**Title page:**

**Phytoremediation of Heavy Metals Contaminated Soil by Marigold Plants:**

**An Overview**

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**ABSTRACT**

The using living plants and accompanying soil bacteria to remove pollutants from contaminated soil, water, and the air is known as phytoremediation. It refers to certain plant’s natural capacity to absorb, digest, or remove pollutants from environment. The growing interest in phytoremediation suggests that it might be a potential method for dealing with soil pollution issues. In contrast to plants whichthat are used for remediation purpose, ornamental plants grown for aesthetic purposes in gardens, balconies, and landscape design projects can contribute significantly to the remediation process in modern times. Additionally, when grown in soil containing heavy metals or organic pollutants, several decorative plants that are used to enhance the environmental condition not only remove but also acquire or degrade toxins.

In this review, we assessed the ability of ornamental plants to clean up organic pollutants, pesticides, and heavy metal-contaminated soils. This review outlined the most recent research on the use of the marigold plant for the phytoremediation of contaminated soils and shows the high capacity for accumulation and resistance to pollutants like heavy metals, pesticides, etc. By building a strong root system that allows them to live in contaminated soil, marigold plants are able to grow quickly. Therefore, marigolds, which are decorative plants, could be utilized to detoxify polluted sites while also offering aesthetic value. They could also be a source of commercially important products that are made by incinerating biomass to extract metals. There is, however, little evidence on the use of different marigold species for heavy metal phytoremediation under varied metal-polluted soils. Additionally, decorative plants contribute to the protection of biodiversity, provide a variety of ecological services, and enhance human well-being. Apart from the primary applications of ornamental plants in phytoremediation of polluted soil, air, and water, as well as the possible effects of ornamental plants in built-in buffer strips meant to reduce contamination of agricultural regions close to pollutant sources. This process supports the ecological and medical advantages of using attractive plants in rural and urban landscape initiatives. Phytoremediation helps to raise awareness of a promising decontamination technique that also beautifies both urban and rural environments, and hence offers a new direction for phytoremediation technology.

**KEYWORDS: -** Phytoremediation, Ornamental plants, Heavy metals, Toxicity.

**INTRODUCTION**

Many Industrial operations and unsustainable agricultural practices in developing nations like India lack the resources to pay for waste management and pollution control. Numerous contaminants are released into our environment in significant quantities (Adriano, 2001). The disruption of biogeochemical cycles caused by the variety of organic and inorganic pollutants emitted by human activity is currently environmentalists’ top concern Vara et al., (2003). Different cleanup technologies were also being used worldwide to address various categories of contaminants along with the growth of industrialization.Heavy metals are a major and important category of toxins in our environment. Unlike other organic contaminants like pesticides or petroleum by-products, heavy metals have a longer lifespan in nature. As a result, heavy metal contamination is a significant problem. Different heavy metals in the environment have steadily grown due to the growth of the global economy, causing the ecosystem to deteriorate (Han et al.,2002).Heavy metals are highly toxic for all living components of the environment. Organic, inorganic, and heavy metal contamination results in either direct sources of water, soil, or through biomagnification. High air concentrations can occasionally act as a source of heavy metal contamination in mining sites (Santona et al 2006). The heavy metal accumulation in the soil is one of the serious threats to our environment as well as human health across the globe (Asgari, et al., 2019). The accumulation of different types of heavy metals in soil can decrease crop yield, cause diseases, and impact food quality (Rai et al., 2019) A new, eco-friendly technology called phytoremediation, which uses plants to remediate pollution, has been proposed as a solution to this issue

Various methods of phytoremediation like chemical, biological, or physical methods to clean up heavy metal-contaminated locations can be quite challenging. Phytoremediation may be utilized in place of expensive remediation and clean-up methods as this is a "low technology, big effect" treatment strategy. As compared to other methods, it is inexpensive, efficient, and environment friendly (Monok et al., 2019). Plants may clean up environmental toxins through phytoremediation. According to Tangahu et al., (2011), plants serve as bioreactors because their roots have specialized and selective pollutant-absorbing capacities. Additionally, pollutant transmission, bioaccumulation, and degradation may occur in some plants' shoots. The plants utilized in phytoremediation should be metallophilic and toxic-resistant (Urbaniak et al.,2020). However, soil quality and plant selection are still research areas of concern. The cost of using traditional remediation approaches, such as soil extraction and thermal, chemical, and physical treatments, is high.

Phytoremediation is a potential environmental biotechnology strategy for contaminated soil and water treatment. This strategy is effective, inexpensive, and without consequences. It may be used in a variety of contexts, from small-scale brownfields to vast open-pit mine landscapes (Choudhury et al., 2016). Even it has been proven effective for the de-contamination of dredged river sediments (M.Urbaniak et al, 2020).Utilizing a variety of chemical, biological, and physical techniques, phytoremediation can remove, degrade, immobilize, convert, or stabilize toxins from the soil so that they cannot be released into the environment (Nakbanpote et al.,2016).

**Sources of heavy metals in the environment**

Heavy metals in the environment can come from both human and natural, geogenic, and lithogenic sources. Weathering of metal-bearing rocks and volcanic eruptions are two examples of the natural or geological sources of heavy metals in the environment. The proportion of heavy metals in the environment that are attributed to humans has increased as a result of the worldwide trends of industrialization and urbanization on Earth (Nagajyoti et al 2010). Industrial, medical, municipal and agricultural activities are some of the anthropogenic sources of heavy metals in the environment.

**Medicinal waste**

The production of persistent organic pollutants (POPs), such as polychlorinated biphenyls (PCBs), dioxins, polycyclic aromatic hydrocarbons (PAHs), and other cancer-causing organics, is a major concern of hospital waste incineration ( WHO. Air Quality Guidelines for Europe 2000 and Beyersmann 2002) It is well known that hospital waste incineration concentrates heavy metals into the bottom ash rather than entirely destroying the metallic waste stream components ( Anamul et al 2012). ). As a result, bottom ash from incinerating hospital waste contains more heavy metals (chromium, cadmium, lead, mercury, zinc, and other metals) as well as organic substances (PCBs, dioxins, benzene, and other cancer-causing organics) that, if improperly disposed of, can pollute the environment and cause problems for the general public's health, including acute respiratory syndromes, gastrointestinal abnormalities, and various cancers ( Zhao et al., 2009; Mohajer et al .,2013)

