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Phytomining of Heavy Metals: A Green Technology to Sustainable Agriculture

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ABSTRACT: Heavy metal pollution is caused by the world's rapidly growing population, increasing economies, and anthropogenic activities, which are non-biodegradable, permanent, and represent a hazard to the environment. The rising number of heavy metals in the environment requires for indigenous techniques, but conventional techniques are excessively expensive, time-consuming, and pollute the environment. Phytomining is a "green" method of metal mining since it has a low environmental impact compared to opencast mining, which causes erosion. Phytomining is the removal of metals from a contaminated site or a sub economic ore body in situ, with the goal of recovering a commercial amount of metal from the plant. Hyperaccumulators are plants that collect high amounts of one or more target metals in their above-ground herbage and are utilised in such processes. This plant material generates a low-volume, sulphide-free 'bio-ore' after harvesting and cremation, which can be securely disposed of or smelted if the metal is of significant value. Low-grade metal and mineral mining, as well as metal recycling of polluted soil, are possible applications for this technique in the metal and minerals industry. This paper provides an overview of pollution by heavy metal, phytomining process as well as discuss about hyperaccumulating plants, mechanism of metal accumulation in hyperaccumulating plants and economic of Phytomining. Advantage and disadvantage of this method are also highlighted. The Phytomining method is eco – friendly, which has resulted in a growth in mineral demand in recent years, thus promoting the development of a preferred phytomining process.

KEYWORDS: Heavy metal, Phytoremediation, Phytomining, Hyperaccumulator plants, Sequestration of metal ions.

I. INTRODUCTION

The rapid growth of the human population, as well as the growing demand for industrial facilities to support human requirements, has resulted in issues such as overuse of available resources and rising pollution in the land, air, and water ecosystems. Heavy metal has economic importance in industrial use and is now a major environmental problem worldwide [30,57]. Heavy metals such as cadmium, arsenic, chromium, nickel, copper, lead and mercury are poisonous and tend to accumulate in the food chain. Heavy metals can be found in both natural and anthropogenic sources in environments. Heavy metals are naturally linked to volcanic eruptions, wind erosion, forest fires, and the usage of fossil fuels. Natural metals have a lower environmental impact, whereas metals from man-made sources, such as smelters, thermal power plants, and mines, represent a danger to humanity [44].

Although a heavy metal has no specific definition, it is defined literature as a naturally occurring element that has a high atomic weight and a five times greater density than the water [6]. When heavy metals are not metabolized by the body and accumulate in the soft tissues, they become poisonous. They may enter the human body in agriculture, manufacture, pharmaceutical, industrial or household environments by food, water, air, or skin absorption when they are in contact with human beings. For adults, industrial exposure is a common route of exposure. In children, the most prevalent route of exposure is through ingestion. Natural and human activities pollute the environment and destroy its

resources, releasing more than the environment can handle [43]. The most prominent natural sources are mineral weathering, erosion and volcanic activity, whereas compost, smelting, electronic plating, pesticide use and fertilizer phosphate release, as well as biosolids (E.g., livestock mushroom, compost and municipal sewage systems), atmospheric retrieval, etc. are anthropogenic sources [17]. Therefore, it is important to remove heavy metals from sites contaminated.

Plants have an amazing ability to store and concentrate metals in their tissues. Commercial techniques for removing heavy metal pollutants from contaminated soils and rivers are being developed to take use of this feature [13,53,60]. Phytomining is a "green" method of metal mining since it has a low environmental impact compared to opencast mining, which causes erosion [65]. Plants that are capable of growing in high-mineral environments are used in the production of phytomines to extract a particular metal from the soil. The biomass are treated for metal enrichment and recovery once the crop is harvested and secured. As a very cheap technology, phytomining has the potential to allow low-grade ores or mineralized soils to be exploited economically and to become too metal-poor for conventional mining. The overall result is a sales able metal product and soil that is better suited for agriculture than before phytomining [9].

Plant species classified as "hyperaccumulators" are essential for phytoremediation and phytomining. Hyperaccumulators are capable of absorbing and storing high amounts of heavy metals without causing harmful physiological effects. Metal hyperaccumulation and detoxifying mechanisms in hyperaccumulator plants are still unknown; nevertheless, a large research effort aimed at commercialising phytoremediation and phytomining processes is underway. Phytomining of metals like nickel, cobalt, and thallium has been proposed using a variety of hyperaccumulator species [9].

