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Roles of Trees for Abatement of Environmental Pollution: A Review

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ABSTRACT

Planet Earth has become inhospitable for the survival of biological species as it is facing the most serious threat from pollution. Forestation for the abatement of pollution and the betterment of the environment is a successful and widely accepted method among the many ways and means to mitigate environmental contamination. Pollutants are collected, assimilated, and stored by trees. The capacity of trees to capture and hold larger particulates on the epidermal and outer leaf surfaces aids in regulating dust pollution. Additionally, trees contribute to high-quality water by reducing soil erosion locally, which lowers silt in water bodies and traps or filters other water pollutants. In the context of noise pollution, trees can reduce 5-8 dB of noise per 100 feet of the forest by reflecting and absorbing sound energy. Utilizing live, green plants to lessen and/or remove toxins from contaminated soil, water, sediments, and the air is known as phytoremediation. Additionally, different types of genetically engineered trees have been developed through recombinant technologies, which can be utilized to remove heavy metals and toxic substances from contaminated sites. Such genetically modified or transgenic plants could help clean up contaminated sites by taking up pollutants using their roots. This review examines both the conventional and recent developments in using trees for bioremediating contaminated or polluted sites. Thus, by proper planting scheme with suitable species will bring healthy life and color to the cement concrete jungle of large congested cities

KEYWORDS: Climate change, genetically modified trees, phytoremediation, transgenic genes

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1. INTRODUCTION

Planet Earth, after the industrial revolution, has become hostile to the existence of biological species as it is facing the most severe threat from pollution, causing irreparable damage. With rapid mechanization and random urbanization, environmental pollution has become severe. Overexploitation of open spaces, an ever-increasing number of automobiles, and demographic pressure have further aggravated the problem. Pollution is a global issue, even though urbanized areas are often more polluted than rural ones, pollution may migrate to isolated areas where no one lives (Khatri and Tyagi, 2015). Pollutants are a big issue in cities, exacerbated by the lack of exhaust for the pollution to escape. Many things that are good for people damage the environment. Pollutants are released into the atmosphere by automobiles through their exhaust pipes. When coal is used to create electricity, it pollutes the air. Industries and homes create garbage and sewage, polluting the land and water (Zhengfu et al., 2010). Pesticides, which are poisonous chemicals used to kill weeds and insects, taint streams and put animals at risk (Mishra et al., 2018).

Pollution is defined as "an undesirable change in the air, water and land's physical, chemical and biological characteristics that may be harmful to living organisms, living conditions and cultural assets." The pollution control board defined pollution as "unfavorable alteration of our surroundings, largely as a by-product of human activities." Various ways and means to mitigate environmental pollution have been recognized, *viz*., removal of the pollutants by numerous mechanizations; use of sources of energy other than fossil fuels (which are one of the major causes of pollution); or by following the slogan Reduce, Reuse or Recycle the trash that causes pollution (Gertsakis and Lewis, 2003; Gaines, 2012). One of the important ways to mitigate pollution is by establishing vegetation cover (forestation).

Planting trees and shrubs to abate pollution and improve the environment is effective and well-recognized worldwide (Kumar et al., 2013). Planting trees in urban areas used to be solely for aesthetic reasons. The ever-increasing levels of urban pollution have forced reconsidering the whole approach of urban landscaping and its orientation to achieve dual effects, i.e., bio-aesthetics and pollution mitigation. Proper planning and planting schemes depending upon the magnitude and type of pollution, selection of pollution-tolerant, and dust-scavenging trees and shrubs should be made for bioremediation of urban environmental pollution. Landscape architects can solve the pollution problems related to urban landscapes by creating a micro-climate (Anupriya, 2016; Agarwal and Sharma, 1980).

Furthermore, knowing the importance of trees in mitigating various types of pollution, it becomes prudent to understand that genetically engineered trees could also help remove toxins and explosive residues from the environment more quickly and cheaply than ever (Joseph et al., 2011). More insight is yet necessary to conduct research to investigate whether genetically modified or transgenic plants could help clean up contaminated sites by taking up pollutants using their roots. The genes that researchers plugged into such trees/plants could then break down impurities such as carcinogens or cancer-triggering molecules. This review article envisages all the roles of tree that aids in the abatement of various environmental pollutions including both conventional and novel approaches.

