Identification Efficient Air Pollution Mitigating Tree Species Considering Tree and Regional Characteristic

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***Abstract*–The rapid industrialization and urbanization worldwide have resulted in a notable surge in air pollutants and the prevalence of atmospheric haze, exerting detrimental effects on public health. South Korea has been rated as having the highest concentration of PM2.5 among OECD member countries in 2019 (OECD, 2019), posing a severe health risk. Establishing urban forests and street trees has been proposed as an environmentally friendly solution to mitigate this issue. Trees are crucial in filtering ParticulateMatter (PM), improving air quality, and mitigating the Urban Heat Island effect. This research established a system to evaluate and rank the suitability of trees for PM reduction by incorporating regional and tree-specific characteristics into a formula. We systematically consider region-based, place-based, and detailed characteristics-based criteria of trees to rank their suitability for different urban environments. Region-based criteria consider climate and environmental factors, while place-based criteria assess tree properties relevant to urban locations. Detailed characteristics-based criteria allow for personalization based on aesthetic preferences. By integrating these factors into an equation, we provide a tool for informed tree selection, enhancing the efficiency of the process. Additional variables can be incorporated to refine tree rankings based on specific purposes. The research selects effective tree species for PM reduction and aims to develop a platform for broader accessibility. This platform will consider city landscapes and citizen preferences when choosing street trees and urban forests. Future work includes enhancing citizen participation in particulate matter management, expanding urban ecosystems beyond trees, and incorporating citizen preferences and opinions to maximize social and environmental benefits. By activating this platform, we anticipate a positive impact on urban air quality and overall city well-being and can also provide easy access for local governments and general users for planning city or city forests.**

Keywords: PM reduction, Urban air quality, Environmental sustainability, Tree species selection, Environmental factors, Platform development, Tree ranking system, Particulate Matter

1. Introduction

Industrialization and urbanization in East Asia have significantly contributed to increased air pollution and frequent haze, as highlighted by various studies (Zhu et al., 2018). In South Korea, westerly winds bring additional challenges, with particulate matter (PM) levels rising due to local transportation, industrial activities, and yellow dust from China and Mongolia (Kim et al., 2017). According to Greenpeace's analysis of the 2019 World Air Quality Report, South Korea recorded the highest PM2.5 levels among OECD countries (Greenpeace Korea, 2020). This alarming status underscores South Korea's vulnerability to PM pollution. The rise in PM levels poses severe risks to human health, increasing premature mortality from respiratory and cardiovascular diseases by 7% and heightening the risk of type 2 diabetes with prolonged exposure (Ritz et al., 2019).

Trees offer an effective and environmentally friendly solution, serving as natural filters by capturing PM on their leaves, branches, and bark (Chenet et al., 2017). Urban forests and street trees have the dual benefit of reducing PM and mitigating urban heat islands by providing shade (Bowler et al., 2010; Sanusi et al., 2017).

Despite these benefits, selecting tree species for afforestation requires careful consideration of regional suitability, site characteristics, and the unique traits of each species, making the process time-intensive and complex. The prior analysis of tree compatibility with specific locations is essential to maximize efficiency. This research aims to identify tree species most effective in reducing PM, taking into account environmental variables specific to various regions of South Korea. By selecting suitable species, this study seeks to minimize economic inefficiencies in establishing urban forests and street trees, contributing to improved air quality nationwide.

The research introduces an evaluation framework based on three key factors: geographical regions, specific locations, and botanical characteristics of the trees. This framework systematically ranks tree species by suitability for particular purposes, guiding decision-making in tree selection. Expanding the range of variables within this framework is expected to enhance its precision, allowing more tailored recommendations for specific goals.

2. Research Method

2.1. Target of study

In our research, the selection of trees was specifically curated from the plantation tree species roster provided by the Korea Forest Service, as it is commonly used for street tree planting. The table of trees was further refined using the 2018 Public Procurement Service's landscaping tree announcement, excluding any species not listed by the National Institute of Biological Resources to maintain consistency throughout the study.

For each tree categorized as excellent, good, or recommended by the Korea Forest Service, we analyzed its characteristics, growth environment, allergenicity, PM reduction efficiency, and cost. This selection process was guided by three key objectives:

i. To ensure the use of reliable and credible data.
ii. To maintain uniformity in the research dataset.
iii. To account for the preference for native species in South Korea. Thereby distinguishing between native and non-native species.

