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GREEN PLANT LANDSCAPE DESIGN FOR URBAN AIR QUALITY PURIFICATION WITH COMPUTER IMAGE PROCESSING IN CLOUD, GRID, AND CLUSTER COMPUTING

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Abstract. This research paper explores the innovative integration of green plant landscape design with advanced computer image processing in cloud, grid, and cluster computing environments to enhance urban air quality purification. The study begins by highlighting the critical need for improving air quality in urban areas, considering the rising levels of pollution and its impact on public health and the environment. The methodology involves the use of sophisticated image processing techniques to analyze various sensors on air quality measures and plant species their effectiveness in air purification, facilitated by the computational power of cloud, grid, and cluster computing. A diverse range of green plants was selected, and their air purification capabilities were assessed through a series of computer-simulated models. These models were developed using complex algorithms to predict the plants' performance in real-world urban settings. The research uniquely combines landscape architecture with technology, emphasizing the role of green spaces in urban areas for environmental sustainability. The results demonstrate that certain plant species are more effective than others in purifying urban air. The study provides a comprehensive ranking of these plants based on their purification capabilities, growth requirements, and suitability for various urban landscapes. The paper concludes by proposing practical guidelines for urban landscape designers and policymakers, recommending the strategic incorporation of specific green plants in urban areas to maximize air purification. Additionally, it highlights the potential of leveraging advanced computing technologies in environmental research and urban planning. This research contributes to the fields of environmental science, urban planning, and computer science by showcasing how multidisciplinary approaches can address pressing environmental issues. It opens avenues for further research in the optimization of urban green spaces using advanced computing techniques. The results demonstrate that certain plant species are more effective than others in purifying urban air. The study provides a comprehensive ranking of these plants based on their purification capabilities, growth requirements, and suitability for various urban landscapes. The paper concludes by proposing practical guidelines for urban landscape designers and policymakers, recommending the strategic incorporation of specific green plants in urban areas to maximize air purification.

Key words: Urban Air Quality, Green Plant Landscaping, Environmental Purification, Computer Image Processing, Cloud Computing, Grid Computing, Cluster Computing

1. Introduction.

In the wake of escalating urbanization and industrialization, air pollution has emerged as a critical challenge confronting urban environments globally. The detrimental impact of poor air quality on human health and the ecosystem necessitates innovative solutions. This study explores a novel approach to ameliorate urban air quality: the strategic design of green plant landscapes, aided by advanced computational technologies. The role of green plants in purifying air is well-documented. They absorb pollutants and carbon dioxide, releasing oxygen, thereby improving air quality. However, the effectiveness of different plant species in specific urban contexts remains underexplored. This gap in knowledge presents an opportunity to blend environmental science with cutting-edge computing technologies. The study aims to employ computer image processing, harnessed through the power of cloud, grid, and cluster computing, to analyze and optimize green plant landscapes for urban air quality purification.

The primary objectives of this research are to identify the most effective plant species for air purification in urban landscapes, and to develop a computer-assisted model for landscape design that optimizes these benefits. This involves analyzing large datasets of environmental conditions and plant characteristics, a task well-suited to the capabilities of advanced computing paradigms like cloud, grid, and cluster computing. These technologies offer unprecedented processing power and data storage capabilities, facilitating detailed and complex environmental modeling.

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The introduction of computer image processing into landscape design represents a pioneering step in environmental planning. By harnessing these technologies, this research aims to provide actionable insights for urban planners and environmentalists, contributing to more sustainable and healthier urban environments. This paper is structured as follows: after the introduction, we present a review of the literature, outlining previous studies on green plants for air purification and the application of advanced computing in environmental science. This is followed by a detailed description of the methodology, including the selection of plant species, computational models used, and the design of the study. The subsequent sections present the results, discussion, and conclusions drawn from the research, along with recommendations for future studies in this evolving field.

The study begins by underlining the critical issue of declining air quality in metropolitan areas as pollution levels rise. This first recognition of the problem establishes the context for the study's relevance and significance. The study takes a unique approach by analyzing air quality sensors and the performance of several plant species in air filtration using modern image processing techniques. The usage of cloud, grid, and cluster computing shows a dedication to harnessing current technology to solve environmental problems.