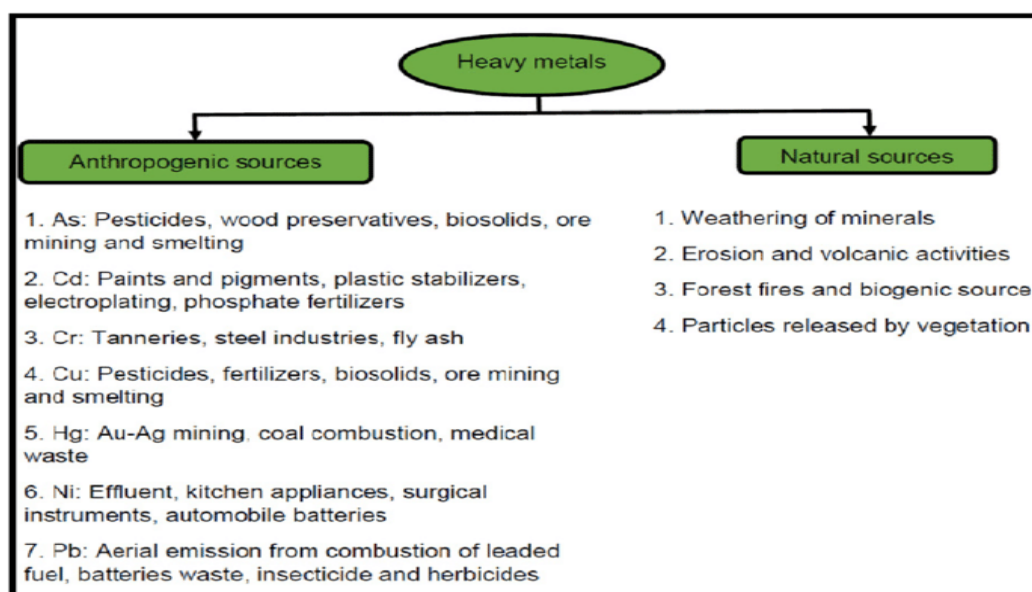


Figure 1 Sources of heavy metals in the environment [17]

The formula can be used to calculate a heavy metal, mass balance in the soil environment [41].

$$M_{total} = (M_p + M_a + M_f + M_{ag} + M_{ow} + M_{ip}) - (M_{cr} + M_l)$$

Where, M is the heavy metal, p is the parent material, a is atmospheric deposition, f is fertilizer source, ag is agrochemical source, ow is organic waste source, ip is inorganic pollutant, cr is crop removal and l is losses by leaching, volatilization and other processes. Anthropogenic sources are expected to emit one to three times larger, more heavy metals into the atmosphere than natural sources [58].

II. PLANT MECHANISM UNDER HEAVY METAL STRESS CONDITION

Heavy metals present as soluble components in the soil solution or those solubilized by root exudates are available for plant absorption [8]. Plants require certain heavy metals for development and maintenance; yet, excessive levels of these metals can be hazardous to plants, and plants' ability to store essential metals also allows them to amass non-necessary metals [18]. Heavy metals have a negative impact on the growth and activity of soil microorganisms, which has an indirect impact on plant growth. Due to a decrease in the number of helpful soil microbes caused by high metal concentrations, organic matter breakdown may be slowed, resulting in lower soil fertility. Enzyme activities are extremely important for plant metabolism; however, they are impeded by heavy metal interaction with soil microorganisms' activities. These harmful effects (both direct and indirect) cause a reduction in plant growth, which eventually leads to plant death [3].

It should be noted that certain plants can tolerate high levels of heavy metals in their environment. Baker, 1981 [4] has notified that these plants are able to tolerate these metals through three mechanisms: (i) exclusion: Limitation of metal transport and maintenance over a huge range of soil concentrations of a constant metal concentration in the spring; (ii) inclusion: Metal concentrations in the shoot are linearly related to those in the soil solution. (iii) Bioaccumulation: Metals accumulate in plant shoots and roots at both low and high soil concentrations [15].

