IJSRM
INTERNATIONAL JOURNAL OF SCIENCE AND RESEARCH METHODOLOGY
An Official Publication of Human Journals
HUMAN

Human Journals
Review Article
November 2016 Vol.:5, Issue:1

Iron Ore Mining, Waste Generation, Environmental Problems and Their Mitigation through Phytoremediation Technology

IJSRM
INTERNATIONAL JOURNAL OF SCIENCE AND RESEARCH METHODOLOGY
An Official Publication of Human Journals
HUMAN

Nilima Chaturvedi* and Hemanta Kumar Patra

Laboratory of Environmental Biotechnology,
Post-Graduate Department of Botany,
Utkal University Bhubaneswar-751004, India.

Submission: 10 November 2016
Accepted: 15 November 2016
Published: 25 November 2016

HUMAN JOURNALS

www.ijsrm.humanjournals.com

Keywords: Iron ores, Mining, Tailings, Overburden, Waste, Phytoremediation

ABSTRACT

Mining activities generally occupy and spoil a large tract of land due to generation of a large amount of waste rocks and tailings, which is deposited at the surface and becomes a continuous source of metal pollution to the soil air and water resources of the area concerned. A number of conventional remediation technologies are already in practice but they are environmentally destructive while Phytoremediation is cost-effective, and environmental-friendly alternative technology, to reduce, remove, degrade, or immobilize environmental toxins using plants. Thus, a brief review on waste generated and general environmental problems related to iron ore mining(with special reference to Indian mining zones), types of phytoremediation processes, plants that can be used a potential phytoremediation tool, examples of field applications of phytoremediation at mining sites have been compiled in this paper.

1. INTRODUCTION

Minerals and metals are considered as the mainstay of the economic development and welfare of the society but their exploration, excavation and processing directly infringe upon and affect the other natural resources like land, water, air, flora and fauna, which are to be conserved and optimally utilized in a sustainable manner. Mining generates considerable waste materials and tailings, which are deposited on the surface as mine spoil dumps. Removal of fertile topsoil, formation of unstable slopes prone to sliding and erosion, and siltation of water bodies due to washing off of mineral overburden dumps are also major negative effects of mining. The metals released from mining, smelting, forging, and other sources would accumulate in the soil (Khan *et al.*, 2009), altering its chemistry. Metal contamination is not restricted to the mining site only because considerable release of metals occurs through acid mine drainage and erosion of waste dumps and tailing deposits (Salomons, 1995).

The hazards of surface and groundwater pollution increases significantly when the mine waste materials contain reactive sulfide minerals such as pyrite (Liao *et al.,* 2007). Pyritebearing mine tailings disposed at neutral or slightly alkaline conditions also can weather within a relatively short period of time to produce extreme acidity and lead to acid mine drainage (Robb and Robinson, 1995). Acid mine drainage usually contains a high load of heavy metals, in addition to having a low pH, which poses a major risk to surrounding water and soil systems (Achterberg *et al.,* 2003). Chemical problems associated with surface mining, such as acid generating materials, are thus significant (Darmody *et al.,* 2002) and in mine spoils, the geomorphic system is in disequilibrium (Dutta and Agarwal, 2001). Unfavorable soil chemistry and poor structure also deprive soil microbe and plant growth (Pederson *et al*., 1988).

Many traditional technologies are extremely costly and time-consuming; other methods for cleaning up the environment require the use of other chemicals that may not always be benign with respect to the various compartments. An alternative to conventional technologies is phytoremediation, in which specially selected plants with a particularly high affinity for heavy metals are used to restore degraded soils (Pilon-Smits, 2005, Mohanty and Patra, 2011, Chaturvedi *et al*., 2015). Thus, a brief review of general environmental problems related to mining activities, types of phytoremediation processes, plants which can be used a potential phytoremediation tool, examples of its field applications, advantages and constrains in application, its cost effectiveness as compared to conventional remediation techniques as well as issues impending its long-term success have been compiled in this section.

2. Wastes associated with iron ore extraction and beneficiation

Waste may mean one or more of the following. Any substance that is discarded, emitted or deposited in the environment in such volume, constituency or manner as to cause an alteration to the environment or any otherwise discarded, rejected, unwanted, surplus or abandoned substance intended for sale or for recycling, reprocessing, recovery or purification by a separate operation from that which produced the substance. Waste generation is a major issue in every country, and waste quantities are generally growing. Total waste quantities continue to increase the problem in mining and allied industries. The impact of waste on the environment, resources and human health depends on its quantity and nature. The generation and of waste include emissions to air (including greenhouse gasses), water and soil, all with potential impacts on human health and nature.

Mining wastes is generated during the process of extraction, beneficiation and processing of minerals. Extraction is the first phase that consists of the initial removal of ore from the earth. This is normally done by the process of blasting, which results in generation of large volume of waste (soil, debris and other material). This is useless for the industry and is normally just stored in big piles within the mine lease area, and sometimes, on public land. The bigger the scale of the mine, greater is the quantum of waste generated.

Though most mining wastes, such as overburden, are inert solid materials, the industry also generates waste that is toxic in nature. Some of these toxic are inherently present in the ore, for example, heavy metals such as mercury, arsenic, lead, zinc, cadmium, etc. These heavy metals leach out of the stored waste piles, contaminating the local environment. Opencast mines are therefore more pollution intensive as they generate much higher quantities of waste compared to the underground mines. Open-pit mines produce 8 to 10 times as much waste as underground mines (Anon, 2006). Once the ore is brought to the surface, it is processed to extract the mineral, which itself generates immense quantities of waste. That is because the amount of recoverable metal in even high-grade ores is generally just a small fraction of their total mass. Moreover, as the higher-grade mineral deposits are being exhausted, the mineral industry is generating more and more quantity of waste, as they have to now depend on lower grades of reserve.

Next to coal and limestone, iron ore mines are the biggest contributor to total mining wastes generated in India. According to the data of the Indian Bureau of mines (IBM), for iron ore mines, the stripping ratio varies widely and is about 1-3:1; this does not include the wastes generated during beneficiation and processing, which can be very high. The main types of mining waste in addition to topsoil and overburden can be classed into two categories as follows.

2.1. Waste rock (Mine Rock Piles)

The solid material generated in the largest quantities by iron ore extraction is the material that overlies the ore body (the overburden) and the other rock that has to be removed to gain access to the ore (the mine development rock and waste rock). The quantity and composition of waste rock vary greatly between sites. These wastes contain minerals associated with the ore body and host rock. The materials can occur in a wide range of particle sizes owing to variations in ore formations and differences in mining methods. In many operations, waste rock is disposed of in piles located near the mine (Van Ness, 1980). It also can be used in dams or other on- or off-site construction. Mining operations generate two types of waste rock - overburden and mine development rock. Overburden is defined as the material other than the mineral generated during the process of excavation, which is not useful including topsoil while mine development rock is a byproduct of mineral extraction in underground mines.

The ratio of overburden excavated to the amount of mineral removed is called the overburden ratio or stripping ratio. For example a stripping ratio of 4:1 means that 4 tons of waste rock are removed to extract one ton of ore. Lower the ratio, the more productive the mine. Stripping ratio varies with the area undermining (Anon, 1998). For iron ore mines, the stripping ratio ranges around 2-2.5. (BBY Limited Resources, POSCO) This means that for every ton of iron ore produced, double the quantity of waste is generated. In 2003-04 themselves, Steel Authority of India (SAIL) generated 4.76 million tons of overburden and rejects from its 12 mines in the country (Anon, 2005). Overburden is typically not contaminated with toxic components. However, when these are disposed on useful and arable lands for indefinite period, it leads to its degradation. Apart from this, they also degrade adjoining lands sometimes due to leachate, change of local drainage pattern and groundwater conditions. Furthermore, overburden management of most Indian mines is rather poor as they make big piles of waste which are often a hazard for the workers and community.

Six workers were killed on 9th December 2006 when iron ore mining waste dumps collapsed in the Tollem mines in Goa, India. The nearly 100-metre high overburden dumps - covering an area in a 200-metre radius - gave way burying the excavating machines as well as the operators beneath them in the interior Sanguem iron-ore mining heartland of the state. The landslide was so sudden that those trapped were unable to even react. Military personnel was called in to carry out the rescue operations. A case of negligence was filed against the board of directors and managers of the mine (India E News, 2006). The low priority is given to the mine operators, especially in small-scale and illegal mines, to overburden management culminated into this tragedy. There are several such cases, many of which are not even reported.

