Screening Urban Tree Species for Air Quality Enhancement – A review

Abstract:

Air pollution poses a significant global challenge, particularly in urban areas, due to factors like industrialization, urbanization, increased vehicular traffic, and high energy consumption. In India, vehicle emissions, industrial activities, and power plants are major contributors to deteriorating air quality, with vehicles alone responsible for substantial carbon monoxide and hydrocarbon emissions. Unplanned urbanization and population growth further exacerbate pollution levels. Urban air pollution is linked to millions of deaths and respiratory illnesses annually, especially in developing countries. Vegetation plays a crucial role in mitigating air pollution by absorbing gaseous pollutants and particulate matter through leaves. Plants also act as bioindicators, displaying characteristic responses to specific pollutants. They employ mechanisms like leaf absorption, particulate deposition, and fallout on the leeward side to cleanse the atmosphere. Bio-monitoring with plants is a cost-effective method to assess environmental pollution impacts, highlighting the vital role of urban green spaces in improving air quality and public health.

Key words: air pollution tolerance index,bioindicators,urban air pollution,bio-monitoring, mitigation by trees

Introduction

Clean air is a diminishing resource in today's communities, with each person taking about 20,000 breaths daily. This constant intake of air exposes our bodies to various pollutants such as carbon monoxide, carbon dioxide, and hydrocarbons, which can significantly impact human health. Air pollution has evolved into a global challenge affecting both developed and developing nations, exacerbated by factors like urbanization, industrialization, increased traffic, rapid economic growth, and high energy consumption (Chandawat*et al.*,2011).Urban areas, in particular, grapple with a complex mix of air pollutants, whose composition varies over time and across cities due to changing emission patterns. In India, urban air quality faces significant threats from vehicle emissions, industrial activities, and power plants. Vehicles, contributing to 70% of carbon monoxide, 50% of hydrocarbons, and a substantial portion of other pollutants, play a major role in deteriorating air quality, with two-wheelers being significant contributors (CPCB, 2009).Unplanned urbanization, rapid industrialization, a surge in vehicular fleets, population growth, and inadequate urban planning are among the key drivers of escalating air pollution levels

(Jayanthi and Krishnamoorthy, 2006). The last six decades have witnessed a staggering increase in urban populations globally, leading to heightened environmental pollution (Lebowitz, 1995; Tripathi *et al.*, 2008; Dwivedi *et al.*, 2008).In India, urban population tripled from 1951 to 2011, reaching 1.21 billion, constituting 25.7% of the total population. The urbanization trend has been marked by a surge in large cities and metropolitan areas, contributing significantly to air pollution (Directorate of Census Operation, India, 2012). The World Health Organization estimates that urban air pollution causes over 2 million deaths annually in developing countries, with millions suffering from respiratory illnesses linked to air pollution in major cities (WHO, 2002).Outdoor and indoor pollutants pose acute health risks to humans and plants. Vegetation plays a crucial role in cleansing the atmosphere by absorbing gaseous pollutants and particulate matter through leaves. Plants exhibit characteristic responses to specific pollutants, making them effective bioindicators (Agrawal *et al*., 2003; Oliva and Mingorance, 2006; Han and Naeher, 2006).Plants employ three mechanisms—leaf absorption, deposition of particulates on leaves, and fallout on the leeward side—to remove air pollutants. Bio-monitoring with plants is a cost-effective method to assess the impact of environmental pollutants. Many trees efficiently trap and absorb pollutants, serving as sinks for various air pollutants (Chandawat*et al*., 2011).

