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The Effectiveness of Green Belt Vegetation in Reducing Air Pollution and Noise

Firnawati [1] , Umara Hasmarani Rizqiyah [1] , Andi Firman Muhibuddin [2]
[1] Architecture Study Program, Faculty of Engineering, Makassar State University
[2] Civil Engineering Study Program, Faculty of Engineering, Makassar State University
[1] firnawati@unm.ac.id * , [2] umara.hasmarani@unm.ac.id , [3] andi.firman.muhibuddin@unm.ac.id

Abstract

Rapid urbanization and industrialization in the modern world have led to increased urban pollution. Road traffic is considered a major source of air and noise pollution, negatively impacting the environment and human health. Roadside green infrastructure, also known as green belts, has the potential to reduce air pollution and noise from traffic by increasing the distribution of plants that effectively absorb pollutants. Vegetation along roads, in addition to acting as a noise barrier, also plays a role in controlling urban air pollution. Studies show that plants can reduce air pollutant content through natural absorption and filtration processes. Meanwhile, noise reduction by vegetation is influenced by the type of vegetation, the level of vegetation density, and the planting combination. The type of vegetation is related to the thickness and flexibility of the leaves. The plant with the highest dust absorption capacity is the Mango Tree (Mangifera indica) at 0.531 g/m2 · Then the second highest is the Saga Tree (Adenanthera pavonina) at 0.224 g/ ^{m2} . Meanwhile, the Kaya Tree (Khaya anthotheca) has the lowest dust absorption capacity, namely 0.212 g/m ^{2} . Land with vegetation is more effective in reducing noise compared to land without vegetation. The greater the distance from the noise source, the higher the level of noise reduction, with a distance of 10 m being set as the minimum limit for green belts.

Keywords: Vegetation, Green Belt, Air Pollution, Noise Reduction, Urban Planning

1. Introduction

Urbanization, characterized by increased vehicle traffic and expanding infrastructure, creates serious environmental challenges, particularly air and noise pollution. These pollutants not only damage the environment but also negatively impact human health [1], [2]. This population growth also leads to increased air pollution around roads. This situation raises significant public health concerns and encourages efforts to regulate air quality in these microenvironments [3]. Road traffic is considered a major source of air and noise pollution, which negatively impact human health [4], [5]

Exposure to traffic-related air pollution (TRAP) can cause various adverse health impacts, such as respiratory and cardiovascular disorders [6]. In the United States, more than 45 million people are estimated to live within 100 meters of a major highway (US Census Bureau, 2009), with minority groups and low-income communities more likely to live in areas adjacent to such roads. Millions of others worldwide also live, work, or attend school in areas close to major roads. Nature-based solutions (NBS), or green infrastructure approaches such as the use of vegetation, have great potential in addressing social and environmental challenges.[7]

Plants growing along roadsides can play a role in mitigating health impacts by reducing the concentration of air pollution exposure due to traffic flow and improving local air quality [8]. However, the ability of vegetation to reduce pollution levels is strongly influenced by its physical and ecological characteristics [9]. In general, vegetation can reduce pollutants through two main mechanisms: deposition, which is the process by which pollutants adhere to leaf surfaces, and dispersion, which is when vegetation modifies the direction of air flow so that pollutant concentrations are more dispersed. The denser the vegetation, the greater the potential for trapping pollutants through deposition and strengthening the effect of windward dispersion [9], [10].