**Municipal waste**

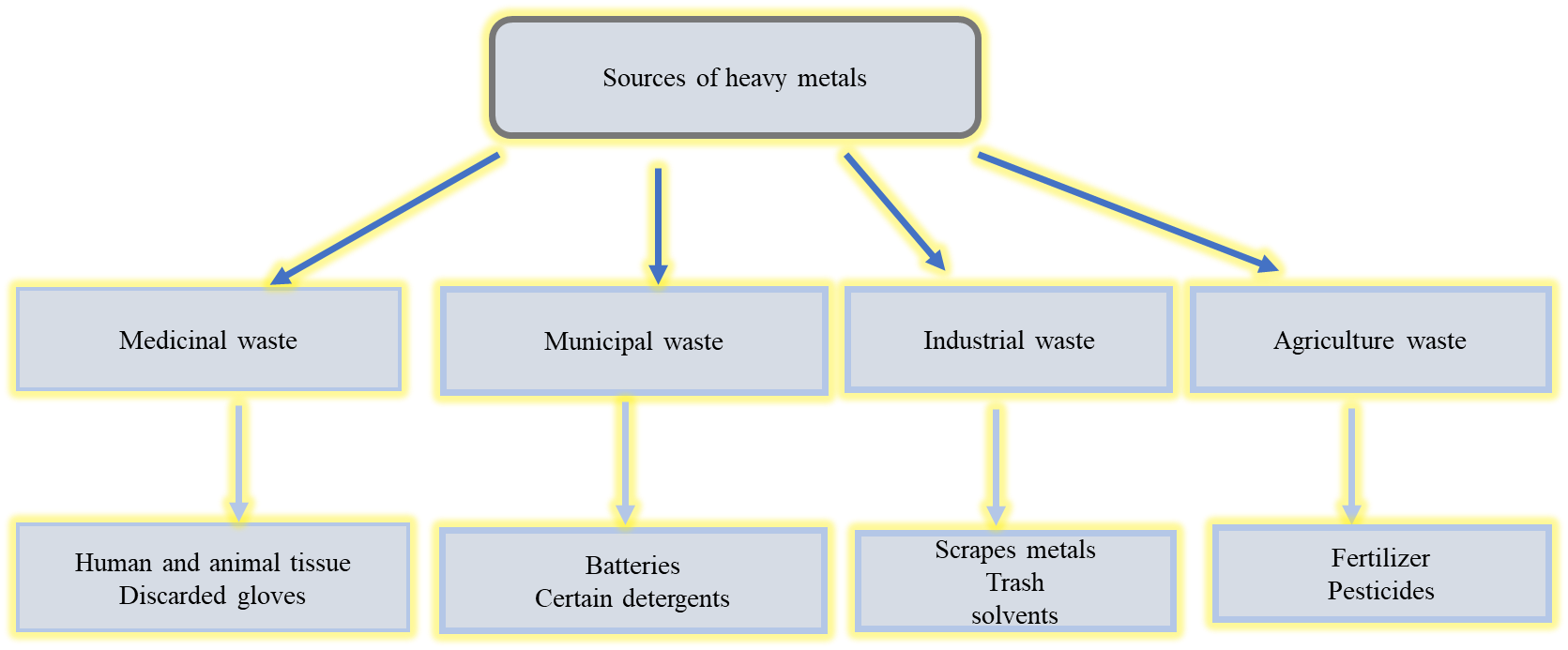
According to Loizidou et al. (1993), various polluted locations create municipal garbage that contains heavy metals. High amounts of organics, nutrients, and heavy metals are known to be present in leachate. Metals are considered to be the most dangerous pollutant among them and have the potential to dangerously degrading groundwater quality ( Danh et al., 2009). Batteries, electronic waste, pesticides, photographic chemicals, personal care products, certain detergents, fluorescent tubes, waste oil, medications, wood treated with harmful compounds, and paints are the primary sources of heavy metals in municipal waste (Tahiri et al., 2017).

**Industrial waste**

Different sectors create heavy metal-filled industrial effluent streams. Significant amounts of effluent containing heavy metals (including cadmium, zinc, lead, chromium, nickel, copper, vanadium, platinum, silver, and titanium) are produced by electroplating and metal surface treatment operations from a range of applications. These include etching, milling, anodizing, conversion coating, electroless depositions, and electroplating. The production of printed circuit boards (PCBs) is a substantial additional source of heavy metal trash. The most popular resistant overplates are made of tin, lead, and nickel (Sorme and Lagerkvist, 2002).

**Agricultural waste**

Sewage sludge, herbicides, and fertilisers are the three most common agricultural sources of heavy metals (Alloway et al.,2013). Whether in soil or plants, the nature and methods of accumulation of the harmful heavy metals differ.  TPhosphate fertilisers, liming materials, and bio-fertilizers are the main inorganic fertiliser varieties that cause the release of heavy metals in agricultural soil, which are then absorbed by plants (Fan et al.,2018). So they enter the food chain and eventually get to people and other animals (Liu 2019.,et al).

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**Fig: -1 Sources of heavy metals in the environment.**

**Uptake And Translocation Of Heavy Metals In Plants**

Accumulation of heavy metals in plants involves several processes, such as heavy metal mobilization, root uptake, xylem loading, root-to-shoot transfer, cytoskeleton compartmentation, and sequestration. Heavy metals are most often found in soil in an insoluble form that is not bioavailable to plants. Plants could also significantly raise their bioavailability by exuding a wide range of rhizosphere, which could also affect the pH of the rhizosphere and enhance heavy metal solubilization (Dalvi and Bhalerao, 2013).The bioactive heavy metal is absorbed from the plant root and transferred to the root cells via the cellular membrane. Heavy metals enter roots primarily via two pathways: passive and active transport. Heavy metal uptake via the symplastic pathway is an energy-dependent process mediated by metal ion carriers or complexing agents (Peer et al., 2005). Theions of heavy metals can form compounds with various chelators, like organic acids, after entering root cells. These solubilized compounds, which include carbonate, sulphates, and phosphate, then are adsorbed in the extravascular environment or intracellular spaces (Ali et al., 2013).The root symplasm might very well allow the metal ions locked inside the vacuoles to relocate into the stele and enter the xylem stream(Thakur et al., 2016) .

**Heavy Metal Ion Transporter**

The uptake and translocation of heavy metals in plants are mediated by several molecules, such as complexing molecules and metal ion transporters. The plasma membrane of the root cell houses these specialized transporters, also known as channel proteins or H+-coupled carrier proteins, which are crucial for the uptake of heavy metal ions from the soil. They can translocate particular metals between cellular membranes and can mediate the influx-effluent of metals from roots to shoots (DalCorso et al., 2019).