2. THE CONVENTIONAL APPROACH OF TREES IN POLLUTION CONTROL

Air pollution is one of the primary environmental pollutions experienced in the recent epoch, induced by solid and liquid particles and some gases suspended in the air. These particles and gases can come from vehicle exhaust, burning of fossil fuels, factories, dust, pollen, mold spores, volcanoes, and wildfires. The solid and liquid particles suspended in our air are called aerosols. Because trees may absorb, bind, intercept, and sequester pollutants, they can be utilized to address or mitigate air pollution. Trees assist in minimizing pollution in the air by leaf stomata absorbing gaseous contaminants during the normal exchange of gases; water-soluble contaminants are adsorbing or dissolving on damp leaf surfaces; the epidermis, which can be waxy, resinous, hairy, or scaly, interacts with and stores bigger particles on the outer leaf surfaces; particulates are captured and stored on uneven, rough branches and bark surfaces; sequestering CO_2 aboveground in woody tissue and belowground in the roots; lowering local air and building temperatures through transpiration, shading, and reducing winter wind infiltration.

Even though trees help purify the air, their sensitivity to pollution and degree of tolerance strongly depend on the pollutant type. Detailed knowledge of pollutant type and concentration of pollutants is necessary to utilize this method for mitigation successfully. Hence, planting the tolerant variety can help in efficient green belt development in polluted areas (Sæbø et al., 2012), improving the overall air quality. Analyzing the mechanisms that underlie sensitivity and tolerance might help us understand how plants respond to physiological and biochemical pollution levels. A technique for determining plant resistance and sensitivity to air pollution using four biochemical characteristics: ascorbic acid, total chlorophyll concentration, leaf-extract pH, and relative water content can be used. Singh and Roa (1983) thus, have evolved an empirical formula to find out Air Pollution Tolerance Index (APTI), i.e.,

APTI=(A(T+P)+R)/10

Where, A=Ascorbic Acid (mg g^{-1}),

T=Total Chlorophyll (mg g^{-1}),

P=Leaf extract pH

R=Relative water content of leaf (%)

Species scoring APTI values towards the higher end are the tolerant species, which have a higher capacity to withstand polluted environments. These can be suggested for sustainable green belt development. At the same time, those scoring low APTI values are more sensitive species and can act as bioindicator species of air pollution. Further, the API accounts for various biochemical and socio-economic parameters of a particular plant, providing a holistic approach.

According to Roy and Battacharya (2020), *Mangifera indica* and *Azadirachta indica* had higher APTI in a study on the air pollution tolerance index of native tropical trees for green belt development in India. The efficiency of vegetative impediments, for example, in lowering ultrafine particle (UFP) concentrations varies (Janhall, 2015). Several complicating variables contribute to this variability. The complex and porous structure of trees and bushes can alter near-road concentrations by capturing pollutants or altering airflow, resulting in either lower dispersion due to reduced wind speed and boundary layer heights (Vos et al., 2013), or enhanced dispersion due to increased air turbulence and mixing as the pollutant plume is lofted up and over the vegetation (Bowker et al., 2007).

Vegetated green belts effectively block dust and filter suspended particles in urban areas (Wang, 2011). It is well documented that plants can effectively adsorb and reduce particulates in the air by capturing particulate matter such as foliar dust, hydrogen fluoride, SO_2, some compounds of photochemical reactions, and heavy metals from the air on their leaves (Liu et al., 2008). Plants remove pollutants from the air in three ways: leaf absorption, particle and aerosol deposition on leaf surfaces, and particulate fallout on the vegetation's leeward side. The ability of vegetation to retain dust is determined by various elements, including tree canopy type, leaf and branch density, and leaf shape, such as roughness, trichomes, and concave/convex, among others, as well as current weather conditions (Rai et al., 2010). Dust deposition is also influenced by leaf orientation and leaves' sessile or semi-sessile structure. This is because they determine the accessible surface for dust deposition. Water droplets on hydrophilic leaves spread out PM and are quickly deposited on these wet surfaces. If the pollutant is water-soluble, e.g., NO_2 or SO_2, direct dissolution on wet plant surfaces is also possible (Samson et al., 2017). Sett (2017) and Chaudhary and Rathore (2019) documented that the evergreen plant with horizontally leaves orientation is good dust trapper than an evergreen or deciduous plant with vertically suspended glabrous leaves.

