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POLLUTION-CONTROLLING PLANTS ALONG ROADSIDES: A GREEN SHIELD AGAINST ENVIRONMENTAL DEGRADATION

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Abstract: The increasing vehicular emissions and urbanization have escalated air pollution levels, particularly along roadsides. Pollution-controlling plants play a pivotal role in mitigating the adverse effects of air pollutants such as particulate matter (PM), nitrogen oxides (NOx), sulfur dioxide (SO_2), and carbon monoxide (CO). This review highlights the physiological, morphological, and biochemical mechanisms through which plants absorb, accumulate, and neutralize pollutants. It further discusses ideal plant traits, suitable species for urban roadsides, recent research developments, and future perspectives on using vegetation for sustainable urban planning.

Keywords: Roadside pollution, phytoremediation, APTI, green belt, particulate matter, pollution-tolerant plants

Introduction

Urbanization, industrial expansion, and an ever-growing network of roadways have led to a dramatic increase in environmental pollution worldwide. Among the major contributors, vehicular emissions account for a significant portion of air pollutants such as nitrogen oxides (NOx), sulfur dioxide (SO_2), carbon monoxide (CO), particulate matter (PM_{10} and $PM_{2.5}$), and volatile organic compounds (VOCs), which not only degrade air quality but also threaten the health of humans and ecosystems (Nowak et al., 2006; Janhäll, 2015). With more than half of the global population now living in urban areas and transportation being a critical factor in economic development, it becomes crucial to adopt sustainable solutions that mitigate pollution while supporting infrastructure growth (Tzoulas et al., 2007; Sharma et al., 2013).

Among various natural pollution-mitigation strategies, the use of plants—especially those grown along roadsides—has garnered increasing attention due to their ability to trap dust, absorb harmful gases, reduce noise, and provide aesthetic and psychological benefits to urban dwellers (Singh & Rao, 1983; Prajapati & Tripathi, 2008; Chauhan & Joshi, 2008). Green corridors and buffer plantations are cost-effective and ecologically friendly means of curbing vehicular emissions (Roy et al., 2009; Jain et al., 2007). These vegetative barriers function through a complex interaction of morphological, anatomical, and biochemical mechanisms, including dust entrapment by trichomes, stomatal uptake of gaseous pollutants, and enzymatic detoxification of reactive oxygen species (Tripathi & Gautam, 2007; Rani et al., 2017; Mukherjee & Agrawal, 2015).

Furthermore, research has demonstrated the potential of various tree and shrub species to act as bioindicators of air pollution and to contribute significantly to improving roadside air quality (Bhatti et al., 2015; Dehghani et al., 2018; Iqbal et al., 2002). With increasing governmental and public interest in environmental sustainability, initiatives like India's National Green Highways Mission aim to integrate vegetation planning into infrastructure projects (Chaturvedi et al., 2013; Sharma et al., 2010). However, the success of such programs depends on careful species selection based on tolerance indices, local climate, pollution load, and other ecological factors (Datta et al., 2003; Mishra et al., 2014).

This review explores the role of pollution-controlling plants along roadsides by examining their mechanisms of pollutant mitigation, identifying key species with high tolerance and absorption capacities, and evaluating the broader ecological and social implications of vegetative buffers in urban and peri-urban settings. Through an integration of recent scientific findings and policy frameworks, the paper aims to present a comprehensive account of the importance of roadside vegetation in combating environmental pollution.

Mechanisms of Pollution Mitigation by Plants

Plants mitigate pollutants through physical and biochemical processes. Leaves act as primary interfaces, trapping particulate matter through trichomes, waxy cuticles, and surface roughness (Tripathi & Gautam, 2007; Rani et al., 2017). Gas exchange through stomata enables absorption of pollutants like SO_2, NOx, and O_3, which are later detoxified by enzymatic antioxidants such as peroxidase and catalase (Mukherjee & Agrawal, 2015; Mathur et al., 2008).