2.2. Tailings (Processing Waste)

Tailings are the result of mineral beneficiation/milling process. Many minerals cannot be used for metal extraction directly as the concentration of the basic ore is less and has to be concentrated before it can be used. During the process of concentration, this involves grinding and milling, tailings are generated which is in a form of slurry. The characteristic of tailings depends on the type of ore and hence varies from mineral to mineral. It also depends on the ore physical and chemical processes used to extract the economic product. However, there are certain common contents of tailings such as arsenic, barite, calcite, cyanide, fluorite, mercury, pyrite and quartz. The slurry or the tailing is stored in a storage area commonly known. Most common storage facility used today are the dams, embankments and other types of surface impoundments and remain of primary importance in tailings disposal planning as a Tailings Dam or a Tailings Management Facility (TMF) or Tailings Storage Facility (TSF).

The quantity of tailings generated from iron ore mining depends on the quality of the ore. In some areas like Kudremukh (Karnataka, India), the ore mined is of low grade and contains about 35 to 38 percent of iron and the balance 62 to 65 percent, after going through the process plant, becomes tailings. Therefore, the mines of Kudremukh Iron Ore Company Limited (KIOCL) generated substantial quantity of tailings, approximately 14.0 million tons per annum. These iron tailings were stored in earthen dam, called Lakya Dam, with a height of 100 meters. As in 2005, around 150 million tons of tailings are stored in Lakya Dam (Anon, 2005a).

Laboratory characterization of iron ore tailings or slimes has indicated that they are largely made up of extremely fine material. More than 60% of the particulates in such slimes have diameters that are <20 µm (Das *et al.* 1993). Moreover, the silica and alumina content of the tailings is quite high, which requires both beneficiation and agglomeration treatment prior to their use in steel making. The distribution of particle sizes in tailing slurries is solely dependent on the beneficiation process adopted. The distribution size of particulates is important because iron-ore particles and associated total suspended solids (TSS) constitute the main water pollutants that require downstream treatment before being discharged. The extent to which iron ore tailings are produced at different washing plants in India from iron-ore mining activities is presented in **Table 1.** From the foregoing, it is evident that large quantities of iron ore slimes are annually produced in India and the iron content of such waste streams varies between 52 and 62.8% Fe. Iron ore tailings are also contaminated with parts per million levels of heavy metal ions such as Cu, Pb, Zn, Cr, Sn, Mo and U as well as lower levels of macronutrients. Many of these potentially toxic elements reach and become pollutants of water.

Table. 1 Fe content of iron ore slimes from mining operations produced at different washing plants in India.

Washing plants	Production (t/year)	Average Fe content (%)
Daitari	0.3	60
Bailadilla-14	1.2	62.8
Bailadilla-5	0.5	61.2
Barsua	0.6	52.5
Kiriburu	1.6	60.4
Donimalai	1	57.9
Meghahatuburu	0.6	60
Bolani	0.4	59.8
Noamundi	0.75	58.1
Kudremukh[a]	15	26.6

[a]No longer in operation; *t* metric tons *Source*: Mohanty *et al.* 2010

The composition of various inorganic contaminants in a typical set of different slimes is shown in **Table 2.** Concentrations of toxic heavy metals such as Cu, Fe, Mn, Zn, Cr, Mo, Ni and Co have been found in mine water, as well as in iron tailings. It has also been reported that high concentrations of heavy metals, viz., Cu, Fe, Mn, Zn, Cr, Mo, Ni and Co, are also found in the soils of surrounding localities. The soil concentration of metal ions at such sites varies as follows: Fe (33.2–121.5 g/L), Mn (0.39–1.39 g/L), Cr (57–204 g/L), Co (1.3–4.6 g/L), Cu (25.8–93.0 g/L), Mo (1.08–4.25 g/L) and Zn (15.5–55.9 g/L; Ghosh and Sen 2001). The high levels of these toxic metal ions produce an adverse effect on growth and development of plants, animals and humans. Therefore, it is essential that eco-friendly techniques are developed to reduce potentially damaging exposures to these metals.

Table 2. Detailed chemical composition of different iron ore slimes at selected mines in India.

Constituents	Mine Locations in India							
	Daitari	**Bailadilla**	**Barsua**	**Kiriburu**	**Donimalai**	**Meghahatuburu**	**Bolani**	**Noamundi**
Fe	59.8	61.2	52.5	60.3	57.9	57.8	59.3	26.8
SiO_2	2.3	6.84	7.82	2.96	6.42	4	4.1	51.2
AlO_3	4.52	2.81	9.88	4.96	6.28	8.3	4.8	1.82
MnO	0.08	0.8	0.1	0.12	0.08	0.03	0.03	0.08
CaO	0.09	0.11	0.11	0.14	0.12	0.08	0.09	0.11
MgO	0.06	0.05	0.07	0.07	0.05	0.04	0.06	0.06
LOI	7	2.34	7.4	5.1	3.9	5.2	5.2	4.05

LOI; Loss on ignition *Source*: Mohanty *et.al*, 2010

In addition to the two major wastes mentioned above **mine waste water** is also of major concern to the environmental health. Because mine water that is discharged or otherwise released to the environment can be a source of contamination, it is addressed in this section although it is not always a RCRA-defined waste (EPA, 1994). It includes mine and mill water. Mining, mineral processing and metallurgical extraction not only involves the removal and processing of rock and the production and the disposal of solid waste, but also the production, use and disposal of mine water. The water commonly contains process chemical. At some stage of mining operation, water is unwanted and has no value to the operation. Such mine water is generated and disposed of at various stages during mining, mineral processing and metallurgical extraction. Water of poor quality requires remediation as it is uncontrollable discharge, heat, suspended solid, bases, acids and dissolves solids including process chemical, metals, metalloids, radioactive substances or salts. Such a release count results in a pronounced negative impact on the environment surrounding the mine site (Kachhap, 2010).

Water exposed to sulfur-bearing minerals in an oxidizing environment, such as open pits or underground workings, may become acidified and leading to acid mine drainage (AMD). "Acid mine drainage" (AMD) refers to the particular process whereby low pH mine water is formed from the oxidation of sulfide minerals. In fact, the acid stream draining such ores and rock can contain high levels of metals and metalloids that exceed water quality standards and result in toxic effect to the aquatic life (Kachhap, 2010).

3. Environmental Impacts of Mining

The environmental problems associated with the iron ore mining are diverse. The removal of vegetation, topsoil, overburden/waste and ore, brings about the inevitable natural consequences, which manifest in many ways, deforestation, climatic change, erosion, air and water pollution and health hazards. A discussion of the potential environmental effects associated with iron ore mining is presented in the following sections. Specific examples from the iron ore mining zones of India are also included in this section, as appropriate.

3.1 Water Pollution

Exposed ore, overburden piles, waste rock and ore piles, tailings impoundments, and other disturbed areas can contribute sediment and increase the total solids load to surface water bodies. Other potential sources of surface and groundwater contamination include fuel spills, flotation reagents, cleaning solutions, and other chemicals used or stored at the site. For iron recovered from sulfide-bearing ores, acid generation due to the oxidation of sulfides (e.g., pyrite and pyrrhotite) in the ore body, host rock, and waste material may be of concern. Trace elements and minerals often associated with iron deposits includes aluminum, antimony, arsenic, beryllium, cadmium, chromium, copper, lead, manganese, nickel, selenium, silver, sulfur, titanium, and zinc (U.S. DOI, Geological Survey, 1973). Lowering of pH increases the solubility of these constituents and may make them available for transport in both surface water and ground water. After a mine is abandoned, pumping is usually stopped, allowing the pit or underground workings to fill with water. Over time, this may lead to uncontrolled releases of mine water.

The Orissa State Pollution Control Board (SPCB) in its “State of environment report, Orissa” (Orissa State Pollution Control Board, 2006) has classified Joda–Barbil region of Keonjhar district as a highly polluted zone (Zone 1). During the rainy season, the water in rivers turns red with heavy concentration of particles of iron oxide and the total suspended solids often go up to 1000mg/liter. Overflow of mine seepage and effluents from beneficiation plants normally find their way to streams and pollute streams passing through the mines areas.