Urban air pollution:

In the context of increasing urban air pollution, the selection of plant species for urban areas should consider not only aesthetic and practical factors but also their ability to enhance air quality (Babu *et al*., 2013). Bio-monitoring of plants through an Air Pollution Tolerance Index (APTI) can be a valuable tool to evaluate the sensitivity of plants to air pollution. This index considers parameters such as ascorbic acid, total chlorophyll content, leaf pH, and relative water content to categorize trees as sensitive or tolerant (Tripathi *et al*., 1999; Raina and Sharma, 2003).In summary, the screening of trees for pollution abatement is essential in urban planning. The APTI, coupled with assessing the dust-capturing capacity and emission reduction of trees, aids in categorizing them as sensitive indicators or effective pollution sinks. As plant responses vary, identifying tolerant and sensitive species is crucial for developing green belts around urban areas. The ongoing study on "Screening Trees for Abatement of Urban Pollution in Chennai City" aims to assess APTI, study pollution mitigation, and monitor eco-physiological behavior in selected trees, contributing valuable insights to urban environmental management.The impact of atmospheric pollution, particularly in urban areas, is a growing concern due to the continuous release of toxic gases and substances from industries and automobiles. Chennai, being a metropolitan city and industrial center, faces challenges from both industrial and vehicular emissions. This chapter reviews relevant literature on the environment of urban areas, past and present trends of air pollutants in urban cities, the importance of trees in urban areas, plant responses to air pollution, and the mechanisms of action of specific pollutants.

Environment of Urban Area

According to the United Nations Environment Programme (UNEP), over 1 billion people are exposed to outdoor air pollution annually. Urban air pollution, linked to up to 1 million premature deaths each year, results from various anthropogenic sources, including automobiles, industries, power generation systems, construction projects, and solid waste. The primary contributors to air pollution in urban areas are automobiles, industries, and domestic fuel combustion. Both developed and developing countries face challenges related to mobile and vehicular pollution, with motor vehicles responsible for a significant portion of urban pollution.

Past and Present Trends of Air Pollutants in Urban Cities

In India, major metropolitan cities have experienced serious air pollution issues, with vehicular emissions contributing about 60-70% and industrial emissions about 20% to ambient air pollution. The trends of major air pollutants, such as sulfur dioxide (SO_2), nitrogen oxides (NOx), and particulate matter, have varied over the years. While SO_2 emissions have shown a decreasing trend since 1980, NOx emissions have increased, especially in metropolitan cities. Particulate pollutants are also a significant concern, affecting air quality.

Importance of Trees in Urban Areas

Plants, particularly trees, play a crucial role in mitigating air pollution in urban areas. They act as efficient filters, absorbing air pollutants and particulate matter. Trees in urban environments contribute to improving air quality by providing a large surface area for pollutant absorption and reducing pollution levels. Plantation in parks, residential localities, and along streets and roads serves as a bio-mitigating measure to enhance environmental quality.

Plant Responses to Air Pollution

Visible Symptoms

Air pollutants can induce visible symptoms on plants, classified as chronic or acute. Sulfur dioxide (SO_2) exposure results in acute injury symptoms such as necrosis and chlorosis on leaves. Nitrogen dioxide (NO_2) uptake predominantly occurs through stomatal openings, leading to increased stomatal conductance. Particulate pollutants can cause visible symptoms, including various necrotic lesions, depending on the plant species and pollutant concentrations.

Uptake of Pollutants

The leaves, particularly stomatal openings, are the most susceptible parts of plants to acute injury due to air pollutants. The entry of pollutants, such as SO_2 and NO_2, occurs through stomatal openings and cuticles. Cuticular resistance, wind speed, and leaf characteristics influence the entry of pollutants into leaves. Reactive pollutants like ozone (O_3) might react with cuticular waxes, leading to penetration through damaged cuticles.

Mechanism of Action

Sulfur Dioxide

The response of stomata to SO_2 entry depends on leaf age, concentration, and pollutant combinations. SO_2 dissolves in apoplastic water, forming sulphite and bisulphite ions. These ions can be detoxified by oxidizing them to less toxic sulphate ions. Disturbances to biochemical functions and cell structure due to SO_2 exposure may precede visible symptoms or growth reductions.

Nitrogen Dioxides

Nitrogen dioxide (NO2) primarily enters leaves through stomatal openings, similar to SO2. Once inside, it dissolves to form nitrate, nitrite, and protons. The ease of dimerization of NO2 may lead to the production of free radicals and free radical chain reactions. Chronic exposure to NO2 may reduce stomatal conductance, affecting plant health.