2.2. Data collection:

This study analyzed 141 tree species-excellent (34), good (75), and recommended (32), excluding ferns and bark plants, based on a 2022 press release by the Korea Forest Service (Lee, 2023). While ferns are known for their PM reduction capabilities, the research focused specifically on medium and large tree species suitable for roadside planting and landscaping purposes.

By narrowing the scope to street and landscape trees, the study aims to provide practical, region-specific recommendations for improving air quality and achieving maximum ecological benefits.

3. **Formulizing - Tools and Variables**

3.1. Type of factors

In this study, scores were first derived according to the ability to reduce the PM of each species, and factors for deriving the ranking of each species were divided into three categories: region, place, and detailed characteristics. The region-based criteria, prioritized as the first tier, consider the average annual temperature, annual humidity levels, and the climate zone of the selected region.

Table 1: Classification of each class's weight

Class	Parameter	Weight subhead	Parameter subhead
PM	Particulate Matter	W_{pm}	PM
Region	Temperature	w_t	t
	Humidity	w_h	h
Place	Toxicity	w_{tox}	tox
	Allergic	w_a	a
	Stink	w_s	s
	Air Pollution Tolerance	w_p	p
	Reduce Temperature	w_r	r

These variables collectively form the primary basis for evaluating the suitability of tree species in a given geographic area. As the second tier of evaluation, place-based criteria include variables such as toxicity levels of tree species, allergenic properties of trees, presence of unpleasant odors, resistance to air pollution (e.g., SO2, O3), and the potential for city temperature reduction. These factors are weighted and considered when assessing tree suitability for specific locations within urban environments such as residential, traffic, and industrial areas. The third tier, detailed characteristics-based criteria, incorporates variables such as the presence or absence of flowers, presence or absence of fallen leaves, year-round green foliage (Evergreen or Deciduous), presence or absence of fruits, fragrance, choice between Broadleaf and Coniferous trees, and selecting the height of trees. These variables allow for a more personalized approach to tree selection, accounting for individual preferences and aesthetics in the urban landscape.

3.2. Reasons for Factor Selection

This study aims to assist in selecting tree species for the purpose of reducing PM, utilizing data provided by the Korea Forest Service. The selection process is driven by factors categorized into three primary domains: regional-based variables, place-based variables, and detailed selection-based variables. These multifaceted elements collectively influence the efficacy of PM reduction strategies and contribute to the overall quality of the urban milieu. Regional-based variables, notably encompassing parameters such as average annual temperature and humidity, serve as pivotal determinants in assessing the appropriateness of tree species for specific geographical locations. These climatic factors directly influence the growth and vitality of trees, rendering the selection of species adapted to local climatic conditions imperative for ensuring the long-term sustainability of urban forests.

Place-based variables encompass an array of considerations, each serving a distinct purpose relating to environmental quality, public health, and the overall habitability of urban areas. The evaluation of tree toxicity assumes a paramount role in safeguarding the well-being of urban residents and the ecological integrity of the urban ecosystem. Evaluating tree toxicity entails mitigating inadvertent exposure to deleterious substances released or encountered by select tree species. Similarly, addressing concerns related to pollen allergies becomes paramount for public health and safety, as including trees with high pollen allergenicity in urban landscapes may precipitate adverse health consequences among residents. For example, breathing in pollen can make persons with hay fever, commonly referred to as "allergic rhinitis," sneeze, have congestion, and have a runny nose (CDC, n.d.). Moreover, odors can cause discomfort in some people (Weber & Heuberger, 2008), which can lead to symptoms such as headaches, vomiting, and mild fever. In addition, prolonged exposure may increase some people's risk of chronic respiratory diseases. Therefore, considering olfactory properties in tree selection greatly contributes to the comfort and overall satisfaction of urban residents, improving the overall urban environment. The imperative of urban temperature reduction assumes critical significance in ameliorating the urban heat island effect, with trees capable of effectively lowering local temperatures (*US EPA*, 2023), contributing to a more temperate and hospitable urban environment. Furthermore, tree species exhibiting resistance to air pollutants, such as sulfur dioxide (SO2) and ozone (O3), are instrumental in mitigating urban pollution and augmenting air quality (Yang et al., 2015).