Goan (India) iron ore has a relatively high overburden to ore ratio (of an average of about 2.5 to 3:1) and thus generates a large quantity of waste material. Since the size of mining leases are small, mining companies often acquire land outside their lease area to dump waste material.(ISID , 2012) Lands being in short supply, waste dumps are typically steep with slopes greater than 30 degrees and height of 30-50 meters. Many waste dumps are situated in the upper part of the valley regions and during the rainy season runoff from dumps settle down on agricultural fields and in water bodies. A 2001 study by the Centre for Ecological Sciences of the Indian Institute of Science, Bangalore, pointed out that large-scale deforestation had resulted in an increased flow of silt and iron ore tailings into the Bhadra Reservoir. Water quality data from various iron ore mines presented in Central Pollution Control Board (2008), India show that in Goa mines different major parameters were within the prescribed standards. The pH, for example, varied from 5.3 to 9.6 with an average of 6.87 (out of 103 observations) as against the prescribed standards of 6.5 to 8.5.

TERI (1998) had concluded that the water of Goa’s rivers “would fall in class B or C of Central Pollution Control Board (CPCB) ambient water classification”. It also came to the conclusion that the major effect of mining activities on the river quality is the presence of high turbidity due to discharge of silt particles and the worst affected rivers were Bicholim, Madei and Khardepur. Another problem that is faced is that deepening of mines (located below the ground water level) has led to loss of recharge area of the wells and springs that serve the nearby villages. NEERI (2009) had concluded that the drying up of the (Sirigaon) village dug wells could be attributed to the loss of recharge area as well as the deepening of the mine.

Take the case of Lamgaon village in Goa 30 kilometers (18.7 miles) east of Panaji, capital of India's Goa State, which is struggling with problems due to waste from the nearby iron ore mine. The waste from mining, mostly, fine clay, is dumped on hill slopes. From there it is washed down by monsoons rains into lakes, riverbeds and irrigation channels. The villagers complain that so much silt runs into the land that the level of the field has raised by about a third of a meter (3.29 feet). The fertile land which used to once yield more than two tons of paddy is buried under the clay from the mine on the hill. The channel that brings water to the fields in this field is also chocked by silt. Its depth has fallen more than a meter (3.29 feet) to 15 centimeters (6 inches) in the last decade. Many villages in the state have been hit by the activities of the 150 mines, which cover about 23,000 in the state (Venkatramani, 1992). Villagers and environmentalists have protested against the side effects of mining, but it is only recently that a series of public forums and a long march have drawn media attention and raised awareness of the problem

3.2 Air Pollution due to Dust and Noxious fumes

The primary sources of air contamination at mine sites are fugitive dust from dry surfaces of dry tailings impoundments, as well as overburden, waste rock, and ore piles. Often, tailings impoundments are not completely covered by pooled water; thus, dry tailings may be available for windblown transport. Deposition of windblown tailings provides exposure routes for contamination of ground water, surface water, and soil. Air pollution is also a major problem in the mines area, with concentration of suspended particulate matter (SPM) in ambient air much above the permissible limit in many places, particularly at crusher loading and transfer points.

Mining, especially surface mining, is extremely devastating, as witnessed in the vast deserts capes created in the iron ore belts of Goa, the limestone belts of Rajasthan, the hills of Uttar Pradesh , and the coal belt of east India, among other areas. In Goa, to the south of Mollem, the Verlem Forest block in the Netravali Sanctuary to the northeast of Cotigao is under pressure from manganese mining. Mountains of overburden are dumped on evergreen forests (Vagholikar, Moghe and Dutta, 2003).

A large number of pine trees have been damaged due to mining activities in the Jhirauli magnesite mines area near Almora, in Uttaranchal. Thick layers (4.5 cm) of magnesite dust can be seen from a distance of 6.7 km away from the mine at Kaphligair. The dust accumulations have drastically influenced the ground flora - the epiphytic cryptogamic vegetation like grasses, herbs, mosses and lichens have completely vanished. Roads connecting the mine sites to the main roads are extremely dusty. As vehicle pass, the dust particles blown in the atmosphere ultimately settle on the trees and grass leaves, causing severe physiological disorders (Upadhyaya and Pant 1988). The State of the Environment Report of Karnataka (2003), India stated that there were mine dust deposits on roadside agricultural land as well. The semi-arid climatic condition of the area combined with unscientific mining, especially by small miners and opting for semi-mechanized and manual mining methods have resulted in dust being the main pollutant.

3.3 Soil Erosion and Contamination

Environmental impacts to soils as a result of mining activities are most commonly associated with erosion and contamination. Erosion may be caused by land disturbances and removal of vegetation related to mining activities. Under these conditions, precipitation events, such as snowmelt, may lead to erosion of soils. Contamination of soils may result from water discharge, runoff, seepage from tailings impoundments, pits and mine workings, as well as from the overburden, waste rock, and ore piles directly to soils. In addition, deposition of windblown particulates from piles and dry tailings impoundments may also be a source of soil contamination. Other sources of soils contamination include spills of fuels, flotation reagents, cleaning solutions, as well as other chemicals used or stored at the site.

4. Waste Management in Mining Industries

Disposal of mine wastes historically involved either returning the materials to the mining site; dumping into the ocean, a stream, or lake; or placing them into a receiving pond. Today, surface containment of tailings within embankments remains a commonly used approach. In 1995, it was estimated that on an annual basis over 700 million kg of Metals in mine tailings were disposed on land (Warhurst 2000). Alternatively, tailings may be returned to the mine (in-pit storage or backfilling) or mixed with coarse mine waste (codisposal). However, they remain unstable and subject to eolian dispersion and water erosion with the potential to contaminate nearby communities and environmentally sensitive areas.

4.1 Conventional Remediation

Conventional technologies for remediation of mine tailings have focused on physical and chemical stabilization. Physical stabilization entails covering mine waste with an innocuous material, generally waste rock from mining operations, gravel, topsoil from an adjacent site, or a clay capping, to reduce wind and water erosion. These solutions are often temporary in nature because of the impermanence of the capping process (Johnson and Bradshaw 1977). Engineering techniques such as soil washing, burning, excavation and removal are used to remediate heavy-metal-contaminated soils, but the cost of these procedures is very high (Pilon-Smits, 2005). For this reason, the development of low-cost, effective, and sustainable technologies to remediate heavy-metal-contaminated soils is very important and long overdue (LeDuc and Terry, 2005), and it should receive considerably more attention. At the same time, phytoremediation is a cost effective and eco-friendly "green" remediation technology for environmental cleanup. (Mohanty et *al*. 2010; Mohanty and Patra, 2011)

4.2 Phytoremediation

The concept of using plants is not new to clean up contaminated environments. About 300 years ago, plants were proposed for use in the treatment of wastewater (Hartman, 1975). *Thlaspi caerulescens* and *Viola calaminaria* were the first plant species documented to accumulate high levels of metals in leaves. In 1935, Byers reported that plants of the genus *Astragalus* were capable of accumulating up to 0.6 % selenium in dry shoot biomass. One decade later (Minguzzi and Vergnano, 1948) identified plants able to accumulate up to 1% Ni in shoots. More recently (Quartacci, 1977), reported tolerance and high Zn accumulation in shoots of *Thlaspi caerulescens*. The concept of using plants to absorb metals from contaminated soil was reintroduced and developed by Utsunamyia and Chaney (Chaney 1983), and the first field trial on Zn and Cd phytoextraction was conducted in 1991 (Baker et al. 1991). In the last decade, extensive research has been conducted to investigate the biology of metal phytoextraction. Although significant success, our understanding of the plant mechanisms that allow metal extraction is still emerging.

4.2.1 Phytoremediation process

The phytoremediation process (**Figure 1**) can be divided into different classes (Pilon-Smits, 2005): (i) Phytostabilisation – the contaminant remains complexed in root tissues, thus being unable to move through the soil; (ii) Rhizodegradation – the contaminant, generally organic, is degraded by rhizosphere-specific microorganisms; (iii) Phytovolatilisation – the contaminant (inorganic or organic), once absorbed, is physically changed to a gaseous state by the plant's metabolism; (iv) Phytodegradation – similar to phytostimulation/ rhizodegradation but occurring in the aerial parts of the plant; (v) Phytoextraction – the contaminant is absorbed, and high concentrations are transported to the aerial parts of the plant, making it possible to harvest the aboveground plant parts containing the contaminant (Souza *et al.* 2013).