Air Pollution

Air pollution poses a significant threat to the environment and human health. Recognizing the impact of air pollution on plant species, researchers have developed the Air Pollution Tolerance Index (APTI) as a tool to assess and select plants that can thrive in polluted environments. The APTI combines four physiological and biochemical parameters—leaf extract pH, relative water content, ascorbic acid, and total chlorophyll content—to provide a comprehensive measure of a plant's tolerance to air pollution (Das and Prasad, 2010).Several studies have employed APTI to evaluate the tolerance of different plant species to air pollution in various regions. In Ghaziabad urban area, Mishra and Pandey (2011) identified plants such as Bauhinia, Pongamia, Citrus, and Enterolobium as sensitive with low APTI values, while Azadirachta, Psidium, Mongifera, Bougainvillea, Lagerstromia, Morinda, Hibiscus, Ixora, Polyalthia, Achras, and Cassia were categorized as tolerant. Similarly, Tanee and Albert (2013) ranked *Psidium guajava* as the most tolerant and *Ocimumgratissimum* as the most sensitive species to air pollution stress.A study in Pithampur Industrial area by Aarti *et al*., (2012) revealed variations in APTI values among six plant species, with *Calotropis gigantea* exhibiting the highest tolerance. The highest reduction in APTI was observed in the industrial area sector-3, indicating severe air pollution. Krishnaveni *et al*., (2013) reported Nerium oleander as an intermediate tolerant species, while *Ficus benghalensis, Psidium guajava, Spathodeacampanulata,* and *Opuntia ficus indica* were identified as sensitive species.Chandawat*et al*., (2011) calculated APTI for various plant species in Ahmedabad city, with *Ficus benghalensis* showing the highest tolerance at all sites. In Rourkela and Aizawl, *F. bengalensis* and *Mangifera indica* were found to be tolerant, respectively (Rai et al., 2013). Babu *et al*., (2013) reviewed APTI for seven plants in polluted and control sites, finding all plants sensitive to air pollution.Miria and Khan (2013) identified *Mangifera indica* as highly pollution-tolerant, recommended for urban areas. The study in Delta state (Nigeria) ranked *Psidium guajava* as the least tolerant and *Mangifera indica* as the most tolerant species (Agbaire and Esiefarienrhe, 2009). Tripathi *et al.,* (2009) assessed APTI for various plant species in the Brass city, categorizing them as high, moderate, and sensitive tolerance.Cement industries, major contributors of suspended particulate matter (SPM), were studied by Radhapriya*et al*., (2012). About 37% of the plant species around cement industries showed tolerance, including *Mangifera indica,* Bougainvillea, and *Psidum guajava*, while 33% were highly susceptible, including *Thevetianeriifolia*and *Saracaindica*.In Kotagiri Municipal Town, Senthilkumar and Paulsamy (2011) identified six tree species with higher APTI values, suggesting their priority for plantation programs. Similarly, Jyothi and Jaya (2010) studied trees and shrubs along National Highway - 47, finding *Polyalthia longifolia* and*Clerodendroninfortunatum* to be tolerant varieties.In conclusion, the Air Pollution Tolerance Index (APTI) serves as a valuable tool for assessing and selecting plant species that can thrive in polluted environments. Numerous studies have applied APTI to evaluate the tolerance of various plant species, providing valuable insights for urban planning, greenbelt development, and environmental conservation. Understanding the relative tolerance of plant species contributes to the development of sustainable ecosystems in the face of increasing air pollution challenges.