**Detoxification Mechanism**

Detoxification of Heavy metalsis a key element for the application of phytoremediation (Thakur et al., 2016).Avoidance and tolerance are typically the two protection mechanisms used by plants to deal with the toxicity of heavy metals.Through these two mechanisms, plants are capable of maintaining the cellular concentrations of heavy metals below the toxicity threshold levels (Hall, 2002).

**Avoidance**

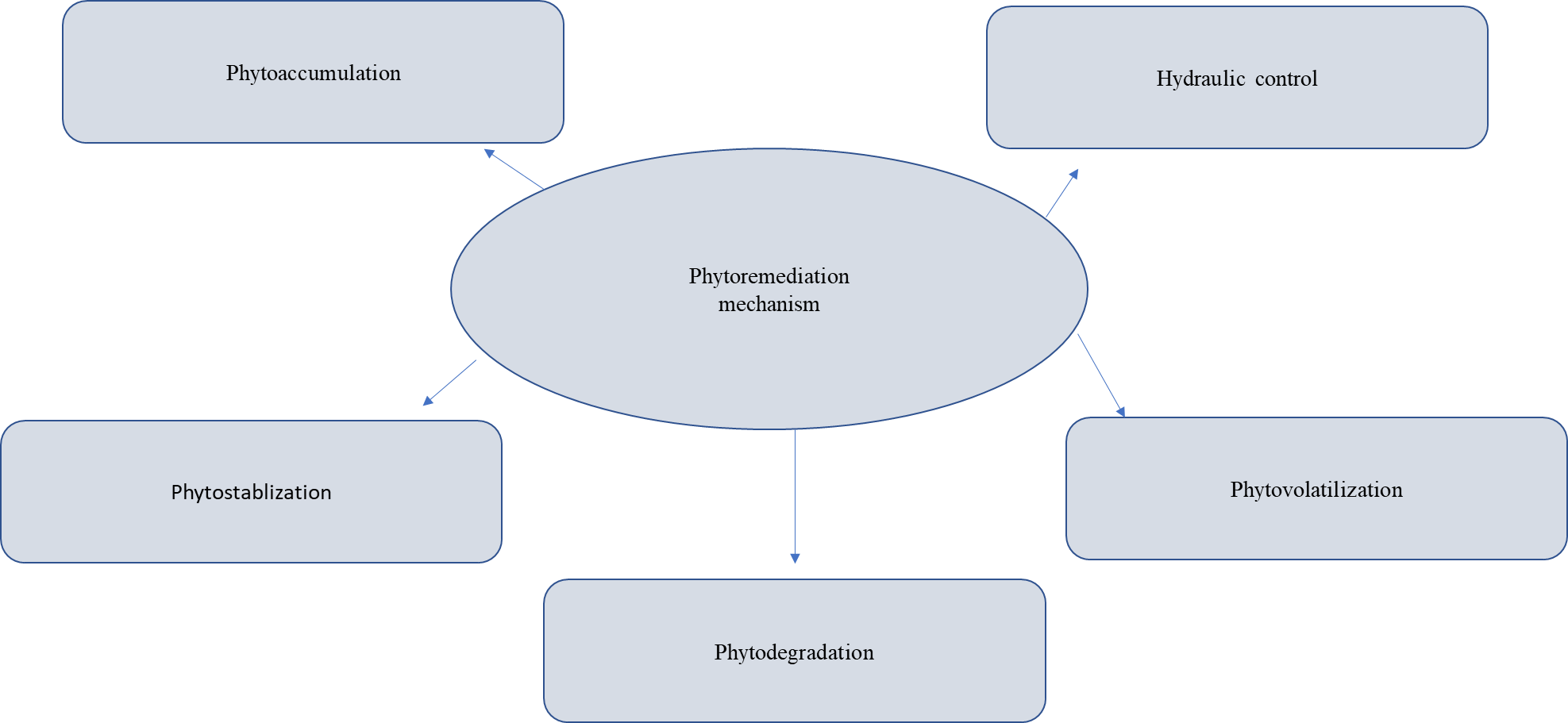
The ability of plants to reduce the uptake of heavy metals and prevent their movement into plant tissues through root cells is referred to as aavoidance mechanism (Dalvi and Bhalerao, 2013).It works as the first line of defence at extracellular level through a range of mechanisms such as root sorption, metal ion precipitation, and metal exclusion (Dalvi and Bhalerao, 2013)

**Tolerance**

Once the heavy metal ions get entry into the cytosol, tolerance strategy is adopted by the plants to cope with the toxicity of accumulated metal ions. It is the second line of defence at intracellular level through various mechanisms such as inactivation, chelation, and compartmentalization of heavy metal ions (Dalvi and Bhalerao, 2013).

**Phytoremediation techniques and mechanisms.**

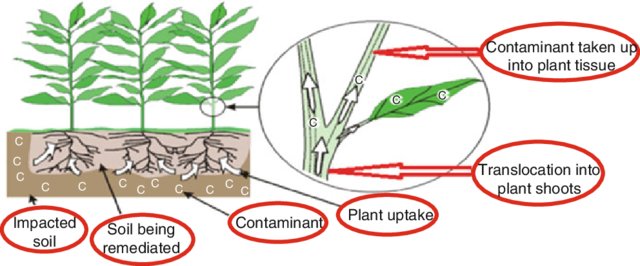
The following techniques or procedures are often used in phytoremediation to remove heavy metals from polluted areas (Fig. 2).

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**Fig: -2 Mechanisms involved in phytoremediation.**

**Phyto-accumulation**

Phyto-accumulation is the process by which plants take in pollutants from contaminated areas together with vital nutrients and water. According to Fig. 1.1, the heavy metals that are consumed are not permanently eliminated but rather build up in the shoots, leaves, and other components of the plants (Rashid et al.., 2014). Due to the low initial investment and potential environmental problems associated with metal-contaminated soils, this approach is frequently utilized for metallic (Kamal et al. 2004) and radioactive (Hossner et al.., 1998) wastes.This creates a significant opportunity for the commercialization of this technology (Salt and Baker 2008; Raskin et al.., 1997).