Chlorophyll stability, leaf area index (LAI), and leaf orientation also influence pollutant interception (Datta et al., 2003; Joshi & Swami, 2009). Plants like Ficus religiosa and Azadirachta indica have large, rough-surfaced leaves that increase PM retention (Bhaskar et al., 2016; Ghosh & Singh, 2005). Similarly, shrubs such as Calotropis procera and Bougainvillea spectabilis exhibit high absorption of PM and VOCs (Kumar & Nandini, 2015; Sharma & Roy,2007).

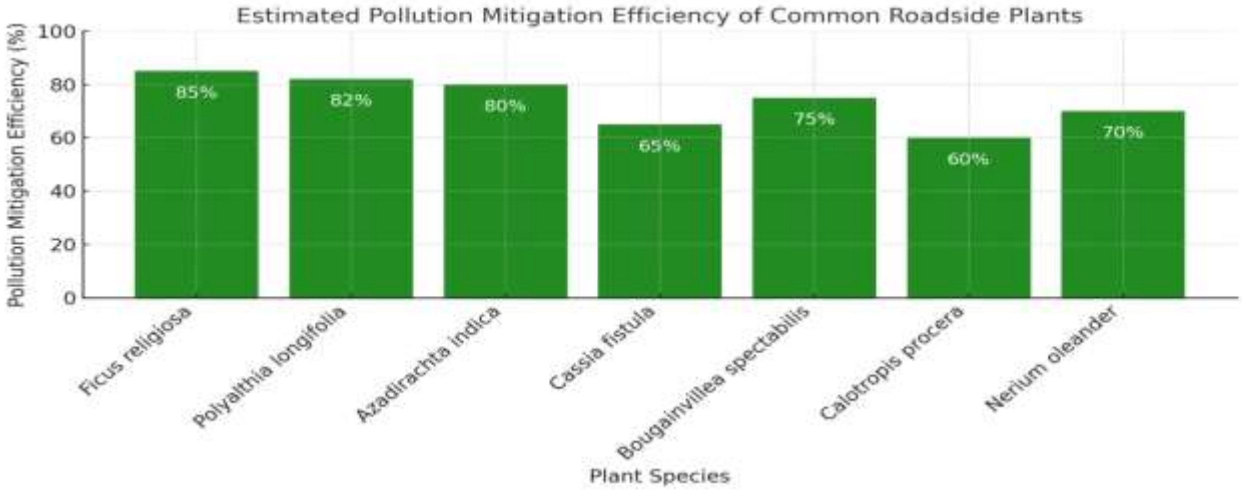


Table-1: Ideal Characteristics of Pollution-Control Plants

Trait	Description
Leaf size and surface	Large, rough, hairy, and waxy leaves trap more pollutants
Growth habit	Dense foliage and fast-growing species preferred
Tolerance index	High Air Pollution Tolerance Index (APTI) desirable
Lifespan and canopy	Perennial with broad canopy for continuous filtering

Air Pollution Tolerance Index (APTI)

The Air Pollution Tolerance Index (APTI) is a quantitative measure that assesses plant tolerance based on four biochemical parameters: total chlorophyll, relative water content, leaf extract pH, and ascorbic acid content (Singh & Rao, 1983). High APTI indicates better pollution tolerance. Studies by Kulkarni et al. (2013) and Mishra et al. (2022) demonstrate that Polyalthia longifolia, Cassia fistula, and Alstonia scholaris are highly tolerant and suitable for roadside planting.

Dehghani et al. (2018) reported that APTI values help distinguish sensitive from tolerant species, enabling informed selection. For example, Ashok (Polyalthia longifolia) exhibits high chlorophyll and pH stability, making it effective against NOx and SO_2 (Verma et al., 2011). Other species with high APTI include Nerium oleander and Terminalia arjuna (Liu & Ding, 2008; Singh et al., 2018).

Selection of Plant Species for Roadside Greening

Selection of plant species for pollution control depends on multiple factors, including APTI, growth rate, canopy structure, drought tolerance, and maintenance needs (Roy et al., 2009; Khan et al., 2012). Table 1 presents a list of common roadside species with their APTI values and pollutant absorption efficiency.

