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The Effectiveness of green belt vegetation in reducing air pollution and noise

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ABSTRACT

Introduction: Urbanization, industrial growth, and heavy traffic are driving a rise in air and noise pollution in cities, posing serious threats to public health and environmental sustainability. Airborne particulates can trigger respiratory and cardiovascular conditions, while chronic exposure to high noise levels impairs mental well-being, sleep, and hearing. As a response to these challenges, green belts—vegetated buffer zones—are increasingly recognized for their dual function in mitigating pollution and enhancing urban livability. **Methods**: This study assessed the environmental performance of three tree species—Moquilea tomentosa Benth, Litsea garciae, and Khaya anthotheca—in reducing air pollutants and noise levels. Data was collected by measuring dust retention per tree and comparing noise intensity between greenbelt and open areas. The pollution capture was analyzed through quantification of particulate deposition, while noise reduction was observed using decibel level comparisons. **Findings**: Among the species tested, Khaya anthotheca demonstrated the highest dust-absorbing capability with 501.86 g/tree, followed by Litsea garciae (338.07 g/tree) and Moquilea tomentosa Benth (141.57 g/tree). In terms of acoustic performance, greenbelt areas showed a noise reduction of approximately 16 dB, compared to only 11 dB in non-vegetated spaces. These outcomes highlight the superior pollution-mitigation benefits of certain tree species, particularly when strategically integrated into urban green infrastructure. **Conclusion**: These findings affirm the vital function of green belts in urban pollution control. The study emphasizes that the strategic selection of tree species and thoughtful planting design can significantly enhance the effectiveness of green infrastructure in improving air quality and reducing environmental noise in city landscapes. **Novelty/Originality:** The novelty of this study lies in its comparative evaluation of specific tree species for their dual ability to mitigate both air and noise pollution in urban environments—a topic that is often studied separately but rarely in a combined context.

KEYWORDS: green belt vegetation, air population mitigation, noise reduction, urban environmental management.

1. Introduction

Air pollution and noise are two major issues faced by urban environments today. The increasing number of motor vehicles, industrialization, and rapid urbanization significantly contribute to environmental pollution. Air pollution, particularly fine particulate matter, and noise from traffic and industrial activities have direct impacts on public health. Long-

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term exposure to air pollutants can lead to various respiratory and cardiovascular diseases and even premature death. Additionally, excessive noise can reduce quality of life, cause stress, disrupt sleep, and lead to hearing problems. Therefore, controlling both types of pollution is a priority in urban environmental management.

Vegetation, whether naturally occurring or strategically incorporated into urban landscapes, has been proven effective in reducing air pollution and noise levels. Plants play a crucial role in absorbing air pollutants through leaf stomata, filtering dust, and producing oxygen, thereby improving air quality. Moreover, vegetation can attenuate noise by absorbing and reflecting sound waves, reducing the intensity of noise that reaches surrounding areas.

The reduction of particulate pollutants by vegetation occurs through mechanisms such as adsorption, deposition, and diffusion, whereas noise reduction is achieved through sound absorption and reflection. Consequently, the microstructure of leaves, canopy density, and the number of tree rows determine the effectiveness of green belts in mitigating these pollutants. Green belts, strategically placed around pollution sources such as highways, can significantly reduce the impact of air pollution and noise generated by motor vehicles. However, the effectiveness of such vegetation is highly influenced by plant species, planting structure, and physical leaf characteristics, including shape, size, and surface properties.