Vegetation along roads, in addition to acting as a noise barrier, also plays an important role in controlling urban air pollution. Studies show that plants can reduce the content of pollutants in the air through natural absorption and filtration processes [5]. The effectiveness of green belts in reducing road traffic noise has attracted the interest of researchers in various countries. Traffic noise has always been a challenge in urban environments, and several mitigation measures that have been considered for existing roads or roads under reconstruction include the creation of buffer zones, the construction of road dividers, planting vegetation, and the installation of sound insulation on buildings.[11]

Air pollution is the presence of harmful substances in the air that can harm human health and the environment. This pollution occurs when various types of other gases are added to the surrounding air, which usually consists of non-reactive gases. Pollutants in the air can be in the form of gases or small particles such as dust, ash, salt, and smoke. Air pollutants can generally be caused by natural occurrences, and due to human activities. To reduce air pollution globally, efforts are needed from national policies and international cooperation [12]. Air pollution is directly mentioned in two of the 17 Sustainable Development Goals (SDGs) of the 2030 Agenda for Sustainable Development, which was signed in 2015 by member states of the United Nations (UN) [13].

The reduction of pollutants by green belts depends on conditions at the location, such as air stability, traffic density and speed, types of vehicles present, turbulence caused by vehicles, the presence of buildings, road configuration, and wind direction. [14]. In addition, the effectiveness of various plant species in absorbing pollutants varies [15]. Vegetation is widely used as a solution to reduce air pollution in urban areas, through various types of green infrastructure. In addition, methods that can increase the ability of plants to absorb fine particulates (PM), are through the selection of appropriate species and increasing biodiversity [16]. According to Mutaqin et al. (2016) the increase in air pollution is generally caused by electricity production, vehicle emissions, industrial activities, increasing population density, lack of forests or city parks, and others.

Planting several species together is more effective in reducing noise than planting a single species [17]. In addition, a combination of vegetation, ranging from ground cover plants, shrubs and trees. For example, recommended ground cover plants are grass and legumes (Leguminosae). Shrub plants include pringgodani bamboo (Bambusa sp), soka (Ixora sp), tea (Durante). Tree plants include acacia (Acacia mangium), johar (Casia siamea), dense trees with low branches (PU Noise Mitigation Guidelines, 2005). This study aims to determine the capacity and effectiveness of road green belt vegetation in reducing particle pollutants and reducing noise. This will help determine the plant species that can be recommended for green belt development in urban areas.

2. Research methods

This research was conducted at the Arboretum of the Department of Landscape Architecture, Graha Widya Wisuda Building, and the Plant Laboratory of the Department of Landscape Architecture, Bogor Agricultural University. On Wednesday, November 7, 2018, air pollution and noise observations were conducted for 5 hours from 11:00 AM to 4:00 PM WIB. This method begins with determining the field observation location, followed by data collection for subsequent laboratory observations. Measuring vegetation effectiveness in reducing air pollution and noise follows the following work procedures:

To measure the effectiveness of vegetation in reducing air pollution, the measurement procedure was carried out using the gravimetric method by taking samples of mature leaves from 3 (three) different types of trees, repeated 3 times with the following conditions: The leaves are mature leaves; The leaves face the road at a distance of 0-3m from the road; The leaves are taken at a height of 3 meters above the ground; The leaves are taken as much as 20 grams of each type at each repetition. Then continue with the laboratory procedure by weighing and recording the initial weight of the beaker as the initial weight (P0); weighing 10 grams of leaves for each repetition; Wash the leaves in the beaker using distilled water and a brush; calculate the area of the washed leaves and record it as L; Evaporate the water in the beaker using an oven at 80 °C for 2x24 hours; Reweigh the dry beaker using an analytical balance and record the weight as P1.

The data obtained was then entered into a formula to calculate the leaf's capacity to absorb particulate pollutants. The formula used is as follows:

$$\text{Leaf capacity to absorb dust (J)} = \frac{(\text{P1})-(\text{P0})(\text{g})}{\text{L}(\text{m}^2)} \quad (1)$$

J is the ability of leaves to absorb pollution (g/m ^{2}), P0 is the initial weight of the beaker (g), and P1 is the final weight of the beaker after being oven-dried (g), while L is the leaf area after washing (m ^{2}).