Detailed selection-based variables encompass various characteristics, encompassing the presence of flowers, flower color preferences, the deciduous or evergreen nature of the foliage, fruit-bearing capabilities, fragrance, the choice between broadleaf and coniferous trees, and selection of height of trees. While these attributes may not directly affect PM reduction efficiency, they diversify the urban landscape and foster a more harmonious and inclusive urban environment. Incorporating these aesthetic considerations facilitates a personalized approach to tree selection, aligning urban denizens' preferences and aesthetic sensibilities with the broader objectives of urban landscape enhancement. Furthermore, allowing users to select the height of the tree based on the specific characteristics of the location where the tree is planted can lead to a more tailored choice of trees that are better suited to the environment, as tree height preferences may vary. This encourages users to make a more environmentally suitable tree selection.

Therefore, the selection of trees for PM reduction in urban contexts mandates a comprehensive evaluation of region-based, place-based, and detailed selection-based variables. By judiciously considering these factors, users including urban planners and environmental practitioners can effectively attenuate PM levels while concurrently enriching the visual and environmental of urban landscapes.

4. Method

This research aims to identify tree species suitable for planting in various regions of South Korea to reduce delicate PM concentration efficiently.

1. Three environmental factors directly influencing PM mitigation were identified. To concretize and measure these factors, a total of eight variables were selected.
2. The database provided by the Korea Forest Service was utilized to gather data for the selected variables. Using this data, about 140 kinds of street trees with excellent efficiency in reducing particulate matter were selected.
3. The selected species were scored using Equation 1, applying weights according to the environmental factors. Through this scoring process, each species' ability to reduce PM was evaluated.

$$\text{Tree Index} = \frac{\mathbf{PM} \cdot \mathbf{W}_{pm} + \mathbf{R} \cdot \mathbf{W}_{r} + \mathbf{P} \cdot \mathbf{W}_{p}}{300}$$

Equation 1. Scoring Tree Index

In Equation 1, PM represents the unique Particulate Matter (PM) score for a specific tree species. The PM value for tree species classifies each tree species as 'excellent' out of 100, 'good' out of 80, and 'recommended' out of 60.

The Region factor (R) is composed of variables that reflect the interaction between climate conditions such as temperature and humidity and the characteristics of the tree. This is to assess the impact of each region's environmental conditions on the survival and growth of the trees.

The Place factor (P) represents the type of location where the tree will be placed (e.g., Residential Area, Traffic Area, Industrial Area) and the interaction with the trees, which is used to evaluate the suitability and efficiency of the trees in specific locations. In this model, the Tree Index score for each tree species is calculated as a weighted sum of the three main environmental factors—PM reduction score, Region factor, and Place factor—considered as Classes, and the weights assigned to the sub-parameters of each Class.

The allocation of humidity scores is as follows: after selecting a tree and a region for which the humidity score is to be calculated, the absolute difference between the tree's optimal humidity level and the region's humidity level is determined. A difference of 0 results in a score of 100 points, a difference of 1 results in 70 points, and a difference of 2 results in 40 points.

4.1 Region Index

The Region Index (Ri) is determined by two parameters : Temperature (T) and Humidity (H). To calculate Ri, a tree's intrinsic T and H values are compared with those specific to a region. This comparison score is then multiplied by the assigned weight value of 50 for each variable. The regions for the R variable are selected from those areas in South Korea where the Korea Meteorological Administration measures humidity. These regions are chosen at the level of cities and counties within provincial governments, with metropolitan cities being considered as a single administrative entity.

The equation for Ri is calculated by multiplying the comparison score of T and H for both the tree and the region by their respective weight value of 50. Temperature scores are derived using the Köppen climate classification (KCC). The tree species' KCC and the region's KCC are compared. Trees are evaluated based on the KCC of the areas where they predominantly grow naturally, while regions are assessed using a KCC map.

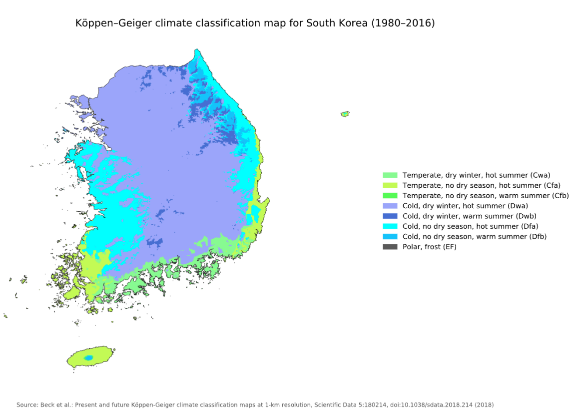

figure 1. Köppen climate classification in South Korea.