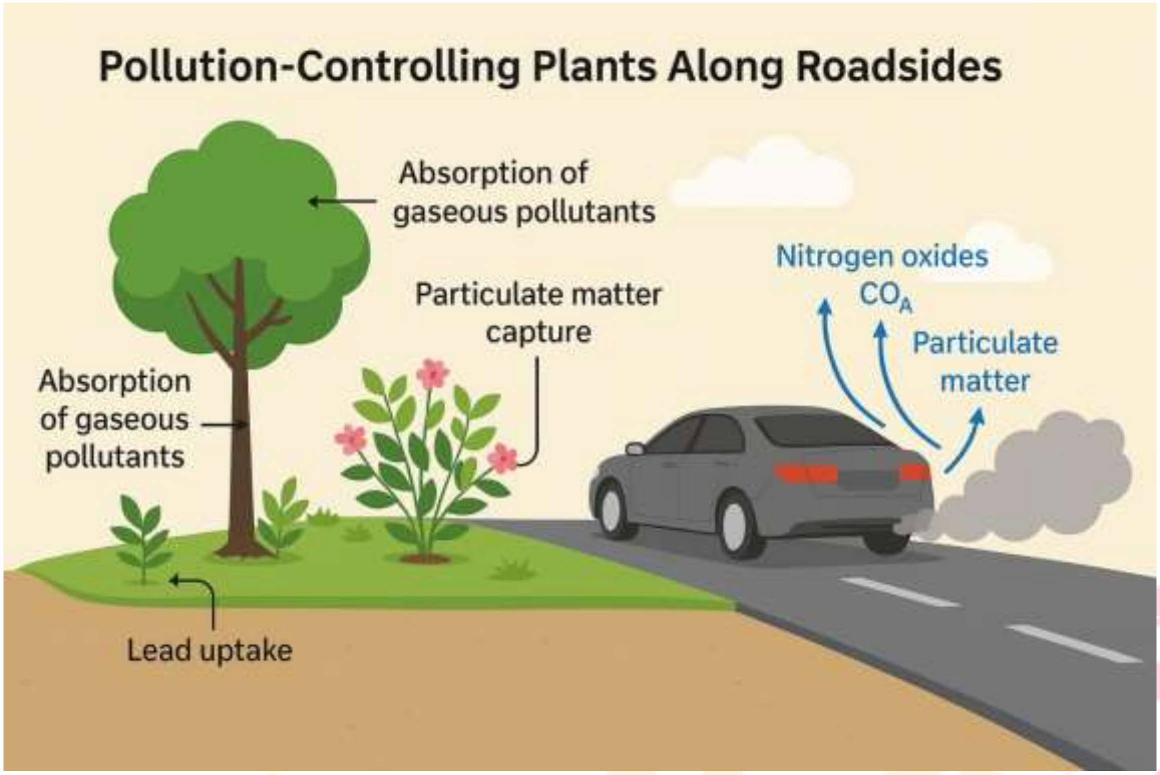
Table 2. Common Pollution-Controlling Roadside Plants and Their Characteristics

Plant Name	**Category**	**APTI**	**Effective Against**
Ficus religiosa	Tree	High	PM, SO_2, NOx
Polyalthia longifolia	Tree	High	PM, CO, SO_2
Azadirachta indica	Tree	High	SO_2, NOx, VOCs
Cassia fistula	Tree	Moderate	PM, CO
Bougainvillea spectabilis	Shrub	High	PM, CO, VOCs
Calotropis procera	Shrub	Moderate	PM, Lead
Nerium oleander	Shrub	High	VOCs

(Compiled from: Singh & Rao, 1983; Ghosh & Singh, 2005; Mishra et al., 2022; Sharma et al., 2010)

Urban Planning and Government Initiatives-India's National Green Highways Mission aims to plant over 100,000 km of green corridors along highways to reduce pollution and improve aesthetics (Chaturvedi et al., 2013). Urban forestry programs by local municipalities have also incorporated plant species with high APTI in their planning (Sharma et al., 2010; Rai, 2016). According to Jain et al. (2007) and Escobedo et al. (2011), inclusion of diverse plant layers (trees, shrubs, herbs) enhances overall efficacy of greenbelts.