Plants have a sophisticated and connected defense strategy network to prevent or tolerate heavy metal poisoning [22]. The first line of defense provided by a plant is to reduce metal uptake when stimulated by heavy metal toxicity, which is performed by cellular and root exudates. These exudates act as an avoidance mechanism, preventing the metals from entering the cell by enhancing efflux or biosorption to cell walls. When plants are exposed to heavy metals, morphological structures such as thick cuticle, biologically active tissues such as trichomes, and cell walls, as well as mycorrhizal symbiosis, can act as barriers [22]. Many plants have unique systems for dealing with certain metal ions, which are classified as tolerance mechanisms. Metal ions are stored in compartments during this process, protecting sensitive cell components from metal interactions [29]. Plants are constantly faced to abiotic stress and have evolved a variety of mechanisms to deal with it [25].

III. WHAT IS PHYTOMINING

Heavy metals such as nickel, cobalt, cadmium, zinc, and even gold can be hyperaccumulated by select plants. Such Plants could be used to extract metals from soils or ores where conventional mining is unprofitable. This concept of new technique is called Phytomining [11]. The phytomining method involves growing hyperaccumulators (ideally native or naturalised non-invasive species) in metal-rich substrates, harvesting the aboveground sections, and processing the biomass to obtain valuable end products [33,48]. There are two main approaches to phytomining that should be considered: (1) phytomining on degraded mine soils and in quarries within the methodology of the simultaneous rehabilitation strategy (along with phytoremediation), where phytomining revenues finance the costs of the phytomining process and (2) Natural-metal rich phytomining of soils not suitable for conventional farming and pasture as part of an integrated agricultural chain called agromining [63]. High plant biomass production and enhanced metal concentrations in aerial plant parts are required for this phytotechnology to be economically viable, because these factors determine the amount of metal that can be extracted from each plant [47].

IV. WHAT IS HYPERACCUMULATOR PLANT

The term "hyperaccumulator" refers to a group of plants that are distantly related but share the ability to grow on metalliferous soils and accumulate extraordinarily high levels of heavy metals in the aerial organs, far exceeding the levels found in the majority of species, without suffering phytotoxic effects. Hyperaccumulators are distinguished from non-hyperaccumulators by three main characteristics: a significantly increased rate of heavy metal absorption, a quicker root-to-shoot translocation, and a stronger ability to detoxify and sequester heavy metals in leaves [56]. Higher plant species with > 100 mg Cd/kg, > 1000 mg Ni, Pb, and Cu/kg, or > 10 000 mg Zn and Mn/kg are classified as hyperaccumulators (dry wt.) [42]. Approximately 400 plant species from at least 45 plant families have been recorded to hyperaccumulate metals, the majority of which are nickel hyperaccumulators found in ultramafic environments worldwide. Heavy metal tolerance in plant cells may be governed by the following mechanisms: 1) metal binding to the cell wall; 2) decreased transport across the cell membrane; and 3) active efflux. 4) Chelation and 5) compartmentalization [21,50]. Although it is a distinct trait, hyperaccumulation is also dependent on hyper tolerance, a

critical important quality that allows plants to resist heavy metal poisoning, to which hyperaccumulator plants are just as vulnerable as non-hyperaccumulators [51]. So far, around 450 angiosperm species have been discovered as heavy metal (As, Cd, Co, Cu, Mn, Ni, Pb, Sb, Se, Tl, Zn)Hyperaccumulators, accounting for fewer than 0.2 percent of all known species. However, additional reports of this type of plant continue to emerge, raising the possibility that numerous unnamed hyperaccumulators exist in nature[33,61].

V. HOW DO PLANT COLLECT HEAVY METALS IN SUCH A WAY?

The degree of hyperaccumulation of one or more heavy metals can vary substantially between species, populations, and ecotypes of the same species. Metal accumulation has been demonstrated to be a defence strategy against pathogens and herbivores [28]. Comparing hyperaccumulating plants to common plant species, the compartmentation of HM and the formation of complexes in hyperaccumulating plants is typically extremely distinct[40,38].Cadmium, for example, stimulates the synthesis of phytochelatins (PCs), but in hyperaccumulators, it is bound by weak oxygen ligands rather than strong sulphur ligands [64].This is common for many other hyperaccumulated heavy metals and metalloids [64,59].