Image Processing in Cloud, Grid, and Cluster Computing" would be focused on exploring and achieving specific goals at the intersection of environmental science, urban planning, and advanced computing. The key objectives for this research:

1. Determine using image processing methods are most effective in purifying air in urban environments. This involves assessing various plants' ability to absorb pollutants and improve air quality.
2. Utilize computer image processing tools within cloud, grid, and cluster computing environments to analyze the physical and biological characteristics of different plant species. This includes studying their growth patterns, pollution absorption rates, and adaptability to urban settings.
3. Create computational models that can simulate and predict the effectiveness of different green plant arrangements in urban landscapes for maximizing air purification.

Research questions that concentrated in this research are,

1. What are the most effective methods for purifying urban air?
2. How does the integration of specific plant species in urban landscapes impact overall environmental and public health?
3. What are the challenges and limitations of using advanced computing technologies in environmental planning and monitoring?

Urban areas worldwide are grappling with escalating levels of air pollution, which pose serious risks to public health and the environment. Addressing this issue is vital for the well-being of urban populations and the sustainability of cities. Green plants are known to improve air quality by absorbing pollutants and carbon dioxide, offering a natural solution to the air pollution problem. However, the effectiveness of specific plant species and configurations in urban environments needs further exploration. The rapid development in computing technologies, such as cloud, grid, and cluster computing, offers unprecedented capabilities in data processing and analysis. Applying these technologies to environmental challenges presents an opportunity to innovate in urban air quality management.

2. Literature review. Globally, air quality issues are a major concern in urban areas, necessitating effective detection and management of air pollution variations over time and by region. This is essential for developing affordable solutions[10]. In India, air pollution remains a persistent public health issue[5]. The "Global Burden of Disease Study, 2019" reported that in 2019, air pollution was responsible for 1.67 million deaths, which is 17.8% of total deaths in India, leading to an economic loss of approximately USD 36.8 billion, or 1.36% of the country's GDP. Furthermore, in 2019, 22 Indian cities ranked among the top 30 most polluted cities globally, with many Indian cities appearing in the top 10 (IQAir, 2020). The COVID-19 lockdown in 2020 unexpectedly contributed to environmental recovery, significantly improving urban air quality[5, 12]. However, this improvement was temporary. [24] described the lockdown as an "anthropause," a brief pause that is unlikely to have a lasting impact on the detrimental effects of human activities. In India, as the lockdown was lifted, air pollution levels began to increase again [8], mirroring trends observed in other cities around the world [3, 9]. Post-lockdown, many Indian cities saw a significant increase in ambient particulate matter levels (PM10), with levels in the last quarters of 2020 approaching those seen in 2019 (life-as-usual situation).

In many developing nations, traditional methods for addressing air pollution have been largely unsuccessful.

This is due to a combination of factors including institutional weaknesses, infrastructural challenges, economic constraints, and political hurdles[13]. Consequently, air pollution continues to pose a significant threat to both environmental sustainability and public health, especially in India[14, 16, 18]. A key factor behind these shortcomings is the predominantly technocratic approach, which often neglects the socio-cultural aspects like public expectations, community capacity, and public participation in decision-making [17]. Recognizing these issues, the main motivation for this discussion is to shift from a purely technocratic mindset to one that harmonizes with nature. We advocate for policymakers to consider urban green spaces not just as aesthetic elements, but as vital components that enhance and strengthen efforts in air pollution prevention and control.

In their recent bibliometric study, [20] categorized the primary mechanisms by which plants remove pollutants, as they relate to public health, into three main groups: (I) dry deposition, (II) dispersion (the process by which plants alter air pollutants' path and speed through their physical structure), and (III) modification (including selective sorption, microbial reactions, and chemical coagulation due to Brownian motion and/or van der Waals forces). It's recommended that city planners and authorities delve into such research to gain a deeper understanding of how plants interact with pollutants and to maximize the effectiveness of urban green spaces. However, the dry deposition process is complicated by various factors, notably the diverse types of leaf surfaces in urban canopies and the movement of submicron particles. Similarly, there is a lack of comprehensive experimental data encompassing all scenarios related to dry deposition [11, 19]. The complexity is further heightened by varying levels of urban development, pollution sources, and human activities. Addressing these complexities will require more case studies in different urban environments and among various population demographics to fully understand and optimize dry deposition processes.

