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Feasibility of Using Ornamental Shrubs in Phytoremediation

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ABSTRACT

Over the past century, especially accelerated by the Industrial Revolution, pollution has evolved into a systemic global crisis. Localised instances of pollution have become hazards that threaten the entire planet, as pollutants are no longer confined to their points of origin. Soil has always been the sink for a diverse range of organic and inorganic pollutants. Urban soils even more so, thanks to industrialisation compounded by urbanization. In the current scenario it becomes imperative to look for and refine new sustainable technologies and concepts to help reduce pollution as well as reclaim and remediate polluted soil, water and air. This review deals with one such 'Green' technology called Phytoremediation. It utilizes the inherent metabolic processes of plants to degrade, contain and/or transfer contaminants from polluted soil and water. The review limits itself to remediation of heavy metal-contaminated soils. It highlights the strategic advantage of ornamental plants, such as Nerium oleander, Tabernaemontana divaricata, Cascabela thevetia, etc. Unlike edible crops, these species provide a biological dead end, preventing toxins from entering the human food chain while offering urban aesthetic benefits. Heavy metal stress negatively affects photosynthesis and even growth via oxidative damage. The effect of plant morphology (roots, stems, and leaves) controls the fate of contaminant binding, exclusion or uptake and further sequestration. By integrating phytoremediation strategies with urban landscaping, phytoremediation using ornamentals may prove to be a technically robust and economically viable sustainable way for remediating and reclaiming polluted soils and ensuring long-term ecological resilience.

Keywords: urban soils, soil pollution, remediation, sustainable, clean up.

1. INTRODUCTION

The environment we live in has been drastically altered by the combined forces of rapid industrial and technological growth, ever-increasing urban spread and intensive agricultural practices. Over the last few decades, pollution that was once limited to specific areas has expanded into a widespread global crisis. Contaminants are no longer restricted to where they are produced; carried across long distances through air and water, they circulate and percolate every compartment of the biosphere, including soil. Soil has always been the sink for a diverse range of organic and inorganic pollutants; urban soils even more so. This widespread transport has introduced harmful contaminants like toxic heavy metals into the core components of ecosystems, leading to their build-up in soils around the world. This process poses a danger to ecological stability as well as long-term human health and survival (Paul et al., 2014).

The key forces behind heavy metal contamination are industrial processes, mining activities and rapid urban development. Metals like Lead (Pb), Cadmium (Cd), Mercury (Hg), Arsenic (As) and Nickel (Ni) are especially harmful because they are persistent and non-biodegradable. Unlike organic pollutants, they do not break down over time. Instead, they spread into wider ecological systems. Through bioaccumulation, these contaminants pass from soil into plant tissues and then move upward through the food chain. With each successive trophic level, their concentrations intensify. Exposure to high levels of these metals has been linked to adverse effects on human health and wildlife (Liu et al., 2018). Cadmium accumulates in the kidneys and is implicated in a range of kidney diseases. Lead poisoning in children causes neurological damage leading to reduced intelligence, loss of short-term memory, learning disabilities and coordination problems. Mercury damages the nervous system with symptoms ranging from uncontrollable shaking and muscle wasting to partial blindness and deformities in children exposed in the womb. Arsenic causes cardiovascular problems, skin problems including cancer, and peripheral neuropathy and kidney damage (WHO, 1997). Long-term exposure to heavy metals may result in chronic physical, muscular, and neurological degenerative processes that mimic Alzheimer's disease, Parkinson's disease, muscular dystrophy, and multiple sclerosis. Also, toxic heavy metals cause DNA damage, and their carcinogenic effects in animals and humans are probably caused by their mutagenic ability (Baudouin et al., 2002).

Conventional remediation methods have depended on physical and chemical remediation approaches. These usually include ex-situ excavation, which involves digging out polluted soil and transporting it to designated hazardous waste landfills. Although such methods provide a rapid solution by eliminating the direct source of toxicity, they come with serious and widespread limitations. They are invasive, labour-, cost- and technology-intensive (Danh et al., 2009). They also demand substantial energy consumption, something which is always at a premium in urban and industrial environments where soil contamination is rife. In addition, Di Baccio et al. (2003) note that such approaches can be unsuitable and even counterproductive for managing contamination on a large environmental scale. Disturbing soil through excavation may increase contaminant movement, enabling pollutants to seep into groundwater or disperse as airborne dust. Most importantly, these mechanical operations damage the biological integrity of the soil, removing vital microbiota and disrupting the physical structure that makes soil a living and fertile system.