One of the most important contributions of forests is to improve water quality. They achieve this by aiding in reducing water and soil erosion, minimizing water sediments, interception of rainwater, developing forested wetlands, establishing riparian forest buffers, and stormwater management. Forests provide a barrier that could slow water flow and trap soil particles. In forested land, below the humus lies the tree roots, each clothed in fungal hyphae and the gels secreted by bacterial colonies. About 30–40% of the bulk of the tree itself lies in the soil; most of this extends over many hectares, with thousands of kilometers of root hairs lying mat-like in the upper 60 cm of soil (only 10–12 % of the root mass is found below this depth, while the remaining roots can reach depths of up to 40 meters in the rocks below). The root mat actively absorbs the water and transports it up the tree, and the tree transpires it to air. This is useful, especially along waterways and slope fields. In this context, trees should be planted in combination with other practices to develop a complete conservation system that enhances landscape aesthetics, improves water quality, and provides wildlife habitat. Well-planned forest shelterbelts retain water and reduce evaporation by blocking dry winds in summer.

Trees play a vital function in the urban environment by regulating the water cycle and influencing local climatic conditions. Because their canopies intercept rainfall and trees are crucial in urban catchment hydrology. Rainfall is intercepted by the canopy, which lowers throughfall beneath the canopy and, as a result, minimizes runoff in metropolitan areas. Increased rainfall interception and evaporation and reduced runoff are critical for restoring the urban water cycle to its natural state in an urban setting with a high percentage of impermeable surfaces. The amount of rain intercepted by a canopy and then evaporated is known as canopy interception (Xiao et al., 2000). The difference between gross rainfall and the quantity of rain going through a crown can be used to compute it. Some raindrops fall directly through foliage and gaps between branches to reach the ground, a phenomenon known as "free throughfall." Raindrops collected by leaves or branches are momentarily retained on their surfaces before evaporating once the rain stops. Trees are essential in urban environments because of the rain intercepted by their canopies. Retaining water for a short amount of time or until it evaporates helps to improve the urban water cycle.

Forested wetlands can cope with nitrogen and heavy metal pollution compared to other types of wetlands (Zhang, 2016). Chen et al. (2002) reported that the effect of forests on water environment protection is vital. When the width ratio of farmland to forest belt was 100–40, the purification effect on the losing nutrients was the best, and 50.05% N loss and 29.37% P loss could be absorbed by forest under rape–rice rotation and 30.98% N and 86.73% P could be absorbed by forest under wheat–rice rotation. Under such circumstances, the purifying ability of water is very satisfactory. Riparian forest buffers could trap sediment and bacteria and absorb nutrients from polluted runoff and subsurface flow. Certain combinations of trees, shrubs, and grasses could function effectively as nutrient and sediment sinks for pollutants (de Blois et al., 2002).

Various research has proved the impact of planted trees in urban forests on noise pollution reduction (Maleki and Hosseini, 2011). By reflecting and absorbing sound energy, trees may lower 5-8 dB noise per 100 feet of the forest; and trees create 'white noise,' which is the noise of leaves and branches in the wind and associated natural noises that hide other human-caused sounds (Coder, 2011). Maleki and Hosseini (2011) deliberated that sound reduction happens *via* average and excess attenuation in an open region with no trees or other obstructions. When sound travels through the atmosphere, it causes spherical divergence and friction between the molecules. Ozer et al. (2008) opined that plants may help reduce noise levels, and among the plants that can thrive in city conditions, pine trees are the most useful and effective trees for noise management.

3. NOVEL APPROACH OF TREES FOR IN POLLUTION CONTROL

3.1. Phytoremediation for pollution abatement

One of the most effective ways to remove toxins from the soil is to use trees in the phytoremediation process (Vassilev et al., 2004; Krämer, 2005; Pilon-Smits, 2005; Peuke and Rennenberg 2006). It is a method that promises effective and economical cleaning of hazardous waste sites by using vegetation to treat contaminated soils and sediments. Heavy metals from contaminated locations could be removed *via* types of phytoremediation. Salt et al. (1998) and Dietz and Schnoor (2001) distinguish between different types of phytoremediation *viz.,* phytoextraction, phytostabilization, phytovolatilization, and phytodegradation.