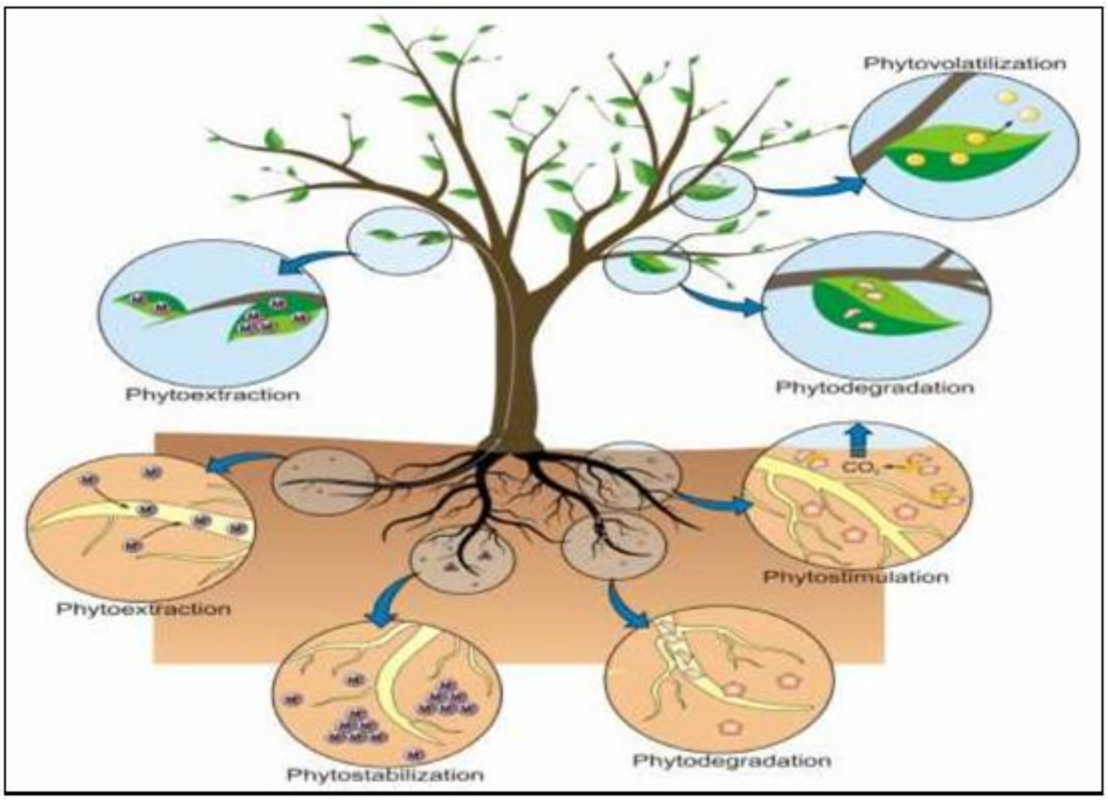

Fig. 1 Phytoremediation processes. (Source; ITRC, 2009)

5. Heavy Metal Uptake by Plants and Their Fate in Cellular Metabolism

Plants, like all other organisms, have evolved different mechanisms to maintain physiological concentrations of essential metal ions and to minimize exposure to non-essential heavy metals as a first line of defense, many plants exposed to toxic concentrations of metal ions attempt to prevent or reduce uptake into root cells by restricting metal ions to the apoplast, binding them to the cell wall or to cellular exudates, or by inhibiting long distance transport. If this fails, metals already in the cell are addressed using a range of storage and detoxification strategies, including metal transport, chelation, trafficking, and sequestration into the vacuole. When these options are exhausted, plants activate oxidative stress defense mechanisms and the synthesis of stress-related proteins and signaling molecules, such as heat shock proteins, hormones, and reactive oxygen species (Manara, 2012).

6. Phytoremediation for Reclamation of Abandoned Mine Sites

The restoration of a dense vegetation cover is the most useful to physically stabilize the mine wastes and to reduce metal pollution effects. Different plant species that are well-adapted to the local conditions, capable of excluding and accumulating heavy metals without showing toxic symptoms are the ideal species that should be considered for early stages of revegetation of the 'green corridor' or establishment of 'green belt'. Several of the grasses, legumes and trees can be a suitable material for this purpose. Bermuda grass (*Cynodondactylon*), has been suggested for stabilizing metalliferous soils. Populations of a variety of higher plant species are known to colonize degraded mine soils in which other cultivated plants cannot survive. Thus, the plant community tolerant to heavy metals plays a major role in remediation of degraded mine soils. So far, approximately 400 metal hyperaccumulators have been identified. The success of any phytoremediation technique depends upon the identification of suitable plant species that hyper-accumulate heavy metals and produce large amount of biomass using established crop production and management. Tree-grass-legume association was found to be the best combination for restoration of mica, copper, tungsten, marble, dolomite, limestone, and mine spoils of Rajasthan state and elsewhere in India.

Bioremediation of mine spoil dumps is being conducted since 1989, which enabled restoration of soil productivity over 247 hectares of mine soil dumps/ (including coal mines) and restoration of silted soil in 2004 at different locations in India (M.N.V.Prasad, 2011). Knowledge of the diversity of plant responses in contaminated sites having different metals and toxicity levels is important to study the composition of plant community that was established on degraded soils or mine spoil, which would serve as a basic approach for mine remediation(Mukhopadhyay and Maiti, 2010). Plant species suitable for revegetation of mine spoils and commercialization of integrated biotechnological approaches for reclamation of abandoned mines are shown in **Table. 3.** The selection of trace element tolerant species is a key factor to the success of remediation of degraded mine soils. For long-term remediation, metal tolerant species are commonly used for revegetation of mine tailings and herbaceous legumes can be used as pioneer species to solve the problem of nitrogen deficiencies in mining wastelands because of their N fixing ability (Lan *et al*., 1997).

Table. 3. Plant species suitable for revegetation of mine spoils (Prasad, 2007)

Mine spoil category	**Suitable plant species**
Bauxite mined area of Madhya Pradesh	*Grevillea pteridifolia. Eucalyptus camaldulensis, Shorea robusta*
Coal mine spoils of Madhya Pradesh	*Eucalyptus hybrid, Eucalyptus camaldulensis, Acacia auriculiformis,Acacia nilotica, Dalbergia sissoo, Pongamia pinnata*
Limestone mine spoils of outer Himalayas	*Salixte trasperma, Leucaena leucocephala, Bauhinia retusa, Acacia catechu, Ipomea cornea, Eulaliopsis binata, Chrysopogon fulvus, Arllndodonax, Agave americana, Pennisetum purpureum, Erythrina subersosa*
Rock-phosphate mine spoils of Musoorie	*Pennisetum purpureum, Saccharum spontaneum, Vitex negundo, Rumeshastatus. Mimosa himalayana, Buddlea asiatica, Dalbergia sissoo, Acacia catechu, Leucaena leucocephela* and *Salix Tetrasperma*, etc.
Lignite mine spoils of Tamil Nadu	*Eucalyptus species, Leucaena leucocephala, Acacia* and *Agave*

Mica, copper, tungiston, marble, dool, mite, limestone, and mine spoils of Rajasthan	*Acacia tortilis. Prosopis juliflora, Acacia Senegal, Salvadora oleoides, Tamarix articulata.* *Zizyphus nummularia, Grewia tenax, Cenchrus setigerus. Cymbopogon, Cynodon dactylon.* *Sporobollis marginatus, D.annlllalum*
Iron ore wastes of Orissa	*Leucaena leucocephala*
Haematite, magnetite, manganese spoil from Karnataka	*Albizia lebbeck*

Maiti and Nandhini (2005) reported that nine plant species grown on Fe tailings as a part of their pilot scale study conducted in Noamundi, Tata- Steel were able to survive the tailings and Maximum accumulation of Fe was found in *Oxalis* (7442 mg kg -1) whereas Mn and Zn accumulation was maximum in *Blumealacera*(88 mg kg-1) and *Averaaspera*(109 mg kg-1) respectively.In another field study conducted by Das and Maiti (2007) in an abandoned copper mine tailings (Rakha mine, Jharkhand, India), to find out accumulation of metals (Cu, Ni, Mn, Zn, Pb, Cd and Co) in the naturally colonizing vegetation. It was observed that out of 11 species, growing on copper tailings, in *Ammannia baccifera* levels of Cu accumulation in the root parts was found even more than 1000 mg kg^{-1} dry weight (DW). Metals accumulated by *A. baccifera* were mainly restricted to root tissues.

