficient metal removers. Algae removes copper (Chlorella), Manganese, iron and lead (Hydrodictyon), Nickel, Copper (Scenedesmus).Terrestrial plants that remove excess metals from soil are Ocimom, Thlapsi and Arabidopsis. Benthic microalgae of sea (fucus, ulva) are act as metal chelators. Genetic engineering is used for enhanced phytoremediation that alters the physiological functioning of plants through modification of primary and secondary metabolism. Genes from microbes are recombined in plants that have increased biodegradable properties to assimilate metals. Gene from hyper accumulating or metal accumulating plants and micro-organisms, that can readily remove and detoxify pollutants are identified and transferred to fast growing plants to increase the efficiency of phytoremediation in short period of time. Phytoremediation strategy, a better understanding is necessary of the absorption, transport and tolerance of metals in plants, since they are of great importance for the planning of large scale application of this technique under field conditions.

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