

# The Relationship Between Urban Green Spaces and Local Air Quality

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**Abstract:** Urban air pollution has become a major environmental challenge in rapidly growing cities worldwide. Urban Green Spaces (UGS), including parks, gardens, roadside vegetation, and urban forests, are increasingly recognized for their potential role in improving environmental quality and human well-being. This study examines the relationship between urban green spaces and local air quality, with a focus on major atmospheric pollutants such as particulate matter (PM<sub>2.5</sub> and PM<sub>10</sub>) and nitrogen dioxide (NO<sub>2</sub>). Vegetation can influence air quality through mechanisms such as pollutant deposition, absorption of gaseous pollutants, and modification of local microclimates and airflow patterns. However, the effectiveness of urban green spaces in reducing pollution levels depends on several factors including vegetation density, plant species, spatial distribution, and urban morphology. In certain cases, dense vegetation may also restrict air circulation and contribute to localized pollutant accumulation. This paper reviews recent research and explores how different types and configurations of urban green spaces interact with atmospheric pollutants. The study highlights the importance of strategic urban green planning to maximize environmental benefits while minimizing potential adverse effects. The findings emphasize that well-designed green infrastructure can play a significant role in improving urban air quality and supporting sustainable urban development.

**Keywords:** Urban Green Spaces, Air Quality, PM<sub>2.5</sub>, PM<sub>10</sub>, Nitrogen Dioxide (NO<sub>2</sub>), Urban Ecology, Environmental Pollution

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## I. Introduction

Air pollution has emerged as one of the most serious environmental and public health challenges facing modern cities. Rapid urbanization, population growth, industrial expansion, and increasing vehicle emissions have significantly contributed to the deterioration of air quality in many urban regions [1]. Pollutants such as particulate matter (PM<sub>2.5</sub> and PM<sub>10</sub>), nitrogen dioxide (NO<sub>2</sub>), sulfur dioxide (SO<sub>2</sub>), and carbon monoxide (CO) are commonly found in urban atmospheres and are known to have harmful effects on human health and ecosystems.

Exposure to high levels of air pollution has been linked to various health problems including respiratory illnesses, cardiovascular diseases, and reduced life expectancy. Recent longitudinal studies have demonstrated that even moderate increases in localized PM<sub>2.5</sub> are associated with a significant rise in hospital admissions for respiratory distress. As urban populations continue to grow, addressing air pollution has become a critical priority for policymakers, urban planners, and environmental researchers [2].

Urban Green Spaces (UGS) have gained attention as a potential natural solution to mitigate some of the environmental challenges associated with urbanization. UGS include parks, urban forests, green belts, community gardens, green roofs, and roadside vegetation that are integrated into city landscapes. These vegetated areas provide numerous ecological and social benefits such as climate regulation, biodiversity conservation, recreational opportunities, and improvement of air quality [3].

Vegetation influences air quality through several mechanisms. Plant leaves and surfaces can capture airborne particulate matter through dry deposition, while plants can absorb gaseous pollutants through stomatal uptake. In addition, vegetation can modify local microclimates by reducing temperature, increasing humidity, and influencing wind patterns, which in turn affects the dispersion and dilution of air pollutants [4]. Because of these functions, urban green spaces are often described as the lungs of the city.

Despite these benefits, the relationship between urban green spaces and air quality is not always straightforward. The effectiveness of vegetation in reducing air pollution depends on factors such as plant species, leaf surface characteristics, canopy density, and spatial distribution of green areas [5]. In certain urban environments, particularly narrow street canyons with dense tree cover, vegetation may reduce air circulation and trap pollutants at ground level, potentially worsening local air quality.

Understanding the complex relationship between urban green spaces and air quality is essential for developing effective urban environmental management strategies. Proper planning and design of green infrastructure can enhance pollutant removal while avoiding unintended negative effects on airflow and pollutant dispersion [6]. The objective of this study is to examine the relationship between urban green spaces

and local air quality by exploring the mechanisms through which vegetation interacts with atmospheric pollutants. This paper reviews recent research findings to identify key factors that influence the effectiveness of UGS in improving air quality, contributing to more sustainable urban planning.

## II. Literature Review

Urban air pollution is a critical concern driven by rapid urbanization and intensified transportation and industrial activities. Consequently, researchers have pivoted toward Urban Green Spaces (UGS) as essential components of nature-based solutions for atmospheric mitigation [7]. Current literature explores the complex interactions between vegetation and pollutants, moving beyond simple filtration models to evaluate the aerodynamic impacts of green infrastructure.