Diagram: This diagram illustrates common roadside plant species and their mechanisms for mitigating air pollution, including particulate entrapment, gas absorption, and other phytoremediation processes.



Kulshreshtha et al. (2014) demonstrated that vegetative buffers reduce ambient noise levels by 10–15 dB. Similarly, studies by Roy et al. (2009) and Bhatti et al. (2015) suggest that well-planned greenbelts can reduce PM concentrations by 40–50%.

Socio-Ecological Benefits

Beyond pollution control, roadside plants improve human well-being, increase biodiversity, and mitigate climate change (Tzoulas et al., 2007; Gupta et al., 2011). Green corridors provide habitats for birds and insects and serve as carbon sinks (Sharma et al., 2010; Ghude et al., 2016). Pathak et al. (2011) showed that vegetative surfaces reduce surface temperature by 2–4°C, thereby combating urban heat islands. Bhardwaj et al. (2019) found that individuals residing near green corridors report fewer respiratory problems compared to those living near barren roads. This underscores the role of green infrastructure in public health improvement (Yoon et al., 2010; Sahu et al., 2019).

Challenges and Future Directions

Despite the evident benefits, there are limitations such as species misidentification, poor maintenance, and limited public awareness (Chauhan & Joshi, 2008; Rani et al., 2017). Government agencies should collaborate with ecologists and urban planners to optimize species selection (Liu & Ding, 2008; Giri et al., 2023). Future research should focus on developing genetically modified species with enhanced pollution tolerance and examining long-term effectiveness of vegetative buffers (Mukherjee & Agrawal, 2015; Mishra et al., 2022).

Conclusion

In the face of rising air pollution and increasing global urbanization, vegetation—particularly roadside plantations—emerges as a critical, cost-effective, and ecologically sound solution for environmental amelioration. The review clearly demonstrates that plant species differ in their ability to trap particulate matter, absorb gaseous pollutants, and tolerate environmental stress, making the process of species selection central to successful greenbelt development (Joshi & Swami, 2009; Kumar & Nandini, 2015; Mishra et al., 2022). Trees such as Azadirachta indica, Ficus religiosa, Polyalthia longifolia, and Cassia fistula are frequently cited for their high Air Pollution Tolerance Index (APTI), while shrubs like Bougainvillea spectabilis and Calotropis procera also show promising pollutant-absorbing traits (Ghosh & Singh, 2005; Kulkarni et al., 2013; Singh et al., 2018).

The environmental benefits of these plants go beyond pollution control—they enhance biodiversity, improve microclimate, sequester carbon, reduce noise pollution, and contribute to psychological well-being (Escobedo et al., 2011; Sharma et al., 2010; Bhaskar et al., 2016). When integrated into urban planning frameworks, roadside vegetation can play a vital role in building resilient and healthy cities. However, for maximum impact, such green infrastructure must be designed scientifically, incorporating knowledge of local pollution patterns, meteorological conditions, and ecological characteristics (Roy et al., 2009; Sahu et al., 2019).Despite the wealth of data supporting their utility, the practical implementation of green belts often suffers from inadequate maintenance, poor species selection, and lack of public awareness. Addressing these issues requires intersectoral collaboration among urban planners, environmentalists, policymakers, and local communities (Chaturvedi et al., 2013; Sharma et al., 2013; Rai, 2016). Future research should also focus on long-term monitoring of plant health, pollution mitigation efficiency, and the development of genetically resilient varieties.

In conclusion, pollution-controlling plants serve not only as natural air purifiers but also as essential components of sustainable urban ecosystems. Their deliberate and strategic deployment along roadways offers a multifaceted approach to environmental management—one that aligns with the principles of ecological conservation, climate resilience, and public health improvement.

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