The initial consideration for selecting tree species for air pollution mitigation should focus on their climatic characteristics and the impact these have on the length of their growing season, which determines the duration of leaf cover[6, 22]. In temperate regions, deciduous trees lose their leaves during winter, thereby reducing the total leaf surface area available for pollutant absorption. Among these, conifers are often favored due to their lipophilic wax-coated needles, smaller leaf size, and intricate shoot structures, which are advantageous for pollutant capture [15, 23]. Additionally, the airflow around conifer needles creates more turbulence compared to larger leaves (broadleaves), which reduces the thickness of the boundary layer on needle leaves (Ackerly et al., [21]; [21, 20]. This means when air carrying pollutants passes over these needles, the boundary layer remains relatively still, creating a barrier between the air and the leaf surface.

However, the high pollutant absorption by conifer needles can sometimes damage the leaves, diminishing their effectiveness in pollutant removal. This issue is more pronounced in drier climates[24, 2]. In such cases, broad-leaved deciduous species or those that retain their leaves throughout winter are more suitable for pollution control [22]. Among broadleaved species, those with a high number of grooves, a large ratio of groove area to total leaf area, and dense epicuticular trichomes are preferred for pollution regulation [17, 7].

In climates with shorter growing seasons but high pollutant levels in winter, evergreen species, which maintain their foliage all year, are preferable over deciduous varieties[1]. The selection should also take into account the type of pollutants targeted. For instance, [4] found that oak leaves (deciduous) are more effective against particulate phase PAHs (polycyclic aromatic hydrocarbons) due to their high specific leaf area. Conversely, pine needles (evergreen) may be better suited for gaseous phase PAHs, particularly effective in capturing low and medium weight of PAHs molecules.

3. Methodology. The methodology for this research combines environmental science, landscape architecture, and advanced computational techniques to optimize green plant landscapes for urban air quality purification. For the study, a varied selection of green plant species were carefully selected. Plant kinds (trees, shrubs, ground cover), their capacity to filter the air, growth characteristics, and adaptation to urban situations are all variables in the choosing process. This choice is influenced by scientific understanding as well as landscape architecture concepts.

In metropolitan areas under research, sophisticated air quality monitors are carefully deployed. These sensors capture data on a variety of air quality indicators, including pollutants such as particulate matter (PM), nitrogen dioxide (NO2), and volatile organic compounds (VOCs), in real time. Data from air quality sensors is gathered over time, documenting fluctuations in air quality based on factors such as time of day, meteorological conditions, and traffic density. This information will be used to analyze the efficacy of green plants in air cleansing.

To examine data gathered from air quality sensors, advanced image processing techniques are used. These methods enable the extraction of useful information such as pollutant levels, regional distribution, and temporal trends. To mimic the behavior of chosen green plants in urban contexts, complex computational models are built. These models consider elements such as plant growth, transpiration rates, and the ability of plants to remove toxins from the air. To conduct these simulations efficiently, the computational capacity of cloud, grid, and cluster computing resources is used:

1. Selection of Plant Species
2. Data Collection and Analysis
3. Computer Image Processing
4. Computational Modeling
5. Pilot Implementation and Monitoring

3.1. Phase 1: Selection of Plant Species. In the research on "Green Plant Landscape Design for Urban Air Quality Purification," Phase 1, which focuses on the Selection of Plant Species, is a crucial foundational step. The objective here is to identify plants that are most effective in urban air purification, taking into account various urban and climatic conditions. This phase begins with an extensive literature review, where existing scientific studies, environmental reports, and botanical research are scrutinized to identify plants known for their pollution-absorbing abilities and adaptability to urban stresses. The selection criteria for these plants include their capacity to absorb specific urban pollutants, growth and maintenance needs, environmental adaptability, aesthetic contribution, and practical considerations like space and root development.

Field studies, consultations with experts like botanists and urban ecologists, and citizen science initiatives form the backbone of the data collection strategy. These diverse sources ensure a comprehensive understanding of how different plants perform in urban settings. The analysis of this data is thorough, involving comparative assessments of plants against the set criteria, statistical modeling to understand the correlation between plant traits and pollution absorption, and evaluations of climate adaptability.

The outcome of this phase is a carefully curated list of plant species, each with a detailed profile outlining its environmental benefits, physical characteristics, and care instructions. This list is not only crucial for the immediate next phases of the research, which involve further data collection and computational modeling, but also sets a precedent for interdisciplinary collaboration. By meticulously choosing the right plant species in Phase 1, the research ensures that the subsequent phases are informed by a deep and nuanced understanding of the best natural resources for combatting urban air pollution. Based on diverse urban condition, plant is selected by the user.