**Phytoaccumulation of contaminants by plants from the soils. (ITRC 2009)**

Table 1 List of some plants tested for heavy metals accumulation**.**

|  |  |  |  |
| --- | --- | --- | --- |
| **Heavy metal** | **Plant species** | **Maximum concentration in plant (mg/kg)** | **References** |
| *Co* | *Haumaniastrumrobertii* | *10,232* | *Marqueset al.,2009* |
| *Cr* | *Pteris vittata* | *20,675* | *Kalve et al., 2011* |
| *Se* | *Lecythisollaria*  *Astragalus racemosus* | *18,200*  *14,920* | *Marques et al.,2009*  *Marques et al.,2009* |
| *Mn* | *Schima superba*  *Macadamia neurophylla*  *Maytenusbureaviana*  *Alyxiarubricaulis* | *62412.3*  *51,800*  *33750*  *14000* | *Yang et al., 2008*  *Sheoran et al., 2009*  *Marques et al., 2009*  *Marques et al., 2009*  *Chaney et al., 2010* |
| *Zn* | *Thlaspicaerulescens*  *Deschampsiacespitosa*  *Thlaspicalaminare*  *Eleochairisacicularis* | *51,600*  *3614*  *10,000*  *11,200* | *Cunningham and Ow,1996*  *Kucharskiet al.,2005*  *Sheoran et al.,2009*  *Sakakibara et al.,2011* |
| *Pb* | *Thlaspirotundifolium*  *Deschampsiacespitosa*  *Euphorbia cheiradenia*  *Medicago sativa*  *Brassica junicea*  *Brassica nigra*  *Helianthus annuus*  *Betula occidentalis* | *8200*  *966.5*  *1138*  *43,300*  *10,300*  *9400*  *5600*  *1000* | *Cunningham and Ow et al,1996*  *Kucharski et al.,2005*  *Chehregani and Malayeri,2007*  *Koptik,2014*  *Koptik,2014*  *Koptik,2014*  *Koptik,2014*  *Koptik,2014* |
| *Ni* | *Psychotriadouarrei*  *Alyssum bertolonii*  *Alyssum corsicum*  *Alyssum pterocarpum*  *Alyssum caricum*  *Berkheyacoddii*  *Alyssum serpyllifolium*  *Alyssum murale*  *Alyssum markgrafii*  *Phyllanthus serpentinus*  *Isatispinnatiloba* | *47,500*  *10,900*  *18,100*  *13,500*  *12,500*  *18,000*  *10,000*  *4730-20,100*  *19,100*  *38,100*  *1441* | *Cunningham and Ow,1996*  *Li et al., 2003*  *Li et al., 2003*  *Li et al., 2003*  *Li et al., 2003*  *Mesjasz-Przybylowicz et al., 2004*  *Prasad, 2005*  *Bani et al., 2010*  *Bani et al., 2010*  *Chaney et al., 2010*  *Altinoziu et al.,2012* |
| *Hg* | *Marrubium vulgare*  *Rumex induratus*  *Festuca rubra*  *Poa pratensis*  *Hordeum spp*  *Helianthus tuberosus*  *Armoracia lapathifolia*  *Juncus maritimus*  *Cicer arietinum*  *Archillea millefolium*  *Silene vulgaris* | *13.8*  *6.45*  *3.17*  *2.74*  *2.35*  *1.89*  *0.97*  *0.315*  *0.2*  *18.275*  *4.25* | *Rodriguez et al., 2003*  *Rodriguez et al., 2003*  *Rodriguez et al., 2003*  *Rodriguez et al., 2003*  *Sas-Nowosielska et al., 2008*  *Sas-Nowosielska et al., 2008*  *Sas-Nowosielska et al., 2008*  *Zeng et al.,2011*  *Wang et al., 2012*  *Wang et al., 2012*  *Perez-Sanz et al., 2012* |
| *Cu* | *Ipomoea alpine*  *Haumaniastrum*  *Aeolanthusbiformfolius*  *Eleocharis acicularis*  *Pteris vittata* | *12,300*  *8356*  *13,700*  *20,200*  *91,975* | *Mitch,2002*  *Sheoran et al., 2009*  *Chaney et al., 2010*  *Sakakibara et al., 2011*  *Wang et al., 2012* |
| *Cd* | *Thlaspicaerulscens*  *Arabis gemmifera*  *Salsola kali*  *Sedum alfredii*  *Deschampsiacespitosa*  *Phytolacca Americana*  *Azolla pinnata*  *Prosopis laevigata*  *Turnip landraces* | *1140*  *5600*  *2075*  *9000*  *236.2*  *10,700*  *740*  *8176*  *52.94-146.95* | *Brown et al.,1994*  *Kubota and Takenaka,2003*  *De la Rosa et al.,2004*  *Xiong et al.,2004*  *Kucharski et al., 2005*  *Peng et al .,2008*  *Rai, 2008*  *Buendia- Gonzalez et al.,2010*  *Li et al., 2016* |
| *As* | *Pteris ryukyuensis*  *Pteris quadriauritta*  *Pteris biaurita*  *Pteris cretica*  *Eleocharis acicularis*  *Pteris vittate*  *Corrigolatelephiifolia* | *3647*  *2900*  *2000*  *1800*  *1470*  *8331*  *2110* | *Srivastava et al., 2006*  *Srivastava et al., 2006*  *Srivastava et al., 2006*  *Srivastava et al., 2006*  *Sakakibara et al., 2011*  *Kalve et al.,2011*  *Garcia- Salgado., 2012* |

**Phyto-stabilization**

The phytostabilization process involves using certain plant species to accumulate pollutants in contaminated areas through their root hairs, and adsorb it or precipitate them inside their rhizosphere (Munshower et al. 2003; Berti and Cunningham 2000; Mendez and Maier 2008).

The phytostabilization process involves using certain plant species to accumulate pollutants in contaminated areas through their root hairs, and adsorb it or precipitate them inside their rhizosphere (Munshower et al. 2003; Berti and Cunningham 2000; Mendez and Maier 2008). By transforming PTEs into a new form or altering their bioavailability, plants can lessen their toxicity. Thus, employing plant systems can lower the bioavailability of Potentially toxic elements ( PTEs) in the environment. PTEs in soil is turned harmless by plants, which lowers the possibility of additional environmental damage due to groundwater contamination or airborne transmission of PTEs. By avoiding surface runoff, erosion, and leaching, this is accomplished (Yan et al., 2020). Phytostabilization is vital because it helps prevent PTEs transmission into the food chain. Some of the most important factors determining whether prospective plants can stabilise the element are its chemical characteristics (Hamidpour et al., 2020; Usman et al., 2020b). Although phytostabilization has certain benefits, it is less widely used than phytoextraction because metals are only momentarily immobilized and restricted (Radziemska, 2018). It is frequently used in emergencies to quickly immobilize metal in plant rhizospheres (Meng et al., 2017).