2. Methods

The practicum on the function of vegetation in reducing air and noise pollution was held on Tuesday, September 17, 2024, at Arboretum IPB. Observation of air and noise pollution was carried out for 3 hours at 14.00 - 17.00 WIB. The tools used in this practicum are sound pressure level, tree pruner, meter, large envelope, beaker, brush, oven, leaf area meter, analytical balance, stationery, and smartphone. The implementation stage in practicing the function of vegetation in reducing air and noise pollution consists of two methods, namely the gravimetric and sound pressure level methods. are as follows:

Measurement of tree species' capacity to absorb particulate pollutants. Measurements were carried out using the gravimetric method by taking adult leaf samples from 3 (three) different tree species as many as 3 replicates with the provisions: Leaf is a mature leaf; Leaves facing the road at a distance of 0-3m from the road; Leaves were taken at a height of 3 meters above the ground; Leaves were taken as much as 20 grams of each species in each replicate. Then perform the lab procedure with the following steps as follows: Weigh the beaker empty and record the weight as H0; Wash the leaves in a glass beaker using distilled water and a brush; calculate the area of the washed leaf and record it as L; Evaporate the water in the beaker using an oven at 80oC for 2x24 hours; Weigh the dry beaker using an analytical balance and record the weight as H1.

The data obtained was then entered into a formula to calculate the capacity of the leaves to absorb particulate pollutants. The formula used is as follows.

$$Leaf\ capacity\ to\ absorb\ dust\ (J)\ =\ \frac{(H1-H0)}{L} \qquad \text{(Eq. 1)}$$

Then calculate the capacity of the tree to absorb pollutant particles with the following equation 2.

$$Tree\ capacity\ to\ absorb\ dust\ (PJ) =\ crown\ surface\ area\ (LT) \times J \quad \text{(Eq. 2)}$$

Then calculate the emission of particulate pollutants from the road with the following equation 3.

$$\sum_{i=1}^{n} LN_i \, F_{pi} \qquad \text{(Eq. 3)}$$

Carbon monoxide (CO) pollutant emissions, denoted as Ep, are calculated in grams per kilometer (g/km). This calculation considers several factors: L, which represents the length of the road (measured in units of 1 km); N, the number of type-i motor vehicles traveling on the road; and Fpi, which is an emission coefficient specific to type-i vehicles. By considering these variables, the formula helps estimate the total amount of CO emissions generated per kilometer of road by different categories of motor vehicles. The known vehicle emission coefficients are as follows.

Table 1. Motor vehicle coefficient

Vehicle type	Emission coefficient value
Passenger car	32.4
Trucks	8.4
Bus	11.0
Motorcycle	14.0

Measuring the effectiveness of green belt vegetation in reducing noise. The effectiveness of green belt vegetation in reducing noise is measured using a sound pressure level (SPL) meter by recording SPL values at distances of 0, 10, 20, 30, 50, and 70 meters from the road. Measurements are conducted in both vegetated areas and open/non-vegetated areas, with each distance measurement repeated three times. The SPL values obtained at each distance are then analyzed using a simple linear regression statistical equation to determine the relationship between distance from the road and the measured SPL values. Additionally, the differences in results between vegetated and non-vegetated areas are examined. Simple linear regression in equation 4 is as follows.

$$y = ax + b \qquad \text{(Eq. 4)}$$

In this context, y represents the dependent variable, which is the outcome being measured or predicted. The variable x is the independent variable, which influences or predicts the value of y. The value a is the intercept on the y-axis, indicating the point where the regression line crosses the y-axis when x is zero. Lastly, b refers to the regression coefficient, which represents the slope of the regression line, indicating how much y changes for a one-unit change in x.

3. Results and Discussion

3.1 Capacity of Tree Species to Absorb Particle Pollutants

The tree species selected for this practicum are *Moquilea tomentosa* Benth, Litsea garciae, and Khaya anthotheca. These three tree species are labeled as A, B, and C, respectively. Each replication is then assigned the numbers 1, 2, and 3. At this stage, leaf samples are collected from the three selected tree species. The leaf shapes differ among trees A, B, and C, as shown in the following image.

Fig. 1. Leaf shape of each tree observed (from left to right tree leaf A, tree leaf B, and tree leaf C)

The obtained data is then applied to formula A and calculated to determine the leaf capacity for adsorbing particulate pollutants (J). The average J value for each tree species across replications is then computed. A more detailed representation can be seen in the following table.