In a field study, mine wastes containing Cu, Pb and Zn were stabilized by grasses – *Agrostis tenuis* for acid lead and zinc mine wastes, *Agrostis tenuis* for copper mine wastes, and *Festuca rubra* for calcareous lead and zinc mine wastes (Smith and Bradshaw, 1979; (Mukhopadhyay and Maiti, 2010).

In a field trial conducted by Yang *et al*. (2003) at Lechang Pb/Zn mine tailings of Guangdong Province, Southern China to compare growth performance, metal accumulation of Vetiver (*Vetiveria zizanioides*) and two legume species (*Sesbania rostrata* and *Sesbania sesban*) grown on the tailings amended with domestic refuse and/or fertilizer. It was observed that the combination of domestic refuse and artificial fertilizer significantly improved the survival rates and growth of *V. zizanioides* and two *Sesbania* species.

Bech *et al.* (2002) reported the results of the screening of plant species from three different mining areas in South America: a copper mine in Peru (Mina Turmalina), a silver mine in Ecuador (Mina San Bartolomé) and a copper mine in Chile (Mina El Teniente). Among the grass species (*Poaceae*), the highest concentration of as was observed in the shoots of *Paspalum sp*. (> 1000 mg kg^{-1}) and *Eriochloa ramosa* (460 mg kg^{-1}) from the Cu mine in Peru, and in *Holcus lanatus* and *Pennisetum clandestinum* (> 200 mg kg^{-1}) from the silver mine in Ecuador.

Konstantinou and Babalonas, 1996 studied the metal uptake capacity by *Caryophyllaceae* species (*Dianthus*, *Minuartia*, *Scleranthus* and *Silene*) from metalliferous soils in northern Greece, having different concentrations of Cu, Pb, Zn, Cd, Ni, Cr, Fe, Mn, Ca, Mg and concluded that *Scleranthus perennis* subsp. *Perennis* showed the highest Cu concentration (205 mg kg^{-1}), whereas *Minuartia cf. bulgarica* hyper accumulated Pb (1175 mg kg^{-1}).

Dinelli and Lombini (1996) collected Mine spoil dump material and plants *Silene armeriu* (*Caryophyllaceous*), *Salix* spp. (*Salicaceae*) and *Populus nigra* (*Salicaceae*) samples at 4 different growing stages in order to study their respective metal uptake pattern from the pyrite-chalcopyrite mining area of Vigonzano (Northern Apennines, Italy). The results indicate that metal concentrations increase with plant ageing, the highest concentrations being observed in leaves.

In a study conducted by Blaylock *et al*. in 1999 at a lead-contaminated site in Trenton, New Jersey, the soil was treated for phytoremediation using successive crops of *B. juncea* combined with soil amendments. Through phytoremediation, the average surface soil Pb concentration was reduced by 13%. In addition, the target soil concentration of 400 mg/kg was achieved in approximately 72% of the treated area in one cropping season. It is found that the integration of specially selected metal accumulating crop plants *(Brassica juncea (L.) Czern.*)With innovative soil amendments allows plants to achieve high biomass and metal accumulation rates (Mukhopadhyay and Maiti, 2010).

7. CONCLUSION

The contamination of soil, air and water resources with heavy metals is one of the major environmental concern today. Metals and other inorganic contaminants are among the most prevalent forms of contamination found at waste sites, and their remediation in soils and sediments is technically most difficult due to their persistent nature. The high cost and ineffectiveness of existing cleanup technologies have led to the search for certain low-cost, low-impact, visually benign, and environmentally sound cleanup strategies. Under these circumstances, phytoremediation can be a better alternative to the environmentally destructive traditional remediation technologies. No doubt, phytoremediation technologies are still in research and development phase but various field applications have shown potential for success. This, in turn, has helped to increase interest and research in both public and private sectors, in an attempt to develop phytoremediation into a commercially viable industry. However, Some key technical hurdles must be overcome for an industry to adopt this plant-based technology on commercial scale like identifying more species with remediation abilities, appropriate plant selection and agronomic practices optimizing phytoremediation processes, understanding more about the mechanism of uptake, translocation, and metabolization of the contaminant concerned, to identify or genetically construct plants that are hardy enough to tolerate high shoot metal concentrations and still produce large amounts of biomass which in turn can reduce the required number of cropping cycles to a minimum, identifying genes responsible for the tolerance of the concerned plant species with respect to a particular contaminant and extensive research under field conditions. Furthermore, the technique must be tailored to the physicochemical characteristics (pH, cation exchange capacity, electrical conductivity, and metal content) of individual mine tailings sites. Sufficient and honest advertisement of the successful ventures must be made to the scientific community as well as public to enhance its acceptability as global sustainable technology.

8. REFERENCES

1. Achterberg, E.P., Herzl, V.M.C., BraungardtC.B. and Millward G.E. (2003). Metal behaviour in an estuary polluted by acid mine drainage: The role of particulate matter. *Environmental Pollution* 121:283–292.

2. Anon (1998). Base metal and iron ore mining, Pollution Prevention and Abatement Handbook, World Bank, pp 1.

3. http://www.ifc.org/ifcext/enviro.nsf/AttachmentsByTitle/gui_mining_WB/ $FILE/mining_PPAH.pdf. As viewed on 2nd Feb, 2007.

4. Anon (2005a). Environmental Management at KIOCL, Kudremukh, MINENVIS, a newsletter of the ENVIS Centre on environmental problems of mining areas, Indian School of Mines, pp 1.
5. Anon (2006). Dirty Metal, Mining Communities and Environment, Earthworks, Oxfam America, Washington, pp 4.
6. Andrés-Colás N., Sancenón V., Rodríguez-Navarro S., Mayo S., Thiele D.J., EckerJ.R., Puig S., and Peñarrubia L. (2006). The Arabidopsis heavy metal P-type ATPase HMA5 interacts with metallochaperones and functions in copper detoxification of roots. *Plant J* 45:225–236.
7. Arazi T., Sunkar R., Kaplan B. and Fromm H. (1999). A tobacco plasma membrane calmodulin binding transporter confers Ni2+ tolerance and Pb2+ hypersensitivity in transgenic plants. *Plant J* 20:171–182.
8. Assunção A.G.L., Da Costa Martins P., De Folter S., Vooijs R., Schat H. and Aarts M.G.M. (2001). Elevated expression of metal transporter genes in three accessions of the metal hyperaccumulator *Thlaspi caerulescens*.*Plant Cell Environ* 24:217–226.
9. Bah, A.M., Dai, H., Zhao, J., Sun, H.,Cao, F., Zhang, G. and Wu,F.(2011). Effects of cadmium, chromium and lead on growth, metal uptake and antioxidative capacity in *Typhaangustifolia*.*Biol.Trace.Elem.Res.*142: 77–92.
10. BBY Limited Resources, POSCO, Murchison Metal Limited.
11. Barber SA. 1984. Soil Nutrient Bioavailability, John Wiley & Sons, NY.
12. Baker A.J.M., Reeves R.D. and Chin M. (2000). Improving metal hyperaccumulator wild plants to develop commercial phytoextraction systems: approaches and progress, N. Terry, G. Banuelos, Editors , Phytoremediation of Contaminated Soil and Water, Lewis, Publ., Boca Raton, FL, 129– 158.
13. Blaylock, M.J., M.P. Elless, Huang, W. Jianwei, S.M. Dushenkov (1999). Phytoremediation of lead-contaminated soil at a New Jersey brownfield site. *Remediation*, 9(3): 93-101.
14. Bringezu K., Lichtenberger O., Leopold I., Neumann D. (1999).Heavy metal tolerance of *Silene vulgaris*.*J Plant Physiol* 154:536–546.
15. Central Pollution Control Board. (2008). “Comprehensive Industry Document on Iron Ore Mining” (COINDS/77/2007-08), Central Pollution Control Board (CPCB), Ministry of Environment and Forests, May.
16. NilimaChaturvedi, N.K. Dhal and H.K. Patra (2015).EDTA and citric acid-mediated phytoextraction of heavy metals from iron ore tailings using *Andrographis paniculata:* a comparative study. International Journal of Mining, Reclamation and Environment29 (1)33-46.
17. Chaney R.L. (1983). “Plant uptake of inorganic waste, Inland treatment of hazardous waste”, eds Parr JE, Marsh PB, KlaJM, 50-76.
18. Cobbett C.S. (2000). Phytochelatin biosynthesis and function in heavy-metal detoxification. *CurrOpin Plant Biol* 3:211–216.
19. Cobbett C.S. and Goldsbrough P. (2002).Phytochelatins and metallothioneins: roles in heavy metal detoxification and homeostasis. *Annu Rev Plant Biol* 53:159–182.
20. Cohen C.K., Fox T.C., Garvin D.F., KochianL.V. (1998). The role of Iron-deficiency stress responses in stimulating heavy metal transport in plants. *Plant Physiol* 116:1063–1072.
21. Crowley D.E., Wang Y.C., Reid C.P.P., SzansiszloP.J. (1991).Mechanism of iron acquisition from siderophores by microorganisms and plants.*Plant Soil* 130: 179-198.
22. ColangeloE.P, GuerinotM.L. (2006). Put the metal to the petal: metal uptake and transport throughout plants. *CurrOpin Plant Biol* 9:322–330.
23. Curie C., Alonso J.M., Le Jean M., EckerJ.R. Briat J.F. (2000). Involvement of NRAMP1 from Arabidopsis thaliana in iron transport.*Biochem J* 347:749–755.
24. Darmody, R.G., Dunker, R.E. and Barnhisel, R.I. (2002). Reclamation of prime agricultural lands after coal surface mining: the Midwestern experience. National Meeting of the American Society of Mining and Reclamation, Lexington KY, June 9–13, 2002. Published by ASMR, 3134 Montavesta Rd., Lexington, KY 40502, pp 900–915.
25. Das B/, Ansari M.I., Mishra D.D. (1993). Effective separation of Barsua iron ore slimes using hydro cyclone. *Miner Metallurg Process* 52:52–55.
26. DalCorso G., Farinati S. and Furini A. (2010). Regulatory networks of cadmium stress in plants. *Plant Signal Behav* 5:663–667.