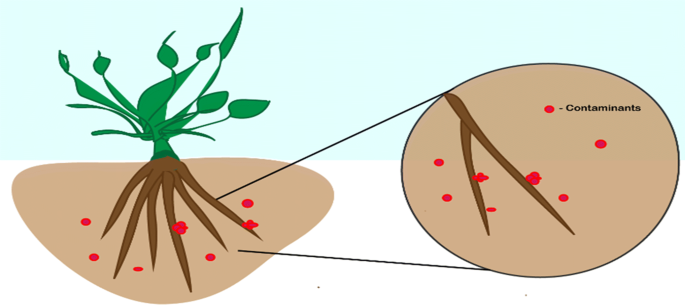
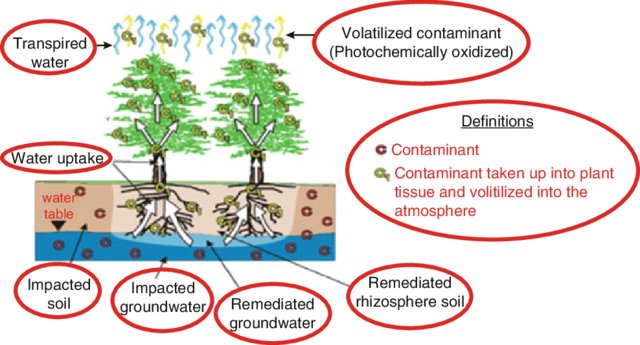


Fig: 4 Phytostabilization mechanism

**Phyto-volatilization**

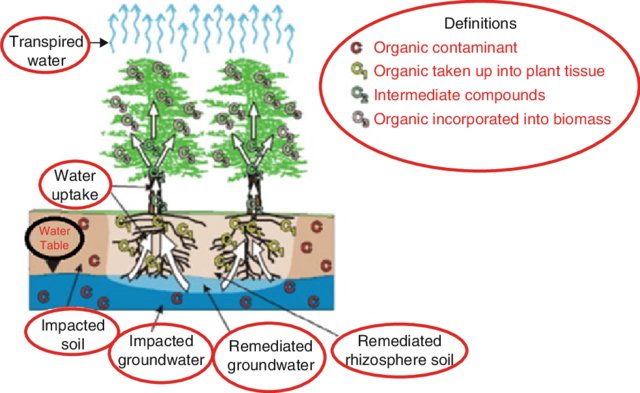
During the phyto-volatilization process, pollutants are consumed by plants, grown, and then released into the atmosphere in a less dangerous form (Moreno 2004). Mercury, arsenic, and selenium are a few of the dangerous elements that may be transformed into vapors like mercuric oxide and dimethyl selenide and evaporate or volatilize into the environment. Potentially toxic elements (PTEs) are just moved to other areas of the ecosystem during this process; they may still be redeposited into the soil after precipitation. So, compared to phytoextraction and phytofiltration, phytovolatilization is less common (Nikoli and Stevovi, 2015; Bisht et al., 2020).



Phyto-volatilization of contaminants by plants from the soils

**Phyto-degradation**

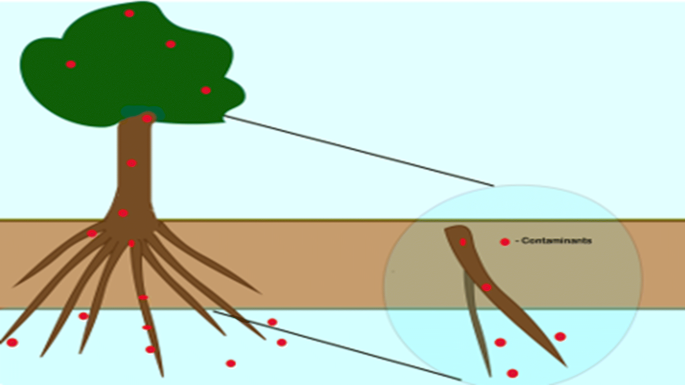
It is also known as Phytotransformation**.** Plants absorb pollutants during phytodegradation and convert them to less harmful, simpler forms. The breakdown can happen in two ways. The plant uses the pollutants that are transformed into easier-to-use substances to promote rapid development. Various inorganic and organic substances, including pesticides and chlorinated solvents, can be destroyed by photo-degradation (Newman and Reynolds 2004).Commonly used against organic contaminants is phytodegradation. However, it is less effective and infrequently employed, especially when dealing with PTEs and other inorganic pollutants.

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**Phyto-degradation mechanism of contaminated soil.**

**Hydraulic control**

Plants were employed in this method to regulate groundwater flow, so limiting the transport of toxins from the impacted site through the groundwater. The large amount of water needed as the primary ingredient in this procedure can only be utilized by plants with lengthy roots (Ahlfeld and Heidari 1994).



**Hydraulic control mechanism**

**Challenges of Phytoremediation**

Although phytoremediation is a beneficial technique for preparing the soil to deal with heavy metal contaminants, it also has certain drawbacks as it requires longer cleaning time (Verma et al.,2018). Due to their slow development rate and low biomass, many metal hyperaccumulators usually have limited phytoremediation efficiency. As plant growth is not supported in highly contaminated soils, it applies to regions with low to moderate levels of metal contaminants. If it is not handled correctly and with sufficient care, there is a risk that the food chain may get contaminated (Sankhla et al., 2018). Some characteristics like fast-growing, high biomass production, abundant shoots, and extensive shoot system of common plants are required for the phytoremediation of various types of contaminants to work well. In order to ensure that the plant is adapted to the temperature and soil in the proper location and, more importantly, to activate the phytoremediation of contaminants close to the surface, careful selection of the plant and its variations is essential.

When a plant satisfies the following four requirements, it is deemed to be a heavy metal hyperaccumulator: (a) Translocation Factor (TF) > 1, (b) Enrichment coefficient factor (ECF) > 1, (c) greater levels of heavy metal total uptake (TU), 10-500 times more than normal plants (uncontaminated plants in check conditions), and (d) must collect a minimum of 0.1% dry weight each of Co, Cu, Cr, Ni, and Pb, as well as 0.01% dry weight each of Cd, As, and a few other trace elements, and 1% dry weight each of Mn and Ni (Reeve and Baker 2000).