2. PHYTOREMEDIATION: THE GREEN CLEAN-UP TECHNOLOGY

The pursuit of more sustainable solutions led to the development of phytoremediation, which utilizes plants to restore contaminated environments (Garbisu and Alkorta, 2001; Vidali, 2001). The word phytoremediation itself derives from the Greek ‘phyton’ for plant and Latin ‘remedium’ which means to remediate. Driven by cons of conventional soil remediation methods and the focus on sustainability and ‘green’ processes, workers have produced an impressive body of research on plants to remediate soil contaminants ranging from metals, pesticides, solvents, explosives, petroleum hydrocarbons, to radionuclides.

A wide range of plants have been assessed for potential application for phytoremediation of different contaminants in soil and water. The choice of plant depends on the geography, topography, climate, soil characteristics, contaminant type and concentrations. Researchers have actively evaluated aquatic plants and mosses (Favas et al., 2017, 2018), grasses (Gomes et al., 2014; Rabêlo et al., 2021), trees ((Bist et al., 2017; Patel et al., 2023)) leguminous plants (Varun et al., 2017), native weeds (Varun et al., 2015, D’Souza et al., 2010;2013), aromatic plants (Kumar et al., 2023; Gupta et al., 2013) and ornamentals (Abdalla and Mahmoud, 2008; Mahajan et al., 2024).

Phytoremediation is a blanket term for different plant-based mechanisms (Fig. 1) for remediating metal-polluted soil, sediments, or water. They all rely on the natural metabolic functions of plants to immobilize, detoxify or eliminate harmful contaminants from soil and water (Wu et al., 2015).

Phytoextraction/Phytoaccumulation relies on plants to function like solar driven pumps, absorbing metals through the roots and transporting and accumulating them in their above-ground parts i.e. stems and leaves (Saleem et al., 2020). Once mature and/or with appreciable metal sequestered in these parts, they are harvested and safely disposed of or treated, permanently removing contaminants from the site. This is one of the most widely recognized methods for heavy metal remediation.

Rhizofiltration utilizes hydrophytes or wetland plants and comes into play for polluted water and/or waterlogged soils. Plants outside the above category can also be used provided hydroponics is an option e.g. in smaller ponds etc. where planted rafts/platforms can be floated with plant roots submerged in the water. The roots absorb, adsorb and precipitate metal contaminants, trapping them within root tissues (Midhat et al., 2019).

Rhizodegradation/Phytostimulation refers to the breakdown of organic pollutants in the narrow zone of soil surrounding plant roots. This is a co-operative approach involving both plants and soil microbes. Plants exude metabolites into soil which help stimulate the growth of microbes which produce enzymes that convert complex, toxic organic compounds into simpler and less toxic forms (Li et al., 2016).

Phytodegradation/Phyto-transformation is also a mechanism that degrades complex organic contaminants but here the organic contaminants are first absorbed by the plant. Then the internal metabolic pathways and enzymes of the plant break chemical bonds within the pollutants, effectively transforming them into harmless by-products (Sharma and Pandey, 2014).

Phytovolatilization is a unique pathway wherein plants absorb pollutants and chemically convert them into volatile forms. These altered compounds are then released into the atmosphere through stomata as part of normal transpiration (Leguizamo et al., 2017). This approach is commonly applied to elements such as mercury and selenium.

Among the above, phytoextraction and phytodegradation are considered the most developed options for addressing heavy metals and organic pollutants, respectively (Lee, 2013; Mani and Kumar, 2014).

Why Ornamental Plants?

Plants being assessed for phytoremediation of heavy metal contaminated soils should possess some inherent characters which make them better suited compared to others. These include the ability to tolerate a certain concentration of a given metal in the soil; accumulate it within its tissues to appreciable amounts; have a good biomass production and root proliferation. The latter growth patterns enhance the uptake efficiency of a plant. Also, it should always be remembered that any plant being used for such clean-up efforts is itself a contamination risk and as such should be kept out of the food web.