27. DiDonato R.J. Jr, Roberts L.A., Sanderson T., EisleyR.B. Walker and E.L. (2004). Arabidopsis Yellow Stripe-Like2 (YSL2): a metal-regulated gene encoding a plasma membrane transporter of nicotianamine–metal complexes. *Plant J* 39:403–414.
28. Dinelli, E. and Lombini L. (1996). Metal distribution in plants growing on copper mine spoils in Northern Apennies, Italy: the evaluation of seasonal variations. *Applied Geochemistry*, 11: 3 7 53 85.
29. doNascimento, C.W.A.; Amarasiriwardena, D.; Xing, B.S. (2006a). Comparison of natural organic acids and synthetic chelates at enhancing phytoextraction of metals from a multi-metal contaminated soil. *Environmental Pollution* 140: 114-123.
30. doNascimento, C.W.A. (2006b). Organic acids effects on desorption of heavy metals from a contaminated soil. *Scientia Agricola* 63: 276-280.
31. Durrett T.P. Gassmann W. and Rogers E.E. (2007). The FRD3-mediated efflux of citrate into the root vasculature is necessary for efficient iron translocation. *Plant Physiol* 144:197–205.
32. Dutta, R.K. and Agrawal, M. (2001).Litterfall, litter decomposition and nutrient release in five exotic plant species planted on coal mine spoils. *Pedobiologia*45: 298–312.
33. Ebbs S.D., Lasat M.M., Brady D.J., Cornish J., Gordon R. and KochianL.V. (1997). Phytoextraction of cadmium and zinc from a contaminated soil, *J. Environ. Qual*. 26:1424–1430.
34. Ebbs S., Lau I., Ahner B. and Kochian L. (2002). Phytochelatin synthesis is not responsible for Cd tolerance in the Zn/Cd hyperaccumulator *Thlaspi caerulescens* (J. & C. Presl). *Planta*214:635– 640.
35. Eide D., Broderius M., Fett J. and GuerinotM.L. (1996).A novel iron-regulated metal transporter from plants identified by functional expression in yeast.*ProcNatlAcadSci U S A* 93:5624–5628.
36. Ernst WHO, VerkleijJAC, Schat H (1992). Metal tolerance in plants.*Acta Bot Neerl* 41:229–248.
37. Foyer, C.H., Lopez-Delgado, H., Dat, J.F., Scott, I.M., 1997. Hydrogen peroxide and glutathione associated mechanisms of acclamatory stress tolerance and signaling. *Physiol. Plant*. 100, 241– 254.
38. Ghosh, M., Singh, S.P. (2005): A review on phytoremediation of heavy metals and utilization of it's by-products. – *Applied Ecology and Environmental Research* 3(1): 1-18.
39. Grill E., Loffler S., Winnacker E.L. and Zenk M.H. (1989). Phytochelatins, the heavy-metal binding peptides of plants are synthesized from glutathione by a specific c-glutamylcysteine dipeptidyl transpeptidase (phytochelatin synthase). *ProcNatlAcadSci U S A* 86:6838–6842.
40. GuerinotM.L. (2000). The ZIP family of metal transporters.*BiochimBiophysActa* 1465:190–198.
41. Gupta, PK (2000) Chemical methods in environmental Analysis: Water, Soil and Air. India, *Agrobios*, 240–241.
42. Hartman WJ. (1975). An evaluation of land treatment of municipal wastewater and physical siting of facility installations. Washington DC; US Department of army.
43. Haag-Kerwer A., Schäfer H.J., Heiss S., Walter C. and Rausch T. (1999). Cadmium exposure in Brassica juncea causes a decline in transpiration rate and leaf expansion without effect on photosynthesis. *J Exp Bot* 50:1827–1835.
44. Howden R., GoldsbroughP.B, Andersen C.R. and Cobbett C.S. (1995). Cadmium-sensitive, cad1 mutants of Arabidopsis thaliana are phytochelatin deficient. *Plant Physiol* 107:1059–1066.
45. India E News (2006). Six Killed in Goa's Mining Tragedy. December 10, 2006, http://www.indiaenews.com/india/20061210/32003.htm.
46. Institute for studies in industrial Development (ISID). Sustainable Development. Emerging Issues in India's Mineral Sector.*Sponsored by* Planning Commission, Government of India, May 2012. ISID, 4 Institutional Area, VasantKunj, New Delhi.
47. Johnson M. S. and Bradshaw A. D. (1977). Prevention of heavy metal pollution from mine wastes by vegetative stabilisation. *Trans Inst Min Metall* A 86:47–55.
48. Jonak C., Kiegerl S., Ligterink W., Barker P.J., HuskissonN.S. and Hirt H. (1996). Stress signaling in plants: a mitogen-activated protein kinase pathway is activated by cold and drought. ProcNatlAcadSci U S A, 93:11274–11279.
49. Jonak C., Okrész L., Bögre L. and Hirt H. (2002).Complexity, cross talk and integration of plant MAP kinase signalling. *CurrOpin Plant Biol*, 5:415–424.