Table 2. Leaf Capacity to Absorb Particle Pollutants (J)

Plant species	Code	H0 (mg)	H1 (mg)	L (cm^2)	J (mg/cm^2)	$\underline{J}$ (mg/cm^2)
Moquilea tomentosa Benth.	A.1	63.30	63.342	941.17	4.463×10^{-5}	6.456×10^{-5}
	A.2	70.33	70.387	734.92	7.756×10^{-5}	
	A.3	63.03	63.096	923.20	7.149×10^{-5}	
Litsea garciae	B.1	70.07	70.135	535.81	1.213×10^{-5}	10.298×10^{-5}
	B.2	72.27	72.330	668.85	8.971×10^{-5}	
	B.3	69.87	69.922	531.05	9.792×10^{-5}	
Khaya anthotheca	C.1	69.34	69.395	860.80	6.389×10^{-5}	7.510×10^{-5}
	C.2	61.46	61.533	799.50	9.131×10^{-5}	
	C.3	69.02	69.079	841.58	7.011×10^{-5}	

The data on the capacity of 20g of leaves to absorb particulate pollutants is then used to calculate the tree's overall capacity for pollutant adsorption. The variables influencing this calculation include crown shape and crown area. Based on the results, broader leaf size affects the total adsorption surface area. The larger the surface area, the greater the number of particles that can be absorbed.

Table 3. The level of pollutant adsorption by the leaves of the three tree species

Plant species	Crown Shape	Σ J (mg/cm^2)	LT (cm^2)	PJ (g/tree)
Moquilea tomentosa Benth.	Spherical (globular)	0.00006456	2,192,766.67	141.57
Litsea garciae	Cone	0.00010298	3,282,960.00	338.07
Khaya anthotheca	Dome	0.00007510	6,682,312.50	501.86

Based on table 3, it is known that the Khaya anthotheca tree has the best dust absorption ability of 501.86 grams per tree, followed by Litsea garciae and Moquilea tomentosa Benth. with 338.07 grams and 141.57 grams per tree, respectively. The difference is in line with research, which states that trees with leaf morphology. Can absorb dust pollutants better. The high level of uptake is in line with the large average leaf area per tree.

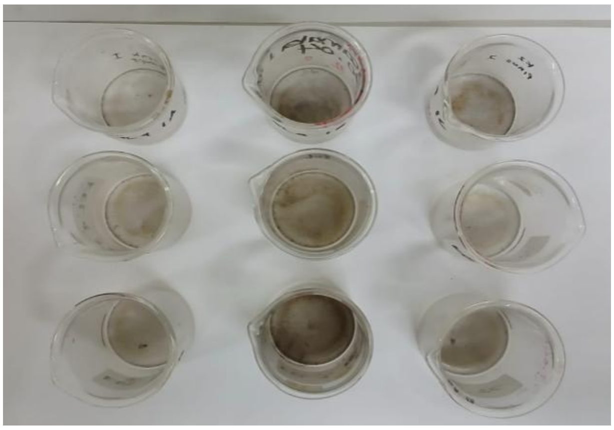

Fig. 2. Comparison of gravimetric turbidity results

An increase in the number of motorized vehicles can increase pollutants emitted into the atmosphere. The calculation of vehicle emission load uses emission factor data sourced from MOE No.12/2010. The emission factor shows the number of emissions per year of a unit of activity carried out in the form of volume produced or volume consumed. The emission factor will be different for each type of vehicle. Motor vehicle gas exhaust produces emissions of 75% carbon monoxide (CO).

Table 4. Vehicle Measurement Data

Vehicle type	Frequency (units)	Emission coefficient	Ep (g/jam)
Passenger car	1.156	32.4	37,454
Trucks	160	8.4	1,344
Bus	4	11.0	44,000
Motorcycle	5.432	14.0	76,048

The total emissions (Etotal) are calculated by summing the emissions from different vehicle types, including cars (Emobil), buses (Ebus), trucks (Etruk), and motorcycles (Emotor). The emissions from each vehicle type are as follows: 37,454 g/hour for cars, 1,344 g/hour for buses, 44 g/hour for trucks, and 76,048 g/hour for motorcycles. Adding these values together, the total emissions result in 114,890 g/hour.