Phytovolatilization could be described as the uptake of soil contaminants and transforming them into volatile forms through their transpiration into the ambient atmosphere. Contaminants that are present in soluble form in plants go through a series of steps before volatilizing into the atmosphere via the stream of transpiration. Phytovolatilization helps to eliminate many contaminants like mercury (Arya et al., 2017); inorganic volatiles such as selenium and arsenate; and organic volatiles like trichloroethene. Phytovolatilization is characterized by evolving toxic pollutants into the atmosphere following their transformation into less toxic forms. Phytovolatilization has been proven to be most effective in removing some organic volatiles such as 1,4-dioxane (Ferro et al., 2013). Numerous studies stated that poplars and willow species can take up contaminants *via* phytovolatilization (Rubin and Ramaswami, 2001; Jasechko et al., 2013).

Phytostabilization, also known as phytoimmobilization, stabilizes heavy metals in disturbed soils by using particular plants. This method could convert organic and inorganic metal contaminants into a stable state, reducing their environmental risks. The major goals of this technique are to (a) minimize the quantity of spilled water into the soil, which might result in harmful leachate, (b) create a barrier that prevents direct contact with polluted soil, and (c) prevent soil weathering and heavy metal dissemination to other locations. Chaturvedi et al. (2012) studied the phytostabilization of iron ore tailings through *Calophyllum inophyllum* L. Iron ore tailings and their varying composition with garden soil were taken to study plant growth, chlorophyll content, and metal uptake pattern of *C. inophyllum*. The increase in growth parameters and chlorophyll content and the high metal accumulation in plant tissues suggest that *C. inophyllum* may be a potential tool for phytoremediation. As a result, choosing the right tree species is critical for phytostabilization success. Because of their vast root systems and high transpiration capacity, trees may be particularly well adapted for phytostabilization (Pulford and Watson, 2003). However, due of soil acidity and the formation of dissolved organic matter, tree development may increase metal leaching (Mayer, 1998). Consequently, when it comes to risk management, it's critical to choose tree species for phytostabilization that generate minimum soil acidity and metal translocation to their leaves (Mertens et al., 2007).

Plant metabolic activities contribute to organic pollutants' internal or external breakdown through phytodegradation, also known as phytotransformation. To put it differently, the breakdown of complex organic substances into simpler forms that the plant can absorb is aided by metabolic processes. Peroxidase, nitroreductase, laccase, nitrilase, and dehalogenase are among the plant enzymes involved in this phytodegradation process (Morikawa and Erkin, 2003). Pilipovic et al. (2006) described the potential of some poplar (*Populus* spp.) clones for phytoremediation of nitrates through biomass production. The nitrate reductase and its activity and nitrate accumulation confirm that the primary process of nitrate assimilation is located in leaves, while roots serve as nitrate deposition places.

Phytoextraction, or phytoaccumulation, photoabsorption, or phytosequestration, is extracting nutrients from plants. It refers to the absorption of pollutants from soil or water by plant roots and their mobility and accumulation in aboveground tissues that are burnt for energy production after harvesting, with the possibility of recovering metal from the ash (Rafati et al., 2011). Metal-accumulating plants may be seeded or transported into heavily contaminated soils and grown using traditional agricultural methods. The phytoextraction capacity of trees growing on metal-contaminated soil was studied by Rosselli et al. (2003). The ability of five woody species (*Salix viminalis, Betula pendula, Alnus incana, Fraxinus excelsior* and *Sorbus mougeotii*) to extract heavy metal (copper, zinc or cadmium) from polluted soil to their aboveground tissues was investigated. Metal content in leaves and twigs was determined. Salix and Betula transferred zinc and cadmium to leaves and twigs, but Alnus, Fraxinus, and Sorbus excluded them from their aboveground tissues.

3.2 Genetically modified trees in pollution control

In the modern aera, it is vital to break new ground. While there are numerous methods to handle pollution concerns with trees using the conventional technique, with increased technology and research, it is critical to employ them judiciously to address problem-causing conditions. One such technological advancement is in the field of biotechnology, which has evolved significantly in forestry research through the development of genetically modified tree (GMT). A genetically engineered tree or genetically modified tree is a tree whose DNA has been modified using genetic engineering techniques. Biolistics (or gene gun method), agrobacterium rhizogenes, and agrobacterium tumefaciens are some of the genetic modification technologies used to deliver genes into plants. (Harfouche et al., 2011; Joseph et al., 2011). The application of genetic modification to forest trees not only contributes significantly to tree breeding and the protection of native forests and endangered tree species but also aids in the reduction of environmental pollution caused by pesticides and industries (Gartland et al., 2003; Hoenicka and Fladung, 2006).