50. Jonak C., Nakagami H. and Hirt H. (2004).Heavy metal stress. Activation of distinct mitogen activated protein kinase pathways by copper and cadmium. *Plant Physiol*, 136:3276–3283.
51. Kachhapsunil (2010). Waste management in mining and Allied industries. Thesis. Department of Mining Engineering National Institute of Technology Rourkela.
52. Kampfenkel K., Kushnir S., Babiychuk E., Inzé D. and Van Montagu M. (1995a). Molecular characterization of a putative Arabidopsis thaliana copper transporter and its yeast homologue. *J BiolChem*270:28479–28486.
53. Khan, M.S., Zaidi, A., Wani, P.A. and Oves, M. (2009). Role of plant growth promoting rhizobacteria in the remediation of metal contaminated soils. *Environmental Chemistry Letters* 7:1–19.
54. Kos, B., Grcman, H. and Lestan, D. (2003). Phytoextraction of lead, zinc and cadmium from soil by selected plants. *Plant Soil and Environment* 49: 548-553.
55. Konstantinou M. and D. Babalonas (1996). Metal uptake by Caryophyllaceae species from metalliferous soils in northern Greece. *Plant Systematics and Evolution*, 203: 1-10.
56. Krämer, U., Talke, I.N. and Hanikenne, M. (2007).Transition metal transport.FEBSLett. 581:2263–2272.
57. Krämer, U., Pickering, I.J., Prince, R.C., Raskin, I. and Salt, D.E. (2000).Subcellular localization and speciation of nickel in hyper accumulator and non-accumulator *Thlaspi* species. *Plant Physiology* 122: 1343-1353.
58. Korenkov V., Park S.H., Cheng N.H., Sreevidya C., Lachmansingh J, Morris J, Hirschi K, and Wagner G.J. (2007). Enhanced Cd^{2+} selective root-tonoplast-transport in tobaccos expressing Arabidopsis cation exchangers.*Planta*225:403–411.
59. Komárek M., Tlustos P., Szakova, J. and Chrastny V. (2008). The use of poplar during a two year induced phytoextraction of metals from contaminated agricultural soils. *Environmental Pollution* 151: 27-38.
60. LeDuc, D.L.; Terry, N. 2005.Phytoremediation of toxic trace elements in soil and water. *Journal of Industrial Microbiology & Biotechnology* 32: 514-520.
61. Lee, C.H., Lee, H., Lee, Y.B., Chang, H.H., Ali, M.A., Min, W., Kim, S. and Kim, P.J.(2007). Increase of available phosphorus by fly ash application in paddy soils. Commun.*Soil Sci. Plant Anal*. 38:1551–1562.
62. Liao, B., Huang, L.N., Ye, Z.H., Lan, C.Y. and Shu, W.S. (2007). Cut-off net acid generation pH in predicting acid-forming potential in mine spoils. *Journal of Environmental Quality* 36:887– 891.
63. Le Jean M., Schikora A., Mari M., Briat J.F. and Curie C. (2005). A loss-of-function mutation in AtYSL1 reveals its role in iron and nicotianamine seed loading. *Plant J* 44:769–782.
64. MaitiS.K. Nandhini S., (2005). Bioremediation of Fe ore tailings and bioaccumulation of metals in the naturally occurring vegetation: A case of Noamundi Fe-ore tailings, TISCO, Noamundi, Int. seminar on Mineral Processing Technology (MPT-2005) Jan.6-8.
65. ManaraMinguzzi C. and Vergnano O. (1948). II content di nichelnelliceneri di Alyssum bertloniiDesv. AttidellasocietaToseana di Science Naturali", MemSer A, 55: 49-77.
66. Maksymiec W, Wianowska D, Dawidowicz AL, Radkiewicz S, Mardarowicz M, Krupa Z (2005). The level of jasmonic acid in *Arabidopsis thaliana* and *Phaseolus coccineus* plants under heavy metal stress. *J Plant Physiol* 162:1338–1346.
67. Maksymiec (2007) Signaling responses in plants to heavy metal stress. *ActaPhysiol Plant* 29:177– 187.
68. Marschner, H. (1995). Mineral Nutrition of Higher Plants, second ed. Academic Press, San Diego.
69. Maas F.M., van de WeteringD.A.M., van Beusichem M.L. and BienfaitHF (1988). Characterization of phloem iron and its possible role in the regulation of Fe-efficiency reactions. *Plant Physiol* 87:167–171.
70. Metwally A., Finkemeier I., Georgi M. and Dietz K. J. (2003) Salicylic acid alleviates the cadmium toxicity in barley seedlings. *Plant Physiol* 132:272–281.
71. Mills R.F., KrijgerG.C, BaccariniP.J. Hall J.L. and Williams L.E. (2003). Functional expression of AtHMA4, a P1B-type ATPase of the Zn/Co/Cd/Pb subclass.*Plant J* 35:164–176
72. Morel M., Crouzet J., Gravot A., Auroy P., Leonhardt N., Vavasseur A. and Richaud P. (2009). AtHMA3, a P1B-ATPase allowing Cd/Zn/Co/Pb vacuolar storage in Arabidopsis. *Plant Physiol* 149:894–904.
73. Mohanty M. and H.K. Patra (2011). Attenuation of Chromium toxicity in mine waste water using water hyacinth. Journal of Stress Physiology & Biochemistry, Vol. 7 No. 4 2011, pp. 335-346.

74. MonalisaMohanty, Nabin Kumar Dhal, ParikshitaPatra, Bisweswar Das, and PalliSita Rama Reddy (2010). Phytoremediation: A Novel Approach for Utilization of Iron-ore Wastes. Reviews of Environmental Contamination and Toxicology 206, 29-47.

75. Mukhopadhyay S. and Maiti S. K. (2010). Phytoremediation of Metal Enriched Mine Waste: A Review. *Global Journal of Environmental Research* 4 (3): 135-150.

76. Murgia I., Briat J.F., Tarantino D. and Soave C. (2001). Plant ferritin accumulates in response to photoinhibition but its ectopic overexpression does not protect against photoinhibition. *Plant PhysiolBioc* 39:797–805.

77. Murgia I., Delledonne M. and Soave C. (2002). Nitric oxide mediates iron-induced ferritin accumulation in Arabidopsis. *Plant J* 30:521–528.

78. Navari-Lazzo, F. and Quartacci, M.F. (2001). Phytoremediation of metals. Tolerance mechanisms against oxidative stress.*Minerva Biotechnol*. 13:73–83.

79. NEERI. 2009. Assessment of the depletion of ground water sources and land degradation in Sirigaon village, Goa and mitigation measures (Submitted to Honorable High Court of Bombay at Goa – PIL No. 1/2008, dated 16 June, 2008), National Environmental Engineering and Research Institute (NEERI), Nagpur, March.

80. Nevo Y. and Nelson N. (2006). The NRAMP family of metal-ion transporters.*BiochimBiophysActa* 1763:609–620.

81. Nishida S., Mizuno T. and Obata H. (2008).Involvement of histidine-rich domain of ZIP family transporter TjZNT1 in metal ion specificity. *Plant PhysiolBiochem* 46:601–606.

82. Orissa State Pollution Control Board. 2006. *State of Environment Report, Orissa*, Bhubaneswar.

83. Ortiz D.F., Kreppel L., SpeiserD.M. Scheel G., McDonald G., OwD.W. (1992). Heavy metal tolerance in the fission yeast requires an ATP-binding cassette-type vacuolar membrane transporter. *EMBO* J 11:3491–3499.

84. Pandey, V.C., Abhilash, P.C., Upadhyay, R.N. and Tewari, D.D. (2009).Application of fly ash on the growth performance, translocation of toxic heavy metals within *Cajanus cajan L.*: implication for safe utilization of fly ash for agricultural production. *J.Hazard.Mater*.166: 255–259.

85. Pederson, T.A., Rogowski, A.S. and Pennock, R. (1988). Physical characteristics of some mine spoils. *Soil Science Society of America Journal*, 44: 131–140.

86. Peleg Z. and Blumwald E. (2011).Hormone balance and abiotic stress tolerance in crop plants. *CurrOpin Plant Biol* 14:290–295.

87. Peiter E., Montanini B., Gobert A., Pedas P., Husted S., MaathuisF.J.M. Blaudez D., Chalot M. and Sanders D (2007). A secretory pathway-localized cation diffusion facilitator confers plant manganese tolerance. *ProcNatlAcadSci U S A 1*04:8532–8537.

88. Pereira, B.F.F.; de Abreu, C.A.; Herpin, U.; de Abreu, M.F.; Berton, R.S. (2010). Phytoremediation of lead by jack beans on a Rhodic Hapludox amended with EDTA. *Scientia Agricola* 67: 308-318.

89. Pich A. and Scholz G. (1996). Translocation of copper and other micronutrients in tomato plants (*Lycopersicon esculentum* Mill.): nicotianamine-stimulated copper transport in the xylem. *J Exp Bot* 47:41–47.