The phloem transport system is responsible for the redistribution of metal particles throughout the plant as well as the relocation of metals in fruits and seeds [59]. It is also possible to pass from the xylem to the phloem (E.g., in minor leaf veins or in cereals via small bundles in stems). However, the transportability of phloem varies. Nickel travels easily via the phloem. As a result, it may be efficiently re-distributed to the plant's increasing portions. Zinc and cadmium are also phloem-mobile elements. Iron and manganese, on the other hand, are poorly transported through the phloem and accumulate mostly in older sections of the plant [49, 23]. The majority of the data supported the notion of "elemental defense," which explained HM hyperaccumulation as a means for plants to protect themselves from viruses or other natural enemies. Concentrating HM can be effectively coordinated with the build-up of organic protecting compounds, boosting total plant defense[59]. Nonetheless, there is a significant intraecotypic genetic variance as well as genetically-based intraspecific variance for hyperaccumulation capacity. This study showed an intriguing feature: the most important stages in hyperaccumulation do not rely on unique genes, but rather on genes shared by hyperaccumulators and non-hyperaccumulators, which are produced and controlled differently in the two types of plants [50].

VI. MECHANISM OF METAL ACCUMULATION IN PLANTS

Metal accumulation in hyperaccumulator plants is a complex and uncommon phenomenon that occurs in plant species that have a high metal uptake capacity [55]. This procedure consists of multiple phases.

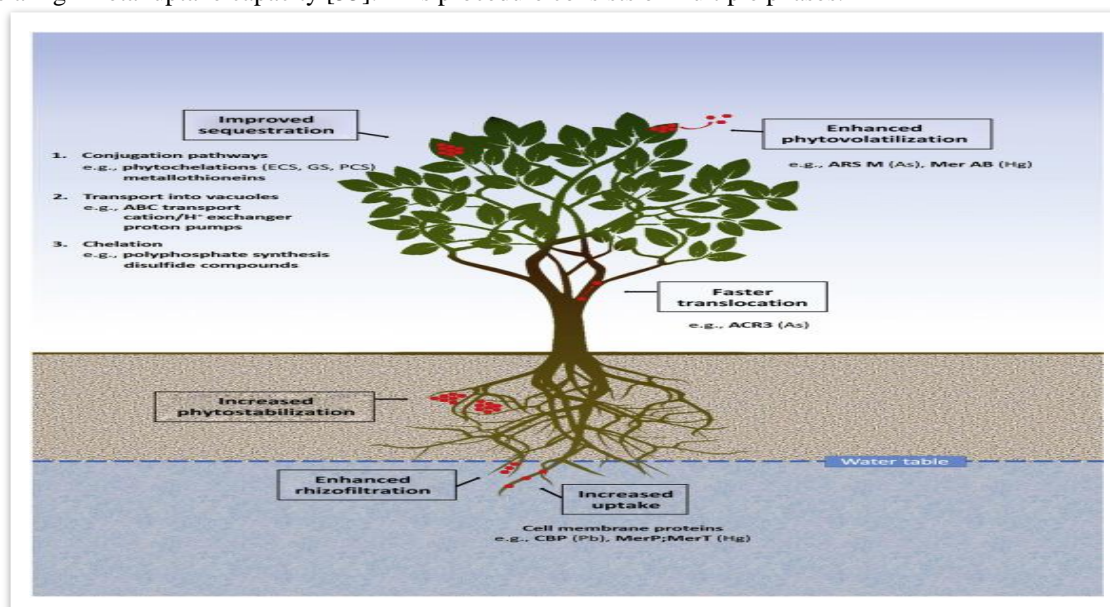


Figure 3 Main mechanisms involved in plant metal hyperaccumulation [35]

1. Solubilization of metal from the soil matrix

Metals are present in three forms in the soil matrix, according to the total metal concentration: available form, possibly accessible form, and unavailable form. Metals are available to organisms at all times in their accessible form. Metal is accessible in possibly accessible form after the accessible fraction has been eliminated. Metals that are inaccessible have extremely limited solubility and are chemically linked to an organic or silicate substrate. Plants desorb metals from the soil matrix in a variety of ways [56,26].

a) Acidification of the rhizosphere

Acidifications of the rhizosphere and carboxylate exudation are thought to be possible targets for increasing metal accumulation. The secretion of H^+ by roots has the potential to acidify the rhizosphere and enhance metal solubility. Plasma-membrane H^+ ATPase and H^+ pumps drive proton extrusion in the roots [26,55,56].