Pollution Mitigation by Trees

Plants play a crucial role in both monitoring and mitigating pollution in urban and industrial environments. Studies have shown that plants are adversely affected by ambient air pollutants, and their physiological responses can be indicative of the environmental quality. Kapoor *et al.*, (2013) demonstrated the successful growth of *Dalbergia sissoo* in areas with mild pollution and frequent droughts, suggesting its potential as a bio-monitor for air pollution.Llinares*et al.*, (1992) investigated nitrogen concentration changes in various plant parts such as leaves, petioles, and branches of different species, including *Alnus glutinosa* and *Elaeagnus angustifolia*. Diazotrophic plants like Elaeagnus exhibited an average nitrogen value of 3.23%, emphasizing the role of plants in nutrient cycling.Dust trapping efficiency was studied by Chandawat (2011), who observed that *Ficus benghalensis, Ficus religiosa,* and *Ficus glomerata* had high dust trapping efficiency, making them effective in areas with elevated pollution levels. The study indicated that the leaves of plants in polluted areas accumulated more dust compared to those in control and low-polluted areas across different seasons.Zhang*et al.*, (2013) investigated the tolerance of six landscape tree species to sulfur dioxide (SO_2) stress. Ilex rotunda was identified as a species that grew normally under SO_2 stress conditions and could effectively absorb SO_2. This highlights the potential of certain tree species in mitigating specific pollutants.Tzvetkova and Kolarov (1996) suggested that *T. argentea* and *A. glandulosa* could serve as good bioindicators, and *Q. cerris* exhibited high resistance to industrial emissions. Urban trees were recognized for their crucial role in cleansing airborne particulate pollution in human environments (Chakre, 2006).A modeling study conducted across the United States by Nowak *et al.*, (2006) demonstrated that urban trees have a substantial impact on improving air quality by removing pollutants such as O_3, PM, NO_2, SO_2, and CO. The total annual air pollution removal by urban trees was estimated at 711,000 metric tons, with a calculated value of $3.8 billion. This emphasizes the potential economic and health benefits of urban tree canopies.In addition to the removal of various pollutants, trees within cities were found to be effective in reducing fine particulate matter (PM2.5) concentrations, contributing to improved air quality and human health (Nowak *et al.*, 2013). The study estimated the annual PM2.5 removal by trees in different U.S. cities, emphasizing the role of trees in enhancing air quality.Plants are widely used as bioindicators in air quality biomonitoring studies due to their immobility and sensitivity to prevalent air pollutants (Nali and Lorenzini, 2007). Various plant parts, such as lichens, mosses, ferns, grass, tree bark, tree rings, tree leaves, and pine needles, have been employed in trace element air monitoring programs (Szczepaniak and Biziuk, 2003; Morselli*et al.*, 2004). Mosses, in particular, have been recognized as effective bioindicators of heavy metal pollution due to their ability to accumulate contaminants from wet and dry deposition (Onianwa, 2000).Lichens, known for their sensitivity to specific pollutants, have been termed "permanent control systems" for air pollution assessment (Conti and Cecchetti, 2001). Kovacs (1992) recommended ruderal plants as bioaccumulative indicators due to their ability to accumulate metals without visible injury.Different types of trees, including coniferous and deciduous species, have been utilized to detect aerial heavy metal pollution. Coniferous trees, such as *Pinus spp.*, have been employed for their ability to indicate pollution over longer periods (Ataabadi*et al*., 2010; Baslar*et al*., 2009). Broad-leaved species sensitive to metal contamination include *Betula pendula, Fraxinus excelsior, Sorbus aucuparia, Tilia cordata,* and *Malus domestica* (Mulgrew and Williams, 2000).Studies have shown that ecophysiologicalbehaviors of trees, such as photosynthetic rate, transpiration rate, stomatal conductance, and intercellular carbon dioxide concentration, vary among different species and under different environmental conditions (Kumar, 2011; Babu, 2012). The physiological activities of trees, such as photosynthesis and transpiration, are influenced by factors like light, temperature, and water availability.Babu (2012) recorded higher transpiration rates in afforested plantations, with *Gmelina arborea* exhibiting significantly higher transpiration rates compared to other species. Similarly, a study by Saraswathi and Paliwal (2008) found variations in transpiration rates between *Albizia lebbeck* and *Cassia siamea* under different drought stress levels.Theecophysiologicalbehavior of trees is not only influenced by environmental factors but also by genetic variations among species and provenances. Studies have reported significant variations in net photosynthetic rates among different tree species and provenances (Kundu and Tigerstedt, 1999; Wu and Ma, 1988).

Conclusion

In summary, plants, especially trees, play a vital role in mitigating pollution through various mechanisms, including pollutant removal, dust trapping, and tolerance to specific pollutants. Their ecophysiologicalbehaviors provide valuable insights into the environmental conditions and air quality. Harnessing the potential of different tree species in urban and industrial settings can contribute to cleaner air, improved health, and a sustainable environment.

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