**Particulate Matter Mitigation and Dry Deposition:** Recent studies confirm that urban vegetation significantly reduces particulate matter (PM) concentrations. Plant surfaces act as biological filters, capturing PM<sub>2.5</sub> and PM<sub>10</sub> through dry deposition—a process involving sedimentation, interception, and impaction [8]. Researchers suggest that leaf micro-morphology, such as hairiness (trichomes) and waxiness, significantly dictates capture efficiency. Urban forests with high Leaf Area Index (LAI) values are particularly effective, though their impact is often localized to within a few meters of the canopy.

**Gaseous Pollutant Absorption:** Beyond physical filtration, vegetation mitigates gaseous pollutants including NO<sub>2</sub>, SO<sub>2</sub>, and O<sub>3</sub> through stomatal uptake. During photosynthesis, these gases are absorbed through leaf stomata and either metabolized or sequestered within the plant tissue. Recent findings indicate that while trees are effective at NO<sub>2</sub> reduction, the benefits are highly species-specific. For instance, certain deciduous species show a measurable reduction in NO<sub>2</sub> in high-traffic corridors during the growing season, though this capacity diminishes in winter [9].

**The Aerodynamic “Canyon Effect”:** Recent research has challenged the more green is better paradigm by examining urban morphology. In street canyons—narrow corridors between tall buildings—dense tree canopies can increase aerodynamic resistance. This reduction in wind speed limits vertical mixing and traps vehicle exhaust at the pedestrian level. Studies in 2024 revealed that in poorly ventilated streets, large tree canopies could lead to localized increases in pollutant concentrations by up to 15–20% [10].

**Species Selection and Strategic Planning:** The effectiveness of UGS depends on a synergy of factors: vegetation density, leaf morphology, and spatial configuration. Strategic planning now emphasizes porous green infrastructure. For example, low-level hedges are currently favored over high-canopy trees in narrow streets because they provide a filtration barrier at the tailpipe level without obstructing air circulation [11]. Furthermore, researchers are identifying species with low emissions of Biogenic Volatile Organic Compounds (BVOCs), as some plants can inadvertently contribute to ground-level ozone formation in high-temperature urban environments.

**Integration with Urban Design:** Modern urban morphology research emphasizes that green infrastructure must be integrated with building layouts to promote the Ventilation Corridor effect. Well-designed UGS, such as stepping stone parks or green roofs, can enhance thermal buoyancy and promote the dilution of pollutants [12]. The consensus in recent literature is that while UGS hold immense potential, their success is contingent upon appropriate species selection and a deep understanding of local wind-flow dynamics.

## III. Methodology

This study adopts a systematic literature review approach to examine the relationship between Urban Green Spaces (UGS) and local air quality. This methodology allows for the objective synthesis of diverse datasets to evaluate the mechanical and aerodynamic roles of vegetation in atmospheric mitigation.

### 3.1 Research Design

The research design is qualitative and analytical, focused on the mechanistic-morphological interaction between urban flora and pollutants. The study categorizes findings into two primary domains:

1. Bio-chemical removal: Including dry deposition and stomatal uptake.
2. Physical modification: Including the alteration of urban wind fields and the canyon effect [13].

### 3.2 Data Sources and Search Strategy

Scientific literature was retrieved from high-impact academic databases, including Google Scholar, Scopus, and Web of Science. To ensure a comprehensive capture of recent data, the search strategy utilized specific Boolean operators and keywords:

- Keywords: Urban Green Space, Air Quality, Particulate Matter, Vegetation Barrier, street Canyon and Dispersion.
- Institutional Data: Reports from the World Health Organization (WHO) and UN-Habitat were included to ground the scientific findings in current global policy frameworks.

### 3.3 Selection Criteria

To maintain high academic standards and temporal relevance, specific inclusion and exclusion criteria were applied:

Criteria	Inclusion Parameters
Temporal Range	Studies published between 2010 and 2028.
Pollutant Focus	Primary focus on PM <sub>2.5</sub> , PM <sub>10</sub> , and NO <sub>2</sub> .
Setting	Strictly urban or peri-urban environments.
Publication Type	Peer-reviewed journal articles and primary environmental reports.

## IV. Mechanisms Through Which Urban Green Spaces Influence Air Quality

Urban green spaces (UGS) influence local air quality through a tripartite interaction of biological, chemical, and physical processes. Vegetation interacts with atmospheric pollutants by facilitating dry deposition of particulates, absorbing gaseous precursors, and modifying the aerodynamic properties of the urban boundary layer [14].

### 4.1 Particulate Matter Deposition and Sequestration

The primary mechanism for local air purification is the mechanical capture of particulate matter (PM<sub>2.5</sub> and PM<sub>10</sub>) on vegetative surfaces. Plant organs—including leaves, petioles, and bark—act as natural filters through several sub-processes:

- **Sedimentation:** Gravity-driven settling of larger particles (PM<sub>10</sub>) on horizontal surfaces.
- **Impaction and Interception:** Wind-borne particles collide with and adhere to leaf surfaces.
- **Diffusion:** Very fine particles (PM<sub>0.1</sub>) move randomly and settle on leaf micro-structures.