b) Secretion of ligands by rhizosphere

Organic acids (malonic and oxalic acids), metal chelating chemicals (Phyto siderophores), and enzymes are all secreted by plant roots (reductase). These operate as chelating agents, enhancing metal desorption from soil and thereby boosting metal bioavailability in soil solutions and plant accumulation [12].

c) Rhizosphere associated with microorganisms

The rhizosphere is teeming with microorganisms, the majority of which are bacteria and mycorrhizal fungus [68]. The hyperaccumulators' rhizosphere has a high proportion of metal-resistant bacterial communities. The rhizosphere is a complex and dynamic milieu in which microorganisms create a distinct community in conjunction with roots [27]. These root-colonizing bacteria and mycorrhizal fungi have been demonstrated to catalyze redox changes that boost soil metal bioavailability [56].

1. Root absorption and transport to shoot

The plasma membrane (PM) is the first structure of living cells to be exposed to heavy metals in the root. The PM acts as a barrier to metal entry into the cytoplasm [27]. Metal hyperaccumulators efficiently transport metal ions to the shoot by radial simplistic transit and active loading into xylem, whereas non-hyperaccumulator plants confine metal ions to root vacuoles or the cytoplasm via metal–ligand complexes [16]. In hyperaccumulators such as *Thlaspi caerulescens* [39] and *S. alfredii* [69], the rate of vascular Zn outflow nearly doubles, and they collect almost twice as much metal in their root vacuoles as their non-hyperaccumulator cousins [59]. According to a review, large-scale transcriptomic data analysis revealed that expression of genes encoding metal and metal–ligand transporters was elevated in hyperaccumulators [64]. Soluble metals can enter the root symplast via the plasma membrane of the root endodermal cells, or they can reach the root apoplast via the gap between cells. Soluble metals can enter the root simplest via the plasma membrane of the root endodermal cells, or they can reach the root apoplast via the gap between cells. While an APO plastic flow can transport solutes up the plant, most effective technique is to transport solutes up the plant via the plant's vascular, known as xylem [56]. To reach the xylem, solutes must pass through the casparian strip, a waxy layer that is impenetrable to solutes until they pass via endodermis cells. Metals must thus traverse a membrane to reach the xylem, most often by the action of a membrane pump or channel. Simplest transfer refers to metal transfer that occurs in xylem after crossing the casparian strip. It is more controlled as a result of the cells' selectively permeable plasma membrane, which controls access to the simplest particular or generic metal ion carriers or channels [62].

The metals will be transported to the shoots by the flow of xylem sap once they have been put into the xylem. Several protein groups have been linked to heavy metal transport in plants. Heavy metal or CPx-type ATPase, natural resistance-associated macrophage protein (Nramp) family proteins, cation diffusion facilitator (CDF) family proteins, zinc–iron permease (ZIP) family proteins, and others are examples. Xylem loading occurs via cation–proton antiport, cation-ATPases, or ion channels [56]. Free amino acids, such as histidine and nicotinamine, appear to play an important role in heavy metal hyperaccumulation by forming stable complexes with bivalent cations. As hyperaccumulator species such as *P. vittata* and *I. Cappadocia* transfer via xylem into the shoot and accumulate a considerable fraction of arsenic (60–80%) in the aerial portions by an unknown transport method, with a shoot/root transport ratio greater than

one [14,59]. According to [66] arsenic translocation from root to shoot in *P. vittata* may occur via both high-affinity and low-affinity transport systems.

2. Detoxification and sequestration of metal ions

Metal hyperaccumulators' heavy metal detoxification effectiveness is determined by how quickly they can chelate with metal ligands or sequester considerable amounts of metal ions from cytoplasm into vacuoles or cell walls of above-ground organs without impairing metabolic activity. This detoxification strategy enables metal hyperaccumulators to accumulate massive amounts of metals into the leaf epidermis [7,24] trichomes [38], and cuticles [52] with only minor inhibition of photosynthetic activities. As a result, they may carry out metabolic tasks, even at very high or hazardous metal concentrations. Heavy metals in various oxidation states have significantly variable absorption, transport, and detoxifying properties in plants. Once metals have been translated to shoot cells, they are stored in cellular places such as tricking (apoplast tissue), epidermis, mesophyll, cell wall, and so on, where they will not disrupt important cellular processes [56]. Sequestration of the metal away from any cellular activities, it can affect is the final stage in the build-up of most metals. The metal/metal-ligand must be transferred through the vascular membrane in order to be sequestered in the plant vacuole. Metal binding proteins in plants, such as metallothionein's (MTs) and phytochelatins (PCs), are critical for sequestration as well as metal tolerance and accumulation. Metals like Ag (I), Cu (II), and Ni (II) are trapped by peptide cysteine residues interacting with organic sulphur (R-SH). Metal ions are inactivated and transported into vacuoles by MTs and PCs for long-term sequestration [55].