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

$$\text{Tree capacity to absorb dust (Pj)} = \text{crown surface area (Lt)} \times \text{J} \quad (2)$$

The formula for calculating the surface area of the crown is: $4/3\pi r^2$

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Where PJ is the tree's ability to absorb pollution (g), Lt is the surface area of the canopy (g/m ^{2})

Calculate particle emissions from roads with the equation:

$$\text{Emisi (Ep) partikel jalan} = \text{Volume Kendaraan x koefisien emisi partikel/kendaraan} \quad (3)$$

Then calculate the particulate pollutant emissions from the road with the following equation 4.

$$\text{Emisi (Ep) perhari} = \frac{\text{Panjang Arboretum (PA)}}{1000} x \text{ N } (g/km) \quad (4)$$

Pollutant emissions are denoted as Ep, calculated in grams per kilometer (g/km). This calculation takes into account several factors: PA, which represents the length of the road (measured in meters); N, the number of producers operating on the road. By considering these variables, this formula helps estimate the total amount of emissions produced per day in the Landscape Arboretum by various categories of motor vehicles. Once the amount of emissions per day is known, the next step is to calculate the amount of vegetation needed based on the type of plant sample, with the following equation:

$$\text{Jumlah Vegetasi yang dibutuhkan} = \frac{\text{Jumlah emisi per hari}}{\text{Kapasitas jerapan debu per tanaman per hari}} \quad (5)$$

Meanwhile, the effectiveness of the green belt in reducing noise was measured using a Sound Pressure Level (SPL) tool and recorded SPL values at each distance of 0, 10, 20, 30, 50 and 70 meters from the road three times. Measurements were carried out in vegetated areas and open/non-vegetated areas. The SPL values obtained at each distance were then analyzed using a simple linear regression equation in statistics to determine the relationship between distance from the road and the SPL values obtained. In addition, differences in results between vegetated and non-vegetated areas were also studied.

3. Results and Discussion

3.1 Vegetation Capacity to Absorb Particle Pollutants

The trees sampled in this observation included Mango (*Mangifera indica*), Kaya (*Khaya anthotheca*), and Saga (*Adenanthera pavonia*). Three different samples were taken from each species. At this stage, leaf samples were collected from the three selected tree species. The leaf shape differed between trees M, K, and S, as shown in Figure 1. Dust absorption capacity was obtained from the gravimetric method carried out within a 2-day interval from the day the observation was carried out.

Figure 1Leaf shape of each observed sample (from left to right, leaves of Mango, Kaya and Saga trees)

The obtained data were then applied to equation 1 to determine the leaf capacity to absorb particulate pollutants (J). The J values for each sample are presented in Table 1 below. Furthermore, Table 2 shows the leaf surface area data for each sample plant.

Table 1Leaf Capacity to Absorb Dust Particle Pollutants

Plant	P0 (g)	P1 (g)	L (m ^{2})	J (g/m ^{2})	Ep Per Day (g/m ^{2})
Mangifera indica	62.9	63.0	0.025	3,935	0.531
	63.2	63.4	0.025	8,002	
	62.4	62.5	0.025	3,933	
Khaya anthotheca	61.2	61.3	0.053	1,900	0.212
	62.6	62.7	0.038	2,619	
	62.0	62.1	0.055	1,832	
Adenanthera pavonia	62.3	62.4	0.071	1,408	0.224

	61.6	61.7	0.116	0.865
	61.9	62.1	0.045	4,451

Source: Primary Data After Processing (2018)

The data on the capacity of 10 g of leaves to absorb particulate pollutants was then used to calculate the overall capacity of the tree to absorb pollutants. Variables affecting this calculation include crown shape and crown area. Based on the results, wider leaf size affects the total surface area for absorption. The larger the surface area, the greater the number of particles that can be absorbed [9]. Plants with very large leaves can act as effective pollutant capture devices.[18]

Table 2Leaf Surface Area Data

Tree Name	Leaf Area (m^2)		
	Test 1	Test 2	Test 3
Mango	0.025	0.025	0.025
Rich	0.053	0.038	0.055
Saga	0.071	0.116	0.045

Source: Primary Data After Processing (2018)