**Table: -1. Some ornamental plantsand theirheavy metal tolerance.**

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
| Name | Metal | Maximum tolerance conc.(mg/kg) | Soil  Mg/kg | Root | Shoot | References |
| *Althaearosea* | Cd | 100 | 100 | 136 | 100 | Liu et al.2008 |
| *Mirabilis jalapa L.* | Cd | 100 | 100 | 68 | 141 | Yu and Zhou 2009 |
| *Taraxacummongolicum* | Cd | 100 | 25 | 12 | 33 | Wei et al.2008 |
| *Calendula officinalis* | Cd | 100 | 100 | 1084 | 284 | Liu et al 2008 |
| *Chlorophytum comosum* | Cd | 200 | 200 | 866 | 1522 | Wang et al 2012 |
| *Chlorophytum comosum* | Pb | 20000 | 1250 | 316 | 202 | Wang et al 2011 |
| *Melastomamalabathricum* | Pb | 200 | 200 | 13800 | 880 | Selamat et al 2014 |

Since the majority of the examined ornamental plants are annual or biennial herbs that typically take at least six months to mature after planting, soil-culture studies may be used to track the plant's development and reactions to stress over the entire growing season (Liu 2008). The most often used indicators to describe plant tolerance are morphological and growth markers, such as root length, shoot height, and plant dry weight. The IC50 (heavy-metal concentration at which 50% of the plants show inhibition) and tolerance (ratio of the maximum root length in an experimental group to that in a control group) indexes, as well as ecotoxicological indexes based on the inhibition rate (IC) of seed germination, root and shoot elongation, and biomass (fresh and dry weights), have also been established (González-Valdez et al. 2016). Several attractive plants have been chosen to evaluate their capacity for Cd or Pb phytoremediation from polluted soils, taking into account the degree of Cd and Pb contamination (Table 1.1).

**IMPORTANCE OF MARIGOLD PLANT**

The finest pioneer plant is the marigold, which is grown on polluted soils (Coelho et al.,2017). Marigold is a member of the Asteraceae family and is native to Mexico and other warm parts of America. It has naturalized in both tropical and subtropical regions. This was introduced by the Portuguese to India (Mehara et al.,1966). There are approximately 33 species in the genus Tagetes, five of which have been introduced into Indian gardens: *Tagetes erecta L., Tagetes minuta L., Tagetes patula L., Tagetes Lucida,* and *Tagetes tenuifolia. Marigolds* are *Asteraceae* (Compositae) genera with golden or yellow capitula (Rydberg et al.,1915). Moreover, some researchers suggest that marigold species reached India anciently through pre-Columbian transoceanic voyages (Sorenson and Johannessen 2004). Marigold was introduced to Georgia from India, and its ground-dried petals became one of the most popular local spices (Akhalkatsi et al 2012). Both *T. erecta* and *T. patula* are grown in Georgia as spice and dye plants (Henalt et al., 1990) recognized for their health-beneficial properties. *Tagetes erecta* L. is primarily grown for its bloom and the extraction of the natural color xanthophyll, while other species are planted for their essential oils (Raghava et al.,1998). There has been a worldwide increase in demand for natural pigments and colors generated from plants and microorganisms as a result of increased public awareness of the environmental and health dangers associated with the consumption of synthetic dyes (Manikprabhu and Lingappa 2013). Natural pigments and dyes are used by a wide range of businesses today, including those in the food, cosmetic, pharmaceutical, and textile industries. They may provide a true substitute for their natural counterparts due to the dangers of employing artificial colors and dyes on living things and the environment (Venil et al.,2013).

Marigold plants of various types are used to purify soil that has been contaminated with heavy metals. The majority of zinc-contaminated locations contain cadmium and many species, such as Brassica napus (rapeseed plants) (Zeng et al.,2020). Alpine pennycress (*Thlaspicaerulescensacaulescent)*, Willow clones (*Salix spp*.), a sunflower (*Helianthus annuus*), Indian mustard (*Brassica juncea*) corn (*Zea mays*), (X.J. Jiang et al., 2003), and sunflower (*Helianthus annuus*) are known to collect Cd (Vanek et al., 2003). The ability of marigolds (*Tagetes erects L*.) to remove cadmium (Cd), lead (Pb), and zinc (Zn) from contaminated soil was stated in the current review.

The cell walls, cytoplasm, and intercellular spaces of *Iris pseudocorus* showed the greatest Cr contents, according to research by Caldelas et al., (2012) using TEM and X-ray microanalysis. Metal deposits are regularly accumulated in cell walls, vacuoles, and cytoplasm, which is crucial for lowering the quantity of free metal. In order to reduce their bio-toxicity, heavy metals are absorbed through the root surface and subsequently detoxified in the tissues of ornamental plants.

Arshad et al., (2008) investigated six fragrant *Pelargonium* cultivars in the field to see how well plants withstood and collected Pb in acidic and calcic soil. In contrast to soil-T, which was acidic, soil-B was a calcic cambic soil. In addition to having a higher pH and less organic matter, Cambic soil was more than 20 times less contaminated than Acidic soil-T. The Pb concentration and translocation factor (TLF) in this experiment were significantly influenced by the soil type, and their values were greater in the less contaminated cambic soil than in acidic soil. Furthermore, the interaction of rhizosphere bacteria with plant roots could make heavy metals more bioavailable.

**Role of marigold for soil clean-up of heavy-metal contamination**

Shah et al., (2021) produced the widely accepted finding that the marigold (*Tagetes erecta* L) could tolerate significant amounts of Zn, Cd, and Pb in polluted soil. While comparing the absorption of Cd, Zn, and Pb, it revealed less absorption of lead and for Cd and Zn, it actacts as a hyper-accumulator. Cd is an excellent candidate for phytoremediation because, after being absorbed by the roots, it is subsequently transported to the shoots. Although there is a fair amount of Zn absorption in the roots, translocation to the aerial section is not optimum. Besides its aesthetic character, it is also the easiest option for phytoremediation of soil contaminated with Zn and Cd, especially in locations where open mining, brownfields, and highway sides are prevalent. When it comes to Pb, it may be investigated whether any acceptable soil amendments would enhance its uptake from soil. *Tagetes erecta* is not a foraged plant, using it in phytoremediation will not endanger human health due to contamination by organic phenomena.

According to Zaki et al.., (2015) Indian mustard (*B. juncea*) and marigold (*T. patula*) grown in contaminated soil, they were able to accumulate heavy metals in various parts of the plant while maintaining a growth rate of more than 90%, when compared to similar plants grown in non-contaminated soil. A higher rate of phytoextraction of chromium, lead, copper, and zinc was observed by Marigold plants from contaminated sediments.

Plants with more biomass are preferred for phytoremediation, according to Ashraf et al., (2019) because *Tagetes erecta*and *Tagetes patula* take up more heavy metals from the soil yet display fewer adverse symptoms because metals are diluted within the plant system. *Tagetes erecta* was preferred due to the higher amount of biomass over *Tagetes patula* during the phytoremediation of contaminated soil

Xiong et al., (2004) according to their results, for Zn, the transportation of the metal was calculated as the stem>leaf>root. However, it is believed that plants with Zn levels below 20 mg/kg are Zn deficient (Schmidt, 2003). As a result, it is thought that the Zn content in the majority of plant species is inadequate. In some proportions, zinc is a vital element, but an excess concentration of it may be harmful to living organisms (Jadia and Fulekar, 2009).