TABLE 1. Some Examples of Metal Hyperaccumulating Plants [32]

SL.NO.	Hyperaccumulator (Part Used)	Metal Accumulated	Amount ($\mu\text{g g}^{-1}$)
1	<i>Alnus nepalensis</i> (root)	Zn, Pb and Cd	573.9, 3550.1, 94.7
2	<i>Acacia dealbata</i> (leaves)	Mn, Zn	74, 36
3	<i>Hypericum perforatum</i> (whole plant)	Mn, Zn	120-127, 425-55.9
4	<i>B. Juncea</i> (whole plant)	Cd	1450
5	<i>Thlaspi praecox</i> (leaves)	Zn, Cd	4190-4530, 1221-1425
6	<i>P. juliflora</i> (leaves)	Cu	775.29
7	<i>Helianthus annuus</i> (seed)	Cu, Mn	18.1, 6.95
8	<i>Amaranthus dubius</i> (leaves)	Zn, Cu, Mn	14.45, 94.05, 96.7
9	<i>Potamogeton crispus</i> L. (leaves)	Cd	49.09
10	<i>B. Napus</i> (seed)	Cu, Mn	2.17, 22.8

VI. PHYTOMINING WORK?

Phytomining is a plant-based Phyto-extraction technology developed by Baker & Brooks (1989) [5] for “metal mining,” with Nicks & Chambers (1995) [46] demonstrating its economic feasibility for nickel (Ni) by producing the Ni hyperaccumulator *Streptanthus polygaloides*. A number of studies on plants growing in soils containing high quantities of metals (either naturally or as a result of pollution) or mineral wastes are presented below. Tobacco plants, for example, have been employed in gold mining [36] and *Miscanthus* or *Salix* species for palladium mining [45]. These elements will be collected in their associated microbes to accumulate commercially valuable elements in their biomass, depending on the plant's ability for intake and distribution patterns [45,56].

Processing in phytomining includes the plant is first planted and developed in harmful condition. After normal growth and development, the plants are harvested. The roots of plants acquire mineral or metals from toxic soils throughout the growing process, and the vascular bundles, including the xylem and phloem, aid in the translocation of those metals from below-ground with aboveground sections of the plants. These translocated minerals tend to accumulate in the axils of plants, such as leaves [56]. Burning the plants after harvest to produce ash ("bio-ore"), from which the metal is recovered through smelting or the use of chemicals. Burning can be used to generate energy. The alternative method is Phyto-remediation, which involves the absorption of metals from contaminated soils by plants, which are subsequently harvested and either stored in secure locations or processed to generate pure metals [19].

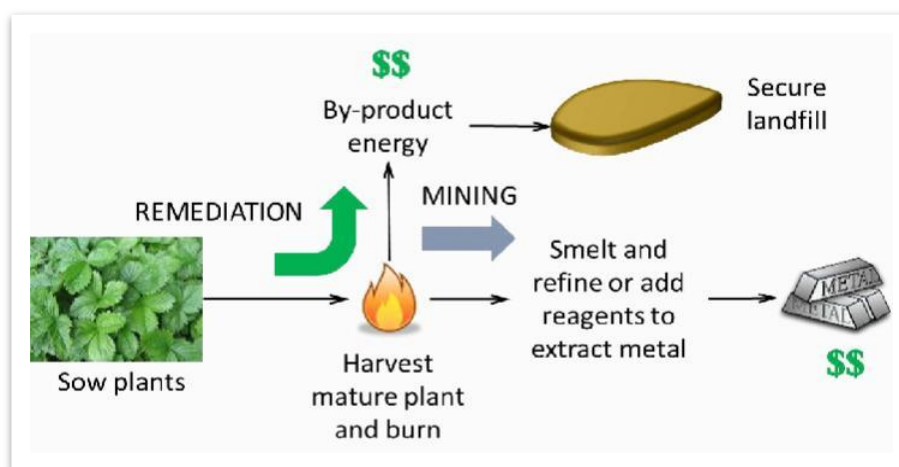


Figure 4 Process of Phyto-mining and phyto-remediation [19]