90. Pilon-Smits, E. Phytoremediation.Annu.*Rev. Plant Biol*. 2005, 56, 15–39.

91. Puig S, Thiele DJ (2002) Molecular mechanisms of copper uptake and distribution. *CurrOpinChemBiol* 6:171–180.

92. QuartacciRascio W. (1977). Metal accumulation by some plants growing on Zn mine deposits. *Oikos*, 29:250-253.

93. RauserW.E. (1999). Structure and function of metal chelators produced by plants. The case for organic acids, amino acids, phytin and metallothioneins. Cell BiochemBiophys 31:19–48.

94. Robb, G.A., and Robinson, J.D.F. (1995).Acid drainage from mines.*Geography Journal* 161:47–54.

95. Robinson N.J., Tommey A.M., Kuske C. and Jackson P.J. (1993).Plant metallothioneins.*Biochem J* 295:1–10.

96. Romheld V, Marschner H. (1986). Mobilization of iron in the rhizosphere of different plant species.*Adv Plant Nutr* 2:155-204.

97. Salomons, W. (1995). Environmental impact of metals derived from mining activities-processes, predictions, prevention. *Journal of Geochemical Exploration* 52: 5–23.

98. Salt D.E. and Wagner G.J. (1993).Cadmium transport across tonoplast of vesicles from oat roots. Evidence for a Cd^{2+}/H^{+}antiport activity. *J BiolChem* 268:12297–12302.
99. Salt, D.E., Smith, R.D. and Raskin, I. (1998).Phytoremediation. *Annu. Rev. Plant Physiol. Plant Mol. Biol,* 49: 643–668.
100. Salt D.E., Kato N., Krämer U., Smith R.D. and Raskin I. (2000). The role of root exudates in nickel hyperaccumulation and tolerance in accumulator and non-accumulator species of Thlaspi. In: Terry N, Banuelos G (eds) Phytoremediation of contaminated soil and water. CRC Press LLC, Boca Raton.
101. Sancenón V., Puig S., Mateu-Andrés I., Dorcey E., Thiele D.J. and Peñarrubia L. (2004). The Arabidopsis copper transporter COPT1 functions in root elongation and pollen development. *J BiolChem* 279:15348–15355.
102. Sarret G., Saumitou-Laprade P., Bert V., Proux O., Hazemann, J.L, Traverse A.S., Marcus M.A. and Manceau A. (2002). Forms of zinc accumulated in the hyperaccumulator *Arabidopsis halleri*. *Plant Physioly* 130: 1815-1826.
103. Schaaf G., Ludewig U., ErenogluB.E. Mori S., Kitahara T., and von Wirén N. (2004). ZmYS1 functions as a proton-coupled symporter for phytosiderophore and nicotianamine-chelated metals. *J BiolChem* 279:9091–9096.
104. Sekhar K., Priyanka B., Reddy V.D. and Rao K.V. (2011).Metallothionein 1 (CcMT1) of *pigeon pea* (*Cajanus cajan*, L.) confers enhanced tolerance to copper and cadmium in Escherichia coli and Arabidopsis thaliana. *Environ Exp Bot* 72:131–139
105. Seth, C.S.; Misra, V.; Singh, R.R.; Zolla, L. (2011). EDTA-enhanced lead phytoremediation in sunflower (*Helianthus annuus* L.) hydroponic culture. *Plant Soil* 347: 231-242.
106. Singh, J.S., Pandey, V.C., Singh, D.P. and Singh, R.P. (2011). Coal fly ash and farmyard manure amendments in dry-land paddy agriculture field: effect on N– dynamics and paddy productivity. *Appl. Soil Ecol*. 47, 133–140.
107. Smith, S.R. (2009). A critical review of the bioavailability and impacts of heavy metals in municipal solid waste composts compared to sewage sludge. *Environment International* 35: 142-156.
108. Smith, R.A.H. and Bradshaw A.D. (1979). The use of metal tolerant plant populations for the reclamation of metalliferous wastes. *J. Appl. Ecol*., 16: 595-612.
109. Souza L. A., Piotto F. A., Nogueirol R. C., Azevedo R. A. (2013). Use of non-hyper accumulator plant species for the phytoextraction of heavy metals using chelating agents. *ScientiaAgricola*.70 (4):290-295.
110. State of the Environment Report of Karnataka, 2003.
111. Sun Y, Zhoua Q, Xub Y, Wang L, Liang X (2011) Phytoremediation for co-contaminated soils of benzo[a]pyrene (B[a] P) and heavy metals using ornamental plant *Tagetes patula. J Hazard Mater* 186(2–3):2075–2082.
112. Tiffin L.O. (1970).Translocation of iron citrate and phosphorus in xylem exudate of soybean. *Physiol* 45:280–283.
113. Thomine S., Wang R., Ward J.M., Crawford N.M. and Schroeder J.I. (2000). Cadmium and iron transport by members of a plant metal transporters family in Arabidopsis with homology to Nramp genes. *ProcNatlAcadSci U S A*, 97:4991–4996.
114. Thomine S., Lelievre F., Debarbieux E., Schroeder J.I. and Barbier-Brygoo H. (2003).
115. AtNRAMP3, a multispecific vacuolar metal transporter involved in plant responses to iron deficiency. *Plant J* 34:685–695.
116. Thumann J., Grill E., Winnacker E.L. and Zenk M.H. (1991). Reactivation of metal-requiring apoenzymes by phytochelatin-metal complexes.FEBSLett 284:66–69.
117. Upadhyaya, R.C and C.C Pant (1988). Mining Activities in parts of Eastern Kumaun Himalaya and their Environmental Impact. In Joshi S.C. and Bhattacharya G., eds. 1988. Mining and Environment in India.Nainital: H.R Publishers.
118. Upadhyay, S.K., Singh, J.S., Saxena, A.K. and Singh, D.P. (2012). Impact of PGPR inoculation on growth and antioxidants status of wheat plant under saline condition. *Plant Biol.* 14: 605–611.
119. U.S. DOI, Geological Survey, 1973.
120. Vagholikar, N., Kaustubh M. A. and Dutta R. (2003).Undermining India Impacts of mining on ecologically sensitive areas. Pune: Kalpavriksh.
121. Van Ness, M., (editor). (1980). *Proceedings of the 7th.Mineral Waste Utilization Symposium*.

122.Cosponsored by the U.S. DOI, Bureau of Mines and IIT Research Institute. Chicago, Illinois.
123.Venkatramani G., Nagpur Times, January 22, 1992.
124.Vert G, Grotz N., Dédaldéchamp F., Gaymard F., GuerinotM.L., Briat J. F. and Curie C. (2002) IRT1, an Arabidopsis transporter essential for iron uptake from the soil and for plant growth. *Plant Cell*, 14:1223–1233.
125.Verret F., Gravot A. , Auroy P., Leonhardt N., David P., Nussaume L., Vavasseur A. and Richaud P. (2004). Overexpression of AtHMA4 enhances root-to-shoot translocation of zinc and cadmium and plant metal tolerance. FEBSLett 576:306–312.
126.Warhurst A. (2000).Mining, mineral processing and extractive metallurgy: an overview of the technologies and their impact on the physical environment. In: Environmental Policy in Mining: Corporate Strategy and Planning for closure (Warhurst A, Noronha L, eds). Boca Raton, FL: CRC Press LLC.
127.Wiersma D., Van Goor B. J. (1979).Chemical forms of nickel and cobalt in phloem of *Ricinus communis*. *PhysiolPlantarum* 45:440–442.
128.Yamamoto, F.; Kozlowski, T.T. (1987). Effects of flooding, tilting of stems, and ethrel application on growth stem anatomy, and ethylene production of *Acer platanoides* seedlings. Scandinavian *Journal of Forest Research* 2: 141-156.
129.Yang T., PoovaiahB.W. (2003). Calcium/calmodulin-mediated signal network in plants. Trends *Plant Sci* 8:505–512.
130.Yeh C. M., Hsiao L. J., Huang H. J. (2004). Cadmium activates a mitogen-activated protein kinase gene and MBP kinases in rice cell. *Plant Cell Physiol* 45:1306–1312.
131.Zhu Y.L., Pilon-Smits E.A.H., TarunA.S. Weber S.U., Jouanin L. and Terry N. (1999). Cadmium tolerance and accumulation in Indian mustard is enhanced by overexpressing gamma glutamylcysteine synthetase. *Plant Physiol* 121:1169–1177.