Sun et al., (2007) suggest that decorative plants like hollyhock (*Althaea rosea*) and pot marigold (Calendula officinalis) can grow in soil that has been contaminated with heavy metals like Cd and Pb without experiencing phytotoxicity. These plants may help to clean up the environment. Another decorative and therapeutic plant, black nightshade (*Solanum nigrum L*.), is a Cd-hyperaccumulator. Black nightshade has high Cd accumulation and tolerance capacities that may be advantageous for the phytoremediation of As and Cd-contaminated areas.

The most popular high explosive, 2,4,6-trinitrotoluene (TNT), is a potentially dangerous chemical and a human carcinogen. Hooda et al., (2016) observed at the viability of phytoremediation 2,4,6-trinitrotoluene (TNT) contaminated soil using *T. patula.* However, beyond a concentration of 200 mg/Kg, shoot and root length growth was reduced in plants growing in TNT-contaminated soil. Plants were able to produce flowers in soil with up to 1000 mg/kg TNT, it is possible to employ them in such conditions. *T. patula* was effective in removing up to 98.6% of the TNT from the contaminated soil. The results suggest that *T. patula* may be able to phytoremediation of soil contaminated with Cd, Cu, and Zn at the measured dosage, and suggest that *T. patula*may be utilized to help a site that has been contaminated by TNT. Due to the fact that it may improve the environment, using this plant in urban settings (such as city parks, gardens, or green spaces beside roadways) has important and beneficial effects. TNT was eliminated from the soil with the help of the ornamental plant *Tagetes patula* (Marigold). TNT in the soil was reduced by marigolds from 87.6 to 98.6% on average after three months. Nitrate and organic matter concentrations in the soil increased. The plant grew slowly overall than the control. As a result, marigolds could be an appropriate ornamental plant for the effective phytoremediation of TNT-contaminated soil.

According to a field experiment conducted in a Thailand region with heavy arsenic contamination, Chintakovid et al., (2008) investigated the nugget marigold, a triploid hybrid of French (*Tagetes patula*) and American marigolds (*Tagetes erecta L*.). Plants not only absorbed a lot of arsenic but also flourished in surroundings with high levels of arsenic. Flowers had the lowest arsenic percentage (5.8%), whereas leaves had the highest (46.2%). HPLC-UV-HG-QF-AAS was used to identify the types of arsenic found in the aqueous extracts of nugget marigolds. Therefore, marigolds should be thought of as a possible revenue crop for phytoremediation.

According to Bharti and Prashad (2014), an organic process known as phytoremediation protects the soil and ecosystem from various pollutants. Utilizing an ornamental plant for phytoremediation is a worthwhile endeavoursendeavour from an economic perspective. Before planting the plantlets, the mixture of ash was treated with various fertilizers to stimulate growth. The development was monitored and recorded after two months of the plantation. The findings were encouraging and demonstrated that the highest productivity is found in fly ash-amended soil with the highest concentration and the marigold plant was able to uptake heavy metals from the soil. The results from the study suggest that adding fly ash to the soil before planting is a good idea for growing ornamental plants like marigolds for waste management, and economic perspective.

Zhao et al., (2022) investigate the impact of tetrasodium glutamate diacetate (GLDA) on French marigold plant biomass, cadmium (Cd) accumulation, and dispersion within cells. The research revealed that:

The main factor affecting the biomass and Cd removal of French marigolds was the total quantity of GLDA used. For instance, GLDA considerably increased the biomass and Cd content of aboveground French marigolds under Cd contamination conditions of mild soil. The amount of DTPA-Cd in the soil was dramatically raised by the usage of GLDA. These results indicate that the enrichment characteristics of Cd in French marigold exhibit an intrinsic relationship with soil physiochemical properties and GLDA application rate, i.e., the enrichment efficiency of Cd in French marigolds increases with increasing GLDA concentration, and higher soil pH values stimulate the Cd migration from roots to the above-ground plant.

**SOCIAL AND ECONOMIC BARRIERS TO PHYTOREMEDIATION APPLICATION**

One of the most significant societal challenges is a lack of technical and social information, which has resulted in the implementation of regulatory instruments that favor chemical cleanup techniques. Traditional approaches have gained significant backing from environmental authorities, putting them at conflict with phytoremediation, which has received restricted financing due to its novelty (Marques et al., 2011). Another hurdle is the usage of genetically altered crops, as well as the harm these crops do to ecosystems. However, these characteristics may increase operating costs owing to the maintenance, monitoring, and proper disposal of plant waste in accordance with each country's environmental standards, as well as reduce the adoption of phytoremediation (Maestri and Marmiroli, 2011).

These socioeconomic constraints influenced opinions of phytoremediation's ineffectiveness for various pollutant types. However, in developing nations, phytoremediation for landfills and possibly polluted regions has been advocated, with prices reduced by 30 to 70% when compared to traditional techniques (Da and Uma, 2012). Some studies discovered that this method decreased pollutants, indicating that it might be used in a variety of contexts (Lamb et al. 2014; Stephenson and Black 2014). As a result, despite being an innovative technology, phytoremediation is still in its early stages; however, it is an economically viable technique for the recovery of contaminated areas, which can ensure biodiversity conservation by forming protected areas such as legal reserves and permanent preservation areas (Ali et al., 2013).

Table 3 shows the economic, environmental, and social benefits of phytoremediation. Wan, Lei, and Chen (2016) demonstrated the efficacy of phytoremediation in contrast to other treatments, demonstrating that phytoremediation may be employed for two years in soil contaminated with arsenic, cadmium, and lead. The results show that the concentration levels of pollutants were reduced to levels lower than the local standards following the application of phytoremediation. The entire cost was 37.70 USD m-3, which was lower than the values observed for traditional cleaning methods. Furthermore, Tavares, Oliveira, and Salgado (2013) found that sorghum and maize species were the most effective in phytoextraction of heavy metals, lowering copper, zinc, and chromium concentrations. This information supports the usage of these species but in future, these plants can use human to eat, we can use these plants’ material for brick formation.