Based on the calculation results along the road in front of the IPB campus used in this practicum has a road length of 1 km. Total vehicles passing through the road section of the IPB road campus at 14.00-15.00 WIB. The total vehicles passing through were dominated by motorized vehicles with a total of 5,432 during the 1-hour duration. The results of the calculation of the emission load show that the highest number of pollutants released into the atmosphere is Co of 114,890 g / hour. Carbon Monoxide is a toxic gas that is odorless and tasteless, resulting from incomplete combustion of natural gas and other materials containing carbon (Saputra & Dharmawan, 2013).

Plants can reduce the concentration of air pollution through the mechanism of absorbing gas pollution and absorbing particles on the surface of the leaves. Motor vehicles in this case are one source of pollutants associated with transportation systems and facilities. Plant species with moderate to high stomatal density have good pollutant absorbing potential (Grey & Deneke, 1978). Vegetation can help reduce air pollution through particulate deposition on vegetation surfaces, as well as by gas exchange mechanisms in the stomata on the reduction of gaseous pollutants (Dover, 2015).

3.2 Effectiveness of Green Belt Vegetation in Reducing Noise

Green belt is a zone planted with various types of vegetation, such as trees, shrubs, and grasses, which is generally placed between the noise source area and the area to be protected from noise pollution. Vegetation in green belts not only functions for the beauty and coolness of the environment, but also has an important role in reducing noise, especially in dense urban areas adjacent to noise sources such as highways, factories, or airports.

Table 5. Noise Measurement Data

Distance from Noise Source (m)	SPL in Greenbelt (dB)	SPL in Open Area (dB)
0	79	80.9
10	73	79.1
20	71	74.4
30	69	73.4
50	67	72.1
70	63	69.9

Based on the data above, the SPL in the open area is always higher than in the greenbelt area. At 0 meters from the noise source, the SPL in the open area reaches 80.9 dB, while in the greenbelt it is only 79 dB. However, with increasing distance, the difference in SPL becomes more significant. Especially at a distance of 70 meters from the noise source, there is a significant difference between the SPL in the greenbelt area and the open area, where the SPL in the greenbelt drops to 63 dB while in the open area it only reaches 69.9 dB, the decrease in noise in the greenbelt area reaches about 16 dB, while in the open area it only drops about 11 dB.