In this research, the characteristics of Broad-Leaved Deciduous Species and Evergreens are considered for pollution control. This research comprehensively evaluates the suitability of Broad-Leaved Deciduous Species and Evergreens in pollution control, emphasizing their distinct characteristics that enhance air purification in urban environments. Broad-Leaved Deciduous Species are noted for their seasonal leaf shedding and large leaf surface area. Despite losing leaves in winter, they offer significant benefits during the growing season. Their broad leaves provide a substantial surface for absorbing pollutants, especially effective in warmer months when pollution levels tend to spike. Evergreens, conversely, retain their leaves year-round, offering continuous air purification, including in colder months. Their resilience across various climates renders them versatile for different urban conditions.

The research further delves into specific traits beneficial for pollution control:

1. High Number of Grooves on Leaves: This feature increases the surface area, enabling the leaves to trap more pollutants. The grooves are particularly adept at capturing fine particulate matter, a major urban pollution component.
2. Large Groove Area Relative to Total Leaf Area: A higher ratio here indicates a more effective trapping mechanism for pollutants, optimizing the leaves for absorption, especially crucial in densely populated areas.
3. Dense Epicuticular Trichomes: These hair-like structures act as pollution filters, trapping and absorbing pollutants. They also protect the plant from environmental stresses, including high pollution levels, maintaining their efficiency in pollutant absorption.

The selection of these plant types underscores the research's focus on natural, sustainable methods for improving urban air quality. Their large leaf surfaces, grooved structures, and trichomes significantly enhance their ability to capture and absorb airborne pollutants, making them highly relevant for application in diverse urban landscapes. This approach not only addresses air quality issues but also promotes a greener, more sustainable urban environment. The selection of broad-leaved deciduous species and evergreens for this research is based on their distinct characteristics that make them suitable for urban air purification. Their large leaf surfaces, grooved structures, and the presence of trichomes enhance their ability to capture and absorb airborne pollutants. This choice underscores the research's emphasis on employing natural, sustainable solutions to address urban air quality issues, making it relevant and practical for application in diverse urban landscapes

3.2. Phase 2: Data Collection and Analysis. .

This phase is critical for empirically validating the pollution absorption capabilities of the selected plant species and understanding their practical implications in urban environments. The approach in this phase integrates traditional environmental science methods with innovative data collection and analysis techniques, focusing on both qualitative and quantitative aspects.

3.2.1. Data Collection Strategy. Deploy air quality sensors in the vicinity of the planted areas to continuously monitor levels of key pollutants (e.g., PM2.5, PM10, NOx, SOx, CO, O3). These sensors should be strategically placed at various heights and distances from the plants to capture a comprehensive data set. Periodically collect leaf samples from the selected plants for laboratory analysis. This will involve examining the physical characteristics of the leaves (such as leaf surface area, groove depth, and trichome density) and quantifying the accumulated pollutants on the leaf surface using techniques like gas chromatography-mass spectrometry (GC-MS) or X-ray fluorescence (XRF) analysis. Record environmental factors such as temperature, humidity, wind speed, and rainfall, as they can significantly influence the plants' pollutant absorption capabilities. Utilize high-resolution photography and drone imagery to document the physical state of the plants over time. This can provide insights into their growth patterns, health, and environmental interactions. Engage with local communities to collect qualitative data on their perceptions of air quality and the impact of the green spaces

3.2.2. Analysis Techniques. Employ machine learning algorithms to analyze the complex dataset. Techniques like regression analysis, cluster analysis, and neural networks can reveal patterns and correlations between plant characteristics, pollutant levels, and environmental factors. Use Geographic Information Systems (GIS) to map pollution levels and plant locations. This spatial analysis can reveal how the distribution of plants affects air quality in different urban zones. Implement time-series analysis to understand how the effectiveness of plants in pollution absorption varies over time and in different environmental conditions. Compare data from sites with the selected plants to control sites without them. This will provide a clearer picture of the plants' direct impact on air quality. Use natural language processing (NLP) to analyze community feedback, providing insights into public perception and acceptance of the green spaces.

Quantitative data demonstrating the effectiveness of the selected plants in reducing specific urban pollutants. Also, understanding how different plant species perform under varying urban environmental conditions helps to plan urban land scape. Data-driven recommendations for urban planners and policymakers on integrating specific plant species in urban landscape design for air quality improvement. Enhanced community involvement and awareness about the role of urban greenery in improving air quality.

By integrating advanced data collection and analysis techniques, this phase aims to provide a robust scientific foundation for the use of specific plant species in urban air purification. The results will not only validate the plant selection but also offer practical guidelines for their effective implementation in urban landscape designs.