Research indicates that leaf morphology is the dominant factor in capture efficiency. Species with high trichome density (hairiness) or thick epicuticular wax layers show significantly higher sequestration rates [15]. Furthermore, a high Leaf Area Index (LAI) increases the total available surface area for deposition, though the efficiency is highly localized and decreases rapidly with distance from the green barrier [16].

### 4.2 Stomatal Uptake of Gaseous Pollutants

Vegetation serves as a sink for gaseous pollutants such as NO<sub>2</sub>, SO<sub>2</sub>, and O<sub>3</sub> through stomatal absorption. During photosynthesis and respiration, these gases enter the leaf interior via the stomatal pores. Once inside, pollutants can be metabolized, neutralized by antioxidants (such as ascorbic acid), or temporarily stored in the mesophyll [17].

The efficacy of this mechanism is governed by the stomatal conductance, which varies based on:

1. **Species Physiology:** Deciduous vs. coniferous uptake rates.
2. **Environmental Stress:** Under drought or extreme heat, plants close stomata to prevent water loss, which simultaneously halts pollutant absorption.
3. **Phenology:** Seasonal variations mean that gaseous removal is significantly higher during the peak growing season.

### 4.3 Microclimate Regulation and Photochemistry

UGS modify the urban microclimate through shading and evapotranspiration, which indirectly improves air quality. By lowering ambient temperatures (mitigating the Urban Heat Island effect), vegetation influences the kinetics of secondary pollutant formation. For example, the formation of ground-level ozone (O<sub>3</sub>) is a temperature-dependent photochemical reaction; by cooling the local environment, UGS can slow O<sub>3</sub> production [18]. Additionally, increased humidity from evapotranspiration can lead to particle agglomeration, potentially increasing the rate of PM sedimentation [19].

### 4.4 Aerodynamic Modification and Airflow Dynamics

The most complex mechanism is the physical alteration of urban airflow patterns. Vegetation acts as a porous medium that modifies wind speed and turbulence:

- **Ventilation vs. Stagnation:** In open parks, trees can increase turbulence, aiding in the dilution of pollutants. However, in street canyons, dense tree canopies create aerodynamic resistance, reducing wind speed at ground level and preventing the vertical escape of vehicle emissions [20].
- **The Barrier Effect:** Strategically placed, low-level green belts (hedges) can create a "buffer zone" that deflects traffic plumes away from pedestrian walkways without creating the stagnation seen with tall, dense canopies [21].

## **V. Factors Influencing the Effectiveness of Urban Green Spaces in Improving Air Quality**

The efficacy of Urban Green Spaces (UGS) in atmospheric remediation is not uniform. The interaction between vegetation and the urban canopy layer is governed by a complex set of biological, structural, and meteorological variables [22].

**5.1 Vegetation Species Selection and Physiological Traits:** Pollutant removal efficiency is highly species-dependent. The physical characteristics of the phyllosphere (leaf surface) dictate the rate of dry deposition.

- **Morphological Traits:** Species with high trichome (hair) density, rugose (rough) textures, or thick epicuticular wax layers capture PM<sub>2.5</sub> up to four times more effectively than smooth-leaved species [23].
- **Tolerance and BVOCs:** Selection must prioritize species with high Air Pollution Tolerance Index (APTI) scores. Furthermore, planners must avoid high-emitters of Biogenic Volatile Organic Compounds (BVOCs), such as certain Isoprene-emitting oaks, which can react with NO<sub>x</sub> to form ground-level ozone (O<sub>3</sub>) in high-heat conditions [24].

### **5.2 Vegetation Density and Structural Configuration**

The total Leaf Area Index (LAI) and Vegetation Volume Density (VVD) are primary determinants of filtration capacity. While increased density provides more surface area for deposition, it also increases aerodynamic resistance.

- **The Porosity Factor:** Optimal air quality is often achieved with porous vegetation. Research suggests that a vegetation porosity of 40–60% allows for pollutant filtration while maintaining sufficient airflow to prevent the stagnation of vehicle emissions at the street level [25].

### **5.3 Urban Morphology and the Built-Natural Interface**

The impact of UGS is fundamentally tied to the Urban Morphology. The ratio of building height (H) to street width (W) defines the Street Canyon dynamics.

- **Canyon Ventilation:** In deep canyons ( $H/W > 2$ ), large tree canopies can act as a physical lid, reducing the Air Exchange Rate (ACH) and increasing local NO<sub>2</sub> concentrations by up to 25%. In these configurations, low-level green hedges or green walls are more effective as they do not obstruct the sky-view factor required for vertical pollutant dispersion [26].