VII. FACTOR AFFECTING PHYTOMINING PROCESS

Hyperaccumulator plants for HMs depend on the favourable soil and environmental factors such as salinity, pH, deficiency nutrients, and toxicity to heavy metals, speciation and bioavailability, flooding, temperature, humidity, water logging, drying and drought resistant conditions [2]. Two of the most critical soil variables that control Cd availability are pH and organic matter [34]. Heavy metals are increasingly bioavailable in low soil pH because acidic metal salts are soluble. Metal desorption from soil binding sites solution is accelerated in acidic soils because of H⁺ competition for binding sites. Not only does soil pH affect metal bioavailability, but it also influences every step of the metal uptake process in roots. This appears to be a metal-specific effect [1]. For example, the root absorption of Zn was less reliant on the pH of *Thlaspi caerulescens* than that of Mn and Cd. The amount and types of organic matter and clay minerals in the soil determine the CEC. Wheat plants absorbed the most CDs when cultivated on soils with a low CEC, and vice versa. More CD was adsorbed to the exchange complexes in the soil with a high CEC, and hence less Cd was accessible for absorption by the wheat plants. Sorption to soil particles diminishes metal activity in the system in general. As a result, the higher the soil's cation exchange capacity (CEC), the greater the metals' sorption and immobilisation [1].

VIII. ECONOMICS OF PHYTOMINING

The operation's economics are determined by a variety of factors, including the metal content of the soil and plant, the amount of biomass produced each year, and whether or not the energy from biomass combustion can be recovered and sold [56]. Phytomining may give additional revenue for some recovered metals (Ti, Au, Co, Ni, Cu, U, Cd, Zn, Pb, Mn, and Se). The global remediation market is expected to be worth around 34–54 billion US dollars [1]. The value of metal ranges from around \$73,555/kg for platinum to around \$2.0/kg of lead. Gold, thallium, cobalt, and nickel are the great options for phytomining because to their expensive cost and high metal concentration in hyperaccumulator biomass [56]. The price of manganese metal is cheap (\$3.1/kg), but the metal content reported in *Macadamia* is high, making it profitable for phytomining. The creation of biomass is critical in the adaption of hyperaccumulators for phytomining operations in future agrofarming. However, the most crucial aspect is the global price of the metal being phytomined [10,1]. After assessing their performance in the fields, many plant species described for phytoextraction of important metals (platinum, thallium, cobalt, nickel, and manganese) may be employed for phytomining [56]. Metal prices are

affected by global economic conditions, and a metal's present low/high value does not guarantee its selection for permanent phytomining. The biomass generated might be combusted to ash and stored until global prices rise [10]. Metal prices have also been included in Table 2. (January 2009).

TABLE. 2 Metal pricing at the moment for reporting metal concentrations and biomass of metal hyperaccumulators [56]

Metals	Biomass (kg/ha)	Metal concentration (mg/kg)	Metal concentration (kg/ha)	Current metal price in \$ per hectare (May 2008)	Current metal price in \$ per hectare (January 2009)
Thallium	8000	4055	32.5	151,125	157,625
Manganese	30,000	55,000	1650	5115	2310
Nickel	18,000	17,000	306	6946	3550
	9000	13,400	120	2724	1392
Uranium	10,000	100	1	132	104
Zinc	10,000	10,000	40	84	52
Gold	20,000	10	0.2	6351	6489
Cobalt	4000	10,200	40.8	4406	1550
Copper	5000	8356	41.8	343	138
Cadmium	4000	3000	12	100	26
Lead	4000	8200	33	66	40

IX. ADVANTAGES AND DISADVANTAGES OF PHYTOMINING

Advantages of phytomining

- The phytomining process assists in the creation of jobs.
- This method is less expensive than ore mining.
- Phytomining also assists in the growth of revenue and infrastructure.
- Phytomining is ecofriendly and does not pollute the environment in any way.
- It can help with more than one or two metal extractions.
- Less carbon dioxide is created during the smelting process, resulting in lower carbon dioxide emissions [37].