Trees were genetically modified as early as the late 1980s, but GM trees have just recently gained popularity and are expected to deliver significant economic and environmental benefits (Verwer et al., 2010). Transgenic trees could enhance the metabolism of organic pollutants and can achieve a rapid rate of uptake of compounds (Azad et al., 2014). Because of their vigorous growth, vast root systems, and enormous biomass, they may be useful for bioremediation. Enhancing tree productivity and clonal propagation, for instance, are practises that are said to have the potential to lessen pressure on native forests by requiring less area for wood production. Furthermore, through dendroremediation, genetic alteration may reduce chemical pollution caused by a transition in raw material processing to end products (Gartland et al., 2003). The Salk Institute recently discovered a gene called EXOCYST70A3, which can improve root development by altering the quantity of auxin that reaches the root tip (Ogura et al., 2019). The extended roots store more carbon and hold it deep in the soil, lowering the likelihood of carbon returning to the atmosphere. As a result, Verma and Verma (2021) deliberated that the planting of genetically engineered trees that absorb more CO_2 from the environment may contribute to increasing carbon stock per unit area, hence lowering CO_2 concentrations; and provided a mathematical model to investigate the influence of genetically modified tree plantation on CO_2 concentration regulation in the atmosphere. Akin Farman et al. (2023) have offered a fractional order model for analysing and modelling the influence of planting genetically modified trees on controlling atmospheric carbon dioxide.

Worldwide, more than 700 field trials with GM trees of 30 genera have been conducted (Walter et al., 2010; Haggman et al., 2013). Most of these, nearly 600, have been in the USA; *Populus*, *Pinus* and *Eucalyptus* species comprise more than 70 % of these (Naidoo et al., 2019; Panda et al., 2020). *Populus* is now the most explored tree genus for genetic modification (CM) purposes, and the others are *Pius* and *Eucalyptus*. Herbicide tolerance, resistance to infections and abiotic stress, wood composition and growth rates, and phenology are the key features subject to genetic alteration in breeding. Poplar hybrids expressing rabbit CYP2E1 have been used for removing volatile hydrocarbons (Doty et al., 2007). The engineered trees were capable of the enhanced metabolism of five volatile toxic compounds: TCE, vinyl chloride, carbon tetrachloride, chloroform and benzene. TNT uptake by transgenic aspen trees was higher than that of unmodified aspen trees (Van Dillewijn et al., 2003). James and Strand (2009) reported the dehalogenation of tetrachloroethylene (PCE) by hybrid poplar trees under controlled field conditions.

Improved pulping quality of GM trees, for example, will minimize the demand for bleaching chemicals and trash from pulp plants. However, public concern about the possible detrimental environmental impacts of releasing transgenic trees has grown. Specific tree features, such as long-distance pollen dissemination, may facilitate transgenic propagation in the ecosystem. Their lifespan may enhance the GM tree's impact on its surroundings, perhaps leading to unexpected environmental consequences. So yet, there has been minimal field experience with GM trees (Verwer et al., 2010). Other options include genetically modifying plants to tolerate the pressures of growing on marginal land and producing enhanced bioenergy and food crops. Drought-resistant plants can be developed through genetic engineering that thrives in stressful environments. Plants are genetically modified, increasing the efficiency of their absorption of direct scattered sunlight; they send more carbon into their roots, where some may be converted into soil carbon and remain out of circulation for centuries; thus, they would be able to withstand the stresses of growing on marginal land. Combining such genetic advances might considerably increase the amount of carbon flora draws from the atmosphere naturally (Joseph et al., 2011).

4. CONCLUSION

Considering the present environmental pollution scenario, there is a growing need to change the approach to planting trees and other plant species. The inclusion of the forested landscape having mitigating pollution ability will serve the dual purpose of making the cities green and pollution-free in the long run. The importance of trees in an urban/ rural environment is widely recognized as they cleanse the particulate polluted environment and help make planet Earth a more agreeable place to dwell.

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