3.3. Phase 3: Computer Image Processing Techniques. The use of high-resolution photography, possibly supplemented by drone imagery, is essential. These images provide detailed visual data on plant growth, health, and environmental interactions, which are crucial for understanding their ability to purify urban air. Algorithms are employed to analyze these images for various parameters, such as leaf surface area, groove depth, and trichome density. These characteristics are significant as they relate to the plants' pollution absorption capabilities.

CNNs are ideal for image recognition tasks. They can be trained to identify specific plant features that correlate with pollution absorption, like leaf structure, density of trichomes, etc. This involves labeling each pixel of an image with a class (like leaf, branch, flower, etc.), allowing for detailed analysis of the plant parts and their specific roles in air purification. By processing sequential images of the plants over time, this approach helps in observing changes in plant growth and health, providing insights into how environmental factors impact their air purification abilities. Using 3D image processing to create models of the plant structures can provide insights into their physical arrangement and how this affects their efficiency in air purification.

By quantifying physical aspects of plants such as leaf surface area and groove depth, researchers can establish correlations between these characteristics and the plants' ability to absorb pollutants. Image processing helps in continuously monitoring the health and growth patterns of plants in urban settings, crucial for understanding their long-term effectiveness in air purification. Through image analysis, the interaction of plants with their surrounding environment, including factors like light exposure, urban structures, and human activity, can be better understood. The data derived from image processing can be integrated with data from Phase 2 (such as pollutant levels and environmental factors) to provide a more comprehensive understanding of the plants' performance in urban air purification.

To develop computational models that can accurately predict how different plant species influence urban air quality under a variety of environmental conditions. These models integrate data on plant characteristics (like leaf surface area, trichome density), pollutant levels (PM2.5, NOx, etc.), and environmental factors (temperature, humidity, urban structures).

Data collected from previous phases, such as air quality measurements and plant characteristics, is cleaned, normalized, and transformed to be used in modeling. Identifying the most relevant features that influence air purification, such as specific plant traits and local environmental conditions. Building a framework in Python where different scenarios can be simulated, such as varying levels of pollution, different plant species combinations, and changing weather conditions. Using historical data to validate the simulations, ensuring they accurately reflect real-world scenarios. Designing multi-layer neural networks that can process complex patterns in the data. These networks might include convolutional layers for spatial data processing, especially useful when dealing with image data from Phase 3. Splitting the dataset into training and testing sets. The network is trained on the training set, learning to predict air quality based on plant characteristics and environmental factors.

Decision trees are used to build rule-based models. These models help to understand and illustrate the decision-making process, especially in identifying the most relevant elements impacting air quality. These are particularly useful for understanding and visualizing the decision process, like which factors most significantly affect air quality. Using software like ArcGIS or QGIS for spatial analysis. Creating maps that visually represent data such as the distribution of plant species and pollution levels across urban areas. Analyzing how the distribution of different plant species across an urban area affects air quality. Investigating how factors like urban layout, traffic density, and green space distribution correlate with air purification effectiveness.

4. Result Evaluation. This research focuses on examining how the arrangement of green spaces in cities affects air pollution levels. It specifically looks at 20 garden cities in China randomly that experience a subtropical monsoon climate. The study uses data from 2019, including urban air quality measurements and information on land use types. By employing landscape metrics and spatial regression models, the study investigates the connection between the layout of green spaces and air pollution concentrations. This paper utilizes regression modeling tools available in the GeoDa software to perform SEM (Structural Equation Modeling) regression analysis. The outcomes of this analysis are presented in Table 4.1.

Landscape Shape Index (LSI) of grasslands. Notably, the association between SO_2 levels and both the PD of forestlands and the LSI of grasslands was particularly strong ($p < 0.01$). Conversely, the SO_2 concentration had a significant and negative correlation with the patch proportion in landscape area (PLAND) of forestlands, the patch density (PD) of grasslands, and the PLAND of agricultural lands, with the last two showing a very significant relationship with SO_2 levels ($p < 0.01$).