Disadvantages and Limitation of Phytomining

- The process of phytomining extracts low quality minerals.
- During this process, toxic chemicals are produced that reduce soil fertility.
- High levels of toxic elements can pollute the poisonous substances of soil water.
- This is a time-consuming and extremely slow process.
- This process extracts only 50% of the metal [37].
- Metals are accumulated by plants in their low-level aboveground biomass.
- Phytomining must be carried out on a polluted site that is large enough.
- Higher chelate application rates are required for the tightly bound proportion of metals in soil clay, resulting in ground water pollution.
- To be pulled up by plants, the pollutants must be in the root zone (rhizosphere). Because of their low biomass and slow growth.
- The repair process will take longer.
- Metal contamination concentrations are limited to low and medium levels [1].

X. FUTURE PRESPECTIVE

The discovery of fast-growing plants with large biomass and the ability to collect high concentrations of metals in harvestable portions has the potential to enhance phytomining [56]. Much study is still needed, notably in the areas of

boosting metal absorption by plants by genetic manipulation or the addition of specialized reagents to the soil [55]. For successful phytoextraction, plant species with a short development period, the ability to rotate, and resistance to environmental stress should be selected. In the future, assisted phytoextraction may be a cost-effective commercial solution for Heavy metal phytomining, which can improve metal absorption while reducing environmental concerns and the time required for the remediation procedure [2]. Individuals with high metal content, high biomass output, and greater tolerance to soil heavy metal concentration will not only benefit metal crops, but may also produce genetic material that can be transferred into other species [56]. Exotic plants do not have to be employed to induce hyperaccumulation. A natural plant with high and quick biomass would be the best option [55]. Changing the oxidation state of metals, enhancing metal transporters and chelators, encoding metal sequestration proteins (MTs and PCs), and encoding transport proteins such as ZIP family proteins (zinc-iron permease), ZAT, and other genetic engineering techniques are currently being used to improve metal hyperaccumulation in plants (Zn transporter) [20,54]. The importance of biotechnology and genetic engineering in enhancing phytomining cannot be overstated. Chelates that are environmentally benign and biodegradable should be developed. If phytomining is permitted to progress past the theoretical and pilot stages. Plants can be collected and used as fodder for burning. This might provide steam for electricity generation [2]. Locations with sub-economic metal mineralization and ultramafic soils may be apparent candidates for the small-scale farmer's scenario [56]. Another area of study is the low-cost technology for recovering metals from plant biomass. The entire potential of phytomining has yet to be realised; it will necessitate integrated interdisciplinary research efforts combining plant biology, genetic engineering, soil chemistry and microbiology, as well as agricultural and environmental engineering [55].

XI. CONCLUSION

Natural metal circulation techniques can be utilized to selectively recover metals. Metal extraction from traditional mining is restricted to proven deposits, which are rapidly diminishing. The phytomining method, which is based on plants' capacity to gather high concentrations of metals, has the potential to produce valuable metals. The economics of phytomining are primarily determined by soil metal concentration, plant metal absorption, plant biomass, and, most crucially, metal pricing. To fulfil their daily needs, the world's rising population necessitates more food, infrastructure, transportation, and industrial expansion. As a result, these activities will contribute to increased metal release into soil, air, and water, resulting in pollution. Plants and microbes have a role in the natural metal cycle. Phytomining has a number of advantages over traditional mining. Metal prices fluctuate cyclically, and a low metal value should not rule out the possibility of extracting it by phytomining. Thus, before beginning phytomining, it is vital to evaluate current metal prices. The majority of the study has been done on a laboratory scale and under relatively controlled settings for a short length of time; the full potential of phytomining has yet to be determined. Phytomining not only creates cash for the planter, but it also offers mineral supplements and biofuel, improves soil health, and mitigates climate change. However, phytomining has not yet been tested on a commercial scale, and much research remains to be done, particularly in the field of increasing metal uptake by plants through genetic manipulation or the addition of specific reagents to the soil, as well as the potential leaching of metals during induced hyperaccumulation. Phytomining is creating technology that may be more cost-effective, efficient, and ecologically friendly than standard methods connected with dirty soil decontamination and remediation. However, only after more study and proper field testing in genuine "real world" situations will it be feasible to draw concrete evidence-based judgments on the long-term feasibility of these new technologies.

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