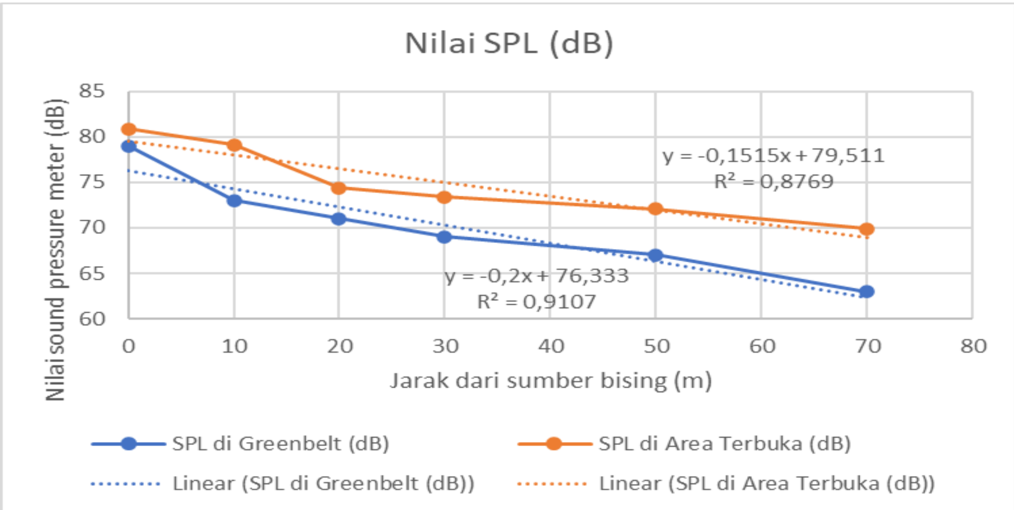

Fig. 3. Simple linear equation graph of noise measurement

The graph above shows that SPL values tend to decrease as the distance from the noise source increases. The blue line represents SPL in the greenbelt area, while the orange line represents SPL in the open area. The linear equations displayed in the graph indicate a significant downward trend in both locations, with a relatively high coefficient of determination (R^2), demonstrating a strong relationship between distance and SPL values. The R^2 value for SPL in the greenbelt area is 0.9107, whereas in the open area, it is 0.8769. This means that the presence of a greenbelt influences noise levels by 91.07%, with the remaining 8.93% being affected by other factors. In contrast, in the regression results for non-vegetated areas, the influence on noise levels is 87.69%, while other factors contribute only 12.31%. Based on Figure 3, it is evident that the farther the distance from the noise source, the lower the noise level.

This finding highlights the crucial role of vegetation in mitigating noise pollution. Greenbelt vegetation consists of multiple layers of plants, including tall trees, shrubs, and ground cover, which could absorb, reflect, and attenuate sound through diffraction (bending of sound waves), absorption, and reflection mechanisms. A study by Dewi et al. (2022) revealed that vegetation with dense and layered canopies is more effective in absorbing sound due to its capacity to block and absorb more acoustic energy. They observed that vegetation can reduce noise intensity by 6–12 dB at 20 meters from the noise source.

Additionally, another study by Yosieguspa (2020) supports these findings, stating that the type and density of vegetation play a crucial role in noise attenuation. Trees with thick and broad leaves are more effective in reducing noise due to their higher sound absorption capacity. Vegetation can also break up sound waves and disperse them in different directions, thereby reducing noise intensity in areas farther from the source. Furthermore, a study by Rahmawati & Wulandari (2024) identified other factors that influence the effectiveness of greenbelts in noise reduction, namely humidity levels and soil type. Vegetated areas with high humidity can absorb more sound energy, especially in moist air conditions. Soil with good moisture retention also contributes to sound wave absorption through diffraction on the ground surface.

Overall, these observations indicate that greenbelt vegetation significantly contributes to reducing noise from road traffic. Vegetation serves as a natural buffer that effectively absorbs sound, particularly at greater distances from the noise source. Therefore, urban landscape planning that incorporates greenbelts along highways or other noise sources can significantly improve the quality of life for surrounding communities.

4. Conlusion

capacity and effectiveness of green belt in pollutant dust capture. Moquilea tomentosa Benth, Litsea garciae, and Khaya anthotheca as leaf observation objects showed diverse results in pollutant dust trapping with Litsea garcia being the most effective in it. Moquilea tomentosa Benth gave an average sorption result of 6.456 x 10^(-5) mg/cm2; Litsea garciae of 10.298 x 10^ (-5) mg/cm2; and Khaya anthotheca of 7.510 x 10^(-5) mg/cm2. The leaf capacity data was processed into final data on the capacity of trees in capturing pollutant dust with the influencing variables of crown shape and crown area, resulting in data of 141.57 g/tree; 338.07 g/tree; 501.86 g/tree, respectively. The data obtained through the processed results show that Khaya anthotheca trees have the best dust absorption capacity of 501.86 grams per tree.

Effectiveness of green belt vegetation in reducing noise. Greenbelt is effective in reducing noise generated by road traffic. The noise reduction is more significant at a greater distance from the noise source, the observation shows that the noise reduction in the greenbelt area reaches around 16 dB, while in the open area it only drops around 11 dB. Therefore, the use of greenbelt can be one of the effective solutions to reduce noise in urban areas.

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Author Contribution

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