The results of the dust absorption capacity calculation were obtained from the dust weight data divided by the leaf surface area. The three plant samples have different canopy areas, therefore each plant has a different dust absorption capacity. Based on the results of observations and calculations that have been carried out, it is known that the plant with the highest dust absorption capacity is the Mango Tree (*Mangifera indica*) which is 0.531 g/m^2. Meanwhile, the lowest dust absorption capacity is the Kaya Tree (*Khaya anthotheca*) which is 0.212 g/m^2. The results obtained are the average results divided by 10 days with the assumption that the dust contained in the sample leaves was already present before sampling. Furthermore, to see the dust absorption capacity of the trees can be seen in table 3

Table 3Capacity to Absorb Dust Pollutants

Tree Name	Lt (m^2)	Dust Absorption (g/m^2)	Pj (g)
Mango	205,146	0.531	108 , 936
Rich	104,667	0.212	22 . 159
Saga	150,720	0.224	33 , 777

Source: Primary Data After Processing (2018)

Mango trees have a *dome- shaped* and dense crown (dense leaf mass). In addition, they have the criteria of embossed leaf veins and a rough leaf surface. Therefore, mango trees are very effective in absorbing pollutant particles compared to Kaya and Saga trees, which have thinner leaves but smoother leaf surfaces and no embossed leaf veins. The effectiveness of green belts in absorbing pollution and reducing noise depends not only on optimal plant height, but also on the selection of species with denser canopies. (Hashad et al., 2023).Leaf thickness is very effective in absorbing dust (adsorption). The thicker the leaves, the leaf absorption (absorption) decreases. Mangoes have thicker leaves compared to Kaya and Saga leaves. In addition, the specific gravity of leaves is also effective in absorbing dust. The higher the specific gravity, the lower the leaf absorption.(Xing et al., 2019).

In laboratory observations, mango leaves have a higher specific gravity compared to Saga and Kaya. However, in terms of absorption of NO2 gas particles , Saga trees are more effective than Mango trees. Mango plants (*Mangifera indica*) can be used as bioindicators of air pollution, because they have a high absorption capacity to accumulate carbon dioxide. According to Mutaqin et al., (2016)a study, mangoes can absorb 1,247 kg of CO2 per day. This shows that mango plants can accumulate carbon dioxide in very large quantities. Furthermore, Samsoedin *et al.,* 2015, mangoes are one of the groups of plants that are effective in absorbing Pb (lead) contained in dust from motor vehicle exhaust. Vegetation that has a high LAD provides a larger surface area for particles to settle, so the deposition process is more effective than vegetation with a low LAD.(Hashad et al., 2023).

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Mango (*Mangifera indica*) Kaya (*Khaya anthotheca*) Saga (*Adenanthera pavonia*)

Figure 2Comparison of remaining particulates after the oven

Table 4the Number of Vehicles per Day

No	Vehicle Type	Number of Vehicles per Day
1	Car	28,320
2	Buses and trucks	3,072
3	Motor	125,376

Table 5Amount of Road Dust Particle Emissions

Vehicle Type	Number of Vehicles	Particle emission coefficient (g/km)	Emissions per Day (g /km)
Gas	36,678	0.22	8,069.16
Solar	3,072	1.28	3,932.16
Total			12,001.32

Source: Primary Data After Processing (2018)

Daily Emissions at the Arboretum

$$\text{Jumlah Emisi}: \frac{288.50\ m}{1000\ m} \times 12.001{,}32\ \text{g/km}$$
$$\text{Jumlah Emisi}: 0.2885\ km \times 12.001{,}32\ \text{g/km}$$
$$= 3.462{,}38\ \text{g}$$

The daily emissions at the Landscape Arboretum are determined by the type of fuel used by motor vehicles. Based on fuel usage, motorcycles and cars are gasoline users, while buses and trucks are diesel users. To simplify the calculation of daily emissions for gasoline, an average was applied to cars and motorcycles, with 15 motorcycles being considered equal to 1 car. This resulted in a daily emission data of 3,462.38 grams at the Landscape Arboretum. Based on the daily emissions obtained, the amount of vegetation needed to absorb particle emissions was calculated as shown in Table 6.