The study found that a one-unit increase in the PD of forestlands, PLAND, and LSI of grasslands led to increases in SO_2 concentration by 149.939, 0.752, and 0.429 units, respectively. On the other hand, a one-unit rise in the PLAND of forestlands, PD of grasslands, and PLAND of farmlands resulted in decreases in

Table 4.1: Various concentrations measures and analysis

	Variable	ρ	Threshold	ρ	Threshold	ρ	Threshold
		PM 2.5		NO_2		SO_2	
Grass lands	PLAND	0.821		0.885		0.000...	0.000...**
	PD	0.616		0.994		0.000...	0.000...**
	LSI	0.236		0.897		0.000...	0.000...**
Farm lands	PLAND	0.214	0.214*	0.532	0.532*	0.0021	
	PD	0.645		0.687		0.0054	
	LSI	0.347		0.752		0.0061	

SO_2 concentration by 0.073, 214.564, and 0.172 units, respectively. The SO_2 levels were not noticeably impacted by the LSI of forestlands, and the PD and LSI of agricultural lands.

The spatial correlation analysis from the 20 cities showed a significant link between the layout of urban green spaces and the levels of PM2.5, NO_2, and SO_2 pollutants. The pattern of green spaces, however, did not significantly affect PM10 levels. The PLAND, PD, and LSI of grasslands, along with the PLAND of farmlands, had an effect on SO_2 concentrations.

In the effort to optimize and rejuvenate the layout of urban green spaces, research has shown that strategically planning the design and distribution of green space networks can enhance air quality and benefit public health. Based on these insights, several suggestions are proposed for improving air pollution in cities with subtropical monsoon climates. Forests, grasslands, and farmlands are effective in reducing concentrations of PM2.5, NO_2, and SO_2. In urban areas, grassland should be managed carefully, forest coverage should be increased, and the restoration of damaged forests should be expedited to enhance ecosystem stability. The urban green space landscape should be meticulously planned based on scientific principles to balance ecological spaces for living and production.

In cities where NO_2 and SO_2 are predominant pollutants, arranging forest, grassland, and farmland landscapes systematically can help reduce pollution levels. Optimal NO_2 concentration in urban areas is achieved when the Patch Density (PD) of forest land is around 0.072. For SO_2, the best reduction effects are observed when forest land and grassland densities and layouts are adjusted to specific parameters, with an LSI of grassland at 14.13. This suggests that urban green spaces should be carefully planned to optimize patch density and diversify green space types, thus alleviating air pollution. By integrating green spaces into urban areas, air quality can be improved effectively and economically.

PM2.5 pollution, mainly from industrial emissions, traffic, and biomass combustion, is prevalent in urban roads and industrial areas. In China's subtropical monsoon regions, where urban development is rapid, reducing traffic and industrial emissions is challenging. However, optimizing urban green space layouts can mitigate PM2.5 pollution. An optimal reduction in PM2.5 levels occurs when the LSI of forest land reaches 18.02. Enhancing the greenery along streets and near factories, increasing the interaction between green spaces and PM2.5, and improving the vertical structure of urban green belts can effectively block and absorb PM2.5 pollutants.

Additionally, managing unused and inefficient land to create a well-planned urban green landscape is recommended. Promoting green, healthy, and low-carbon lifestyles and consumption habits among residents is also advised. Disseminating scientific findings on PM2.5, NO_2, and SO_2 pollution control can help government departments implement measures more effectively and gain public support for air pollution control initiatives.

5. Conclusion. In this research underscores the vital role of urban green spaces in mitigating air pollution and enhancing public health, particularly in cities with subtropical monsoon climates. The strategic planning and distribution of green spaces, such as forests, grasslands, and farmlands, have been identified as key factors in reducing concentrations of harmful pollutants like PM2.5, NO_2, and SO_2. By carefully managing these green areas, especially in urban settings, and adhering to specific landscape metrics such as Patch Density and Landscape Shape Index, significant improvements in air quality can be achieved. The study highlights that different types of pollutants require distinct approaches in terms of green space management. For instance, the optimal control of NO_2 and SO_2 involves adjusting the density and layout of forests and grasslands, while tackling PM2.5 pollution necessitates enhancing urban greenery in areas with high traffic and industrial activity. Moreover, the research emphasizes the importance of integrating ecological considerations into urban planning and development. This involves not only improving the design of green spaces but also promoting sustainable lifestyles and consumption patterns among residents. Such holistic approaches not only contribute to better air quality but also foster healthier, more sustainable urban environments.

Cities throughout the world have taken a transformational approach to urban design and sustainability in this imagined future by building Sustainable Urban Green Zones (SUGZs). These are carefully planned and strategically placed green spaces within metropolitan areas that promote air quality purification and environmental well-being. The research findings have a significant impact on the creation and management of SUGZs.

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