Ornamental species with the above attributes are well suited for phytoremediation. They offer a dual-function approach solution: effectively absorbing pollutants such as heavy metals while also enhancing the visual appeal of urban and industrial landscapes (Liu et al., 2018). When incorporated into city green spaces, these plants allow brownfield areas to be treated without creating the harsh, industrial look associated with conventional remediation sites. This strategy connects environmental restoration with urban design, providing a cost-effective and scientifically reliable route for improving global soil health (Khan et al., 2021). Also, they are not generally cultivated for human consumption thus, pose a lower risk for toxins to enter the human food chain.

3. ORNAMENTAL PLANTS - POTENTIAL FOR PHYTOREMEDIATION

Tabernaemontana divaricata commonly called Pinwheel flower (Eng.) or Chandni (Hin.) is an attractive, tropical bush. Distinguished by shiny, dark-green leaves and spinning white blooms, it is frequently grown throughout Asia due to its visual appeal and its long-standing uses in various types of regional medicine. Beyond its beauty, the plant's quick growth, large biomass, hardiness and tolerance make it an ideal choice for phytoremediation. T. divaricata as a species has been documented to tolerate soil pollution, even in the air in urban areas along roads (Kulshreshtha and Saxena, 2022). Based on a study to assess the effect of long-term stress on ornamental shrubs with lead (Pb), cadmium (Cd) and nickel (Ni) in soil, Abdalla and Mahmoud (2008) recommended Acalypha wilkesiana and Asclepias curassavica for planting in contaminated areas, as they absorbed the highest amounts of these metals followed by T. divaricata and Dodonaea viscose. Mahajan et al. (2024) were able to categorize T. divaricate as a phytostabilizer and Portulaca grandiflora as well as Syngonium podophyllum as potential phytoextractors for Cd-contaminated soil and water, with the harvested biomass potentially serving as bio-ore for recovery of Cd.

Nerium oleander commonly called Oleander (Eng.) or Gulabi Kaner (Hin,) is an adaptable, perennial shrub valued for its flowers in shades of pink, white and red. Originating in the Mediterranean and areas of Asia, it is highly water-efficient and grows well in weak, stony or salty soils. Its leaves contain cardiac glycosides (such as oleandrin) rendering it poisonous and distasteful to animals—nature's assurance that accumulated metals do not enter the food chain through grazing. This makes it stand out among plants with potential for phytoremediation. According to Elloumi et al. (2017) Nerium oleander is suitable for phytostabilization of soils contaminated with Cr and Ni. They also reported increased levels of Zn, Fe, Ni and Cr in the foliage when compared to control. Ibrahim and El Afandi (2020) documented appreciable Pb accumulation in roots of the plant, and Cd /Zn in stems and leaves while estimating the contribution of soil-root-leaf and soil-air-leaf pathways in reducing heavy metals in soil using a simple Uptake Plant Model.

Alawsy and Nafawa (2022) demonstrated accumulation of Pb and Cd in N. oleander with Cd being more readily translocated from root to shoot, recommending it for phytoremediation soils contaminated with the two metals. Interestingly, the metals were not directly applied to the pots as their salts but through dried water hyacinth biomass and compost This highlights the danger of composting with this plant which grows in water bodies which are highly contaminated more often than not. Ibrahim et al. (2025) also found relatively higher accumulation of Ni, Mo, Cs, Pb and Cu in the roots of N. oleander compared to above-ground parts when grown in ground rock-amended soil.

Cascabela thevetia (syn. Thevetia peruviana) known as Yellow Oleander (Eng.) or Kaner (Hin.) is a hardy, perennial shrub that can grow into a small tree. Although native Mexico and Central America, it now grows freely across the tropics. It is easily recognized by its thin, spear-like foliage and vivid, funnel-shaped yellow flowers. It can tolerate drought, pollution, poor soils and bright sun. Additionally it contains cardiac glycosides (like thevetin), which render it poisonous to many leaf-eating animals. Kaur et al. (2022) demonstrated absorption and accumulation of iron, chromium and cobalt in leaf samples of Alstonia scholaris; Nerium oleander; Tabernaemontana divaricata and Thevetia peruviana (syn. Cascabela thevetia) collected from roadside sites of Amritsar

(Punjab), India. Researchers in Ahmedabad city also detected copper and chromium in Nerium oleander, Cascabela thevetia, and Lantana camara leaf samples predominantly from plants growing along the road in heavy-traffic areas (Mahida et al., 2022).