**Table 3 shows the economic, environmental, and social benefits of phytoremediation.**

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| Remediation mechanism | Soil treatment | Studied  contaminants | Environmental benefits | Social benefits | Reference |
| Phytoextraction | Direct | Heavy metals(Cadmium) | The method used can reach a Cadmium rate of 40.5 to 46.1% in contaminated soil, further the improvement of the soil , metabolic functions by increasing enzymatic activity. | Healthier soil for future, besides the landscaping. | (Rakshee et al 2009; Yu et al,2020) |
| Phytotransfomation | Direct | Organic contaminants(methylene) | Absortion and transformation of contaminants, besides the detox of organics pollutants in plants. | Landscaping lakes, and rivers are freeof contaminants. | (Al-Baldawi et al.2018; Tariq and Ashraf 2016) |
| Phytovolatilization | Direct | Semimetal(arsenic) | The capability of fast recovery of contaminated soil and water with high concentration of arsenic by volatilization. | It was possible to recover contaminated water with double the limit of contamination allowed in Europe, making it potable. | (Guarino et al. 2020) |
| Phytostabilization | Indirect | Heavy metals | Bioavability reduction of pollutants by immobilization in root system or biomass in soil rhizosphere. | Limits the leaching of contaminants and entrance in groundwater and futher bioaccumulation interfering in the food chain. | (Khalid et al. 2017) |
| Phytostimulation | Indirect | Heavy metals | The capacity of remediating polluted soils with several heavy metals simultaneously promoting plant growth and reducing metal toxicity. | Cleaning of lands, leaving the possibility of future utilization of the soil. | (Zahoor et al.2017) |

Finally, many case studies were done to illustrate phytoremediation's applicability. A case study was carried out in Hamedan Province, which is located in Iran's west central area. Heavy metal hyperaccumulators Euphorbia macroclada and Centaurea virgata may be employed for phytoremediation of damaged soils (Lorestani et al., 2012). Sidahermaphordita is dependent on soil metal bioavailability. Fertilization can also help to keep heavy metals from accumulating in plants. Sidahermaphordita is a viable biomass source for energy recovery when paired with phytoremediation technology (Pogrzeba et al., 2018).

Eleocharis acicularis, an aquatic macrophyte, was studied for its ability to absorb various heavy metals and for its potential use in phytoremediation in an abandoned mining zone in Hokkaido, Japan. Eleocharis acicularis has a high potential for phytoremediation of heavy metal-contaminated mining tailings and drainage, according to Hoang Ha et al. (2009). Phytoremediation is the use of live plants to remove pollution from the environment, such as removing metal pollutants from soil and restoring ecological balance in a mining zone (Ojuederie et al. 2022; Sarwar et al. 2017).

**HYPERACCUMULATION OF METAL IN VARIOUS PLANT SPECIES**

Metal hyperaccumulation in various plant species has been extensively studied, with significant progress made thus far. Many plant species have unique metal accumulation, exclusion, and compartmentation strategies. T. caerulescens preferentially accumulates Zn in soluble form in epidermal cell vacuoles (Frey et al., 2000). Zn was discovered in the mesophyll cells of A. halleri leaves (Kupper et al., 2000; Zhao et al., 2000; Sarret et al., 2002). Cosio et al. (2004) investigated the processes of Zn and Cd accumulation in three distinct plant species using ion compartmentation by measuring short-term 109Cd and 65Zn absorption in T. caerulescens "Ganges" and A. halleri mesophyll protoplasts.

Their findings indicate the presence of a regulatory mechanism on the plasma membrane of leaf mesophyll protoplasts. Using a rhizosphere bag experiment on contaminated and non-contaminated soils, Puschenreiter et al. (2003) assessed chemical alterations in the rhizosphere of the hyperaccumulators T. goesingense and T. caerulescens, as well as the metal excluder T. arvense. When cultivated on polluted soil, T. goesingense showed hyperaccumulation and depletion of labile Zn in the rhizosphere. Zn was deposited in non-contaminated soil despite the fact that labile Zn in the rhizosphere remained unaffected. T. goesingense absorbed nickel at background levels in both soils when growing on non-contaminated soil. T. goesingense, on the other hand, increased labile Ni in the rhizosphere in both soils, indicating that it has a general inclination to mobilize Ni.

Whiting et al. (2000) discovered that plants from the T. carerulescens population that absorbed Cd had increased root biomass and root length after being planted in Cd-enriched soil, but plants from the T. carerulescens population that did not absorbed Cd did not.

Several researchers have examined Sedum alfredii Hance extensively in hydroponics and/or uncontaminated and contaminated soils (Li H. et al., 2005; Li T.Q. et al., 2005a; Liu et al., 2005; Xiong et al., 2004; Yang et al., 2004; Yang et al., 2004; Yang et al., 2004; Yang et al. The researchers discovered that when Cd and Zn intake levels grew, so did Cd and Zn concentrations in leaves and stems. Metal distributions in various plant portions followed the following pattern: stem>leaf>root for Zn and leaf>stem>root for Cd. These findings suggest that S. alfredii has an exceptional capacity to survive Cd/Zn toxicity while also absorbing and hyperaccumulating Cd and Zn across a wide range of Cd/Zn combined values.

Samal et al. (2017) investigate the phytoextraction ability of sunflower, marigold, and spinach plants in Zn and Cu contaminated soil, as well as the effect of phytoextraction on metal distribution in various soil solid fractions. Sunflower outperforms the other two plants in phytoextraction of Zn and Cu from contaminated soil.

The fractionation study discovered that sunflower and marigold plants outperform spinach in terms of enhancing the bioavailability and toxicity of Zn and Cu for successive crops. The growth of accumulator plants has a large impact on the distribution of Cu in different soil solid fractions. In the future, new accumulator plant choices should be investigated in order to get better outcomes in phytoextraction.

**Conclusions and future scope**

The study of the restoration of heavy metals contaminated soil by the use of ornamental plants as a preferable option to normal plants has gained popularity in recent years. Numerous decorative plant species have shown a strong capacity to withstand and absorb organic pollutants and heavy metal contaminants, which allows them to clean up contaminated soils as well as also improving the environment. The tendency of ornamental plants to absorb contaminants in their non-food components may significantly increase both their ecological and commercial worth.

In order to develop more effective, environmentally friendly methods for maximizing the phytoremediation by ornamental plants and to rationalize the eventual disposal of decorative remediation plants, future research should focus on examining the molecular mechanisms by which toxic substances are accumulated and transferred in ornamental plants. Using knowledge of the accumulation of heavy metals in plants, as well as hyperaccumulation species for heavy metal extraction from soil and water, it is possible to select crops and pasture plants that accumulate fewer heavy metals for food production and animal feed.

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