### **5.4 Seasonal and Climatic Variations**

The air purification service of UGS is temporally variable.

- **Seasonality:** Coniferous (evergreen) species provide year-round PM capture, whereas deciduous species lose up to 90% of their filtration capacity in winter, often when urban heating emissions are at their peak.
- **Meteorological Washout:** Rainfall events provide canopy cleaning, washing accumulated particulates into the soil and regenerating the leaf's capture surface. Conversely, high wind speeds can re-suspend deposited particles back into the atmosphere.

### **5.5 Strategic Green Infrastructure Planning**

To maximize environmental benefits, UGS must move from fragmented pockets to an integrated Green Infrastructure (GI) network.

- **Green Belts vs. Green Roofs:** While roadside green belts target tailpipe emissions, green roofs address vertical pollutant profiles and reduce the building energy demand that drives industrial emissions. Strategic placement of Ventilation Corridors—linear green spaces aligned with prevailing winds—is now recognized as a primary method for flushing pollutants out of dense city centers.

## **VI. Discussion**

The synthesis of recent research confirms that Urban Green Spaces (UGS) are not merely aesthetic additions but are active components of the urban atmospheric system. However, their role is dualistic: they function as both a biological sink for pollutants and a physical modifier of urban aerodynamics.

### **6.1 The Filtration Capacity vs. Aerodynamic Interference**

The most significant finding in recent literature is the tension between pollutant removal and pollutant redistribution. While the deposition of PM<sub>10</sub> and PM<sub>2.5</sub> on leaf surfaces is a proven benefit, the canyon effect remains a critical constraint. In open environments, trees can reduce PM levels by up to 15%. However, in deep street canyons, the reduction in wind speed caused by dense canopies can lead to a 20-30% increase in localized

NO<sub>2</sub> concentrations. This suggests that the lungs of the city metaphor is only accurate when the airways (urban ventilation corridors) are kept clear.

### **6.2 Physiological Limits and Stomatal Uptake**

The discussion highlights that stomatal absorption of gaseous pollutants (NO<sub>2</sub>, O<sub>3</sub>, SO<sub>2</sub>) is a highly sensitive process. Recent studies in 2017 emphasize that climate change-induced heat stress can cause plants to close their stomata during peak pollution hours to conserve water. This means that during extreme heatwaves—precisely when secondary pollutants like ozone are at their highest—the air purification service of UGS may be temporarily suspended. This emphasizes the need for drought-resistant species in urban planning to ensure functional continuity.

### **6.2 Species Selection and the BVOC Paradox**

A nuanced finding in the literature is the role of Biogenic Volatile Organic Compounds (BVOCs). While vegetation removes ozone via deposition, certain species (e.g., *Quercus* or *Populus* species) emit isoprene and monoterpenes, which act as precursors to ozone formation in the presence of traffic-derived NO<sub>x</sub>. Urban planners must shift from a quantity-based greening approach to a trait-based approach, prioritizing species with high capture efficiency and low BVOC emission potentials.

### **6.3 Strategic Integration of Green Infrastructure**

The discussion points toward a shift in Green Infrastructure (GI) design. The consensus is moving away from large, isolated urban forests toward a decentralized network of varied green structures [24]. Recent field trials (2015–2018) have shown that low-level hedges are superior to trees in high-traffic, narrow streets because they provide a filtering wall at the height of vehicle exhausts without obstructing the vertical dilution of air. Green walls and roofs are increasingly recognized as essential for high-density districts where ground-level space for trees is unavailable [25].

Overall, UGS should be integrated into urban planning not as a replacement for emission reductions, but as a critical local-scale mitigation tool. The effectiveness of UGS is maximized when the structural design prioritizes porosity and ventilation alongside biological surface area. Future Smart Cities will likely rely on 3D atmospheric modeling to place vegetation in configurations that enhance, rather than hinder, the natural flushing of urban pollutants.

## **VII. Conclusion**

Urban Green Spaces (UGS) play an important role in influencing local air quality through mechanisms such as particulate matter deposition, absorption of gaseous pollutants, and regulation of urban microclimates. Vegetation can act as a natural filter that helps reduce pollutants like PM<sub>2.5</sub>, PM<sub>10</sub>, and nitrogen dioxide (NO<sub>2</sub>), contributing to healthier urban environments. However, the effectiveness of green spaces depends on factors such as plant species, vegetation density, and urban morphology. In some cases, dense vegetation in poorly ventilated urban areas may restrict airflow and lead to pollutant accumulation. Therefore, careful planning and strategic design of urban green infrastructure are essential to maximize its benefits for air pollution mitigation and sustainable urban development.

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