Nyctanthes arbor-tristis also known as Tree of sorrow (Eng.) or Parijat/Harsingaar (Hin.) is a large shrub/small tree originating in South and Southeast Asia. It is famous for its sweet-smelling, white, star-like blossoms with orange throats which bloom at night and fall by sunrise. Its wide, coarse foliage offers a large surface for catching dust and particulate matter, acting as a green "living shield" for restoration efforts in polluted neighborhoods. Based on exogenous Pb treatments Kumar et al. (2019) concluded Nyctanthes arbor-tristis can potentially be used in phytoremediation due to its Pb accumulation and antioxidant properties.

The MoEF (2005) has suggested plants like Acacia arabica (Babul), Citrus species, Diospyros species, Ficus benghalensis (Banyan), Ficus religiosa (Peepal), Polyalthia longifolia (Ashok), Tamarindus indica (Imli), Thuja occidentalis (Cedar), Prosopis juliflora (Mesquite), and Ziziphus jujuba (jujube) for air pollution control including metals as particulate matter. In a study of Tarapur industrial area Bist et al. (2017) reported many tree species tolerant to air pollution such as Ficus racemosa, F. hispida, F. benghalensis, Pongamia pinnata, Mangifera indica, Acacia auriculiformis etc. including those grown for ornamental and aesthetic purposes like Putranjiva roxburghii, Morinda citrifolia, Polyalthia longifolia and Cassia fistula. Patel et al. (2023) surveyed 16 commonly planted species in urban areas of Delhi for lead (Pb), cadmium (Cd), copper (Cu), and zinc (Zn) accumulation in their leaves. Concentrations of Pb, Cu, and Zn were found to be highest in leaves of Morus alba, while Cd concentrations were found to be highest in Millettia pinnata. The workers concluded that trees such as Ficus religiosa, Terminalia arjuna, Morus alba, Prosopis juliflora and Millettia pinnata proved to be exceptional biomonitors and bioaccumulators for the four heavy metals tested.

Air Particulate Matter with diameters below 10 microns (PM10) is predominantly composed of heavy metallic species like Cd, Cr, Cu, Ni, etc. These end up in the surrounding foliage by deposition or adsorption or in the soil with rain. Thus, metal particles in the air also impact the bio-geo-chemical processes in the soil and food chain, affecting in turn the environment and human health (Matei et al., 2025).

Even if not all of the plants mentioned above are ornamental, many are grown for their cultural and religious significance. These are plants that we are quite familiar with and see around us even in the urban landscape. In a review of phytomonitoring and mitigation of air pollution by plants, Joshi et al. (2020) discuss the role of plants in controlling airborne metals, either by adsorption on the leaf surface or by absorption (as accumulators). If they can tolerate metals as PM10 in the air and soil it follows that they hold potential for phytoremediating soils contaminated with metals through sources other than air pollution. They hold the added advantage of being native and well-adjusted to their local conditions, hence should not need constant monitoring.

4. CONCLUSION: THE FUTURE OF SOIL REMEDIATION

The emergent need worldwide to contain heavy metal pollution and reclaim contaminated soil and water necessitates a move from expensive, destructive engineering techniques toward sustainable ‘green’ and organic alternatives. Phtoremediation—utilizing innate functions like root-filtering and extraction—provides a sun-driven, "natural" choice that decontaminates water and soil, restoring its vitality. Ornamental plants like Nerium oleander, Tabernaemontana divaricata, and Cascabela thevetia, Nyctanthes arbor-tristis offer a tactical advantage within this sector. They are hardy and tolerant to pollution. Also, they are not part of the human diet and are non-palatable to animals, forming an organic "closed loop" for metals like, stopping dangerous heavy metals like Lead (Pb) and Cadmium (Cd) from reaching the human food supply. Moreover, such plants offer aesthetic advantages to otherwise derelict sites, balancing environmental needs and scenic charm. Ornamental plant-based clean-up holds the potential to be a scientifically solid and feasible route towards healing our planet, guaranteeing a better, pollution-free global environment in the future.

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