The Köppen climate classification is divided into primary, secondary, and tertiary categories, denoted by alphabet. The Köppen climate classification is divided into primary, secondary, and tertiary categories, denoted by alphabet. Comparing the KCC of a tree to that of a region for scoring as a following chart:

Table 2: KCC score for region

Classification Matching	Score
Primary classification differs	0
Primary matches, secondary differs	60
Primary and secondary match, tertiary differs	80
All classifications match	100
Thrives throughout Korea	100

Humidity scores are derived using humidity data from the Korea Meteorological Administration. Each local government entity in South Korea calculates its average annual humidity. The humidity levels are then categorized into three stages: 3, 2, and 1. Regions within the top 33% humidity range are assigned level 3, those in the top 66% are assigned level 2, and the remaining regions are assigned level 1. Similarly, each tree species' optimal humidity level is classified into these three stages.

The allocation of humidity scores is as follows: after selecting a tree and a region for which the humidity score is to be calculated, the absolute difference between the tree's optimal humidity level and the region's humidity level is determined. The table below shows the score distribution for each:

Table 3: Humidity score

Difference result	Score
0	100
1	70
2	40

4.2 Place Index

The Place Index (Pi) is an index used to evaluate the environmental suitability of tree species for urban planting. It is determined based on five parameters (Toxicity, Allergic, Stink, APT (Air Pollution Tolerance), R (Reduce Temperature)) and assigned weight values for three types of areas (Residential Area, Traffic Area, Industrial Area) as outlined in Equation 2.

$$Pi = P \times W_p$$

$$P = [Tox\ A\ S\ APT\ R\ ]$$

$$W_p = \left[w_{tox}\, w_a\, w_s\, w_{apt}\, w_r \right]$$

$$p = \{p_{res},\, p_{traf},\, p_{industry}\}$$

Equation 2. Equations for calculating PI

PI incorporates the environmental variance between places by assigning unique weights to three different types of areas: Residential Area, Traffic Area, and Industrial Area. These weights play a crucial role in modulating the impact of the five environmental variables associated with each area type.

Table 4 : Place Weight Parameter

	Parameter				
Place(p)	Tox	A	S	APT	Re
Residual Area	20	20	20	15	25
Traffic Area	17.5	17.5	17.5	30	17.5
Industrial Area	15	15	15	40	15

Table 5: The weight of each parameter

Parameter	Standard	Score
Toxicity	Tree is toxic	1
	No toxicity or no data available	100
Allergic	Severe allergies	1
	Documented potential allergic reaction	50
	Otherwise	100
Stink	Foul odor	1
	No odor or no data	100
APT	No tolerance	1
	Pollution tolerance	100
R	Needle-like leaves	70
	Broad leaves	100

These weights serve as direct indicators for assessing the environmental suitability of tree species in various locations, and they are multiplied by the scores assigned to the tree species for each specific place.

5. Result/Conclusion

This research aimed to identify the most effective tree species for reducing particulate matter in urban areas. By focusing on trees particularly effective in urban environments, a comprehensive data and literature review was conducted for each species. Various evaluation factors were considered, categorizing trees based on region and location, assessing their importance, and assigning weights to determine their priorities. Using these selected factors, an equation was developed to score tree species.

To make this approach practical and accessible, the equation will be implemented into a web-based platform. The platform was chosen as the medium because it allows for user-friendly interaction, accessibility for a wider audience, and dynamic updates with additional features. The platform will incorporate optional features to consider the city's natural landscape when planting street trees and urban forests. Citizens can utilize the scoring system and available options to directly select tree species and derive priority rankings. The intuitive design of the website encourages citizen participation, making it easier for individuals to engage with urban greening efforts.

The platform's impact is anticipated to extend beyond research. It offers practical tools for government agencies, organizations, and urban planners to enhance particulate matter management. Moreover, the platform's scalability ensures that it can adapt to diverse urban contexts, supporting the development of sustainable green spaces. By integrating citizens' preferences and opinions, the platform fosters greater social engagement, enabling users to play an active role in environmental decision-making.

Future development of the platform can include personalized features, allowing citizens to customize their experiences and participate in particulate matter management tailored to their needs. Expanding beyond trees to consider other plant types can enhance urban ecosystem diversity, maximizing ecological benefits. These efforts are expected to directly reduce particulate matter in cities while promoting public interest in environmental issues.

The decision to create this solution as a web-based platform ensures that the tool is not only effective but also inclusive and interactive. It allows users to visualize the impact of their choices, facilitates community involvement, and democratizes access to tools that contribute to improving urban environments. Ultimately, the platform will help reduce particulate matter, foster public engagement, and contribute to building healthier, greener cities.

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