Table 6of Vegetation Required

Species	Amount of Dust Emission per Day (g)	Dust Absorption Percentage (%)	Tree Dust Absorption Capacity (g)	Amount Required
Mango	3,462.38	70	108 , 936	22
Rich	3,462.38	15	22 . 159	23
Saga	3,462.38	15	33 , 777	15
Total		100	164,872	60

Source: Primary Data After Processing (2018)

The amount of vegetation planned as a green belt of the IPB Landscape Arboretum is based on the capacity of the vegetation to absorb all dust particle emissions spread in the first row of plants in the arboretum. The percentage of particle absorption by the mango species (*Mangifera indica*) is planned at 70% of the total daily particle emissions because it has the largest dust absorption capacity, while kaya (*Khaya anthotheca*), and saga (*Adenanthera pavonina*) are each planned at 15% of the total daily dust particle emissions. Table 7 shows the amount of vegetation needed to be able to absorb all daily dust particle emissions. Based on the table, it can be concluded that 60 trees are needed to be able to absorb dust particles per day in the Landscape Arboretum. Dense vegetation with a high LAI value is more effective in reducing pollutants because it increases the deposition and spread of pollutants downwind in the green belt [21]. Plants can be quite effective noise absorbers, especially for high frequency sounds [22]. If planted on the side of the road, the placement method can be more optimal if the

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plant is placed lower facing the sound source and higher facing the listener, so that in addition to absorbing sound, the plant can also reflect noise upwards.

Table 7Adsorbed Dust Emissions and Percentage of Total Emissions per Day

Species	Dust Absorption Percentage (%)	Area (m^2)	Planting Distance (m)	Number of Trees	Adsorbed Dust Emission (g)
Mango	70	2,019.5	10x10	20	2,178,721
Rich	15	432.75	5x5	17	376,717
Saga	15	432.5	5x5	17	574,208
Total	100	2885	[redacted]	54	3,129,646
Percentage of absorbed dust emissions to total emissions per day					90%

Source: Primary Data After Processing (2018)

The area of the Landscape Arboretum used in this calculation is 2,885 m^2 is the length of the arboretum 288.5 meters multiplied by 10 meters which is assumed to be the closest green belt distance from the highway, so that the results of the number of trees in this practicum are used for planting one outer row in the Landscape Arboretum close to the source of dust particle emissions. With a planting distance of 10x10 m for mango, the number of trees is 20 trees, and for kaya and saga planting distances used 5x5 m and the number of trees of each species is 17 trees. By planting 54 trees on the front path in the Landscape Arboretum, it can absorb dust particles as much as 90% of the total emissions per day.

3.2 Effectiveness of Green Belt in Reducing Noise

Observations were carried out at different locations, namely on *the green belt* containing vegetation (near the fence area to the arboretum) and land without vegetation (near the fence area to near the GWW Building) as comparative data (control).

Table 8Noise measurement data using an SPL meter

Distance (m)	Non-Vegetated Area (dB)	Area With Vegetation (dB)
0	66.9	74.3
10	64.5	60.7
20	62.5	58.7
30	59.8	57.3
50	58.5	55.5
70	56.7	55.0

Source: Primary Data After Processing (2018)

Based on the data from noise measurement observations using SPL (*Sound Pressure Level*), it can be seen that the further the measurement distance from the sound source, the lower the noise level. Noise observations on land with vegetation were not carried out at the same time as land without vegetation (control), so the noise level that occurs will not be the same at different times depending on the noise source that passes through the highway. However, based on observations, land with vegetation is more effective in reducing noise compared to land without vegetation, this can be seen from the decrease in noise levels on land with vegetation that is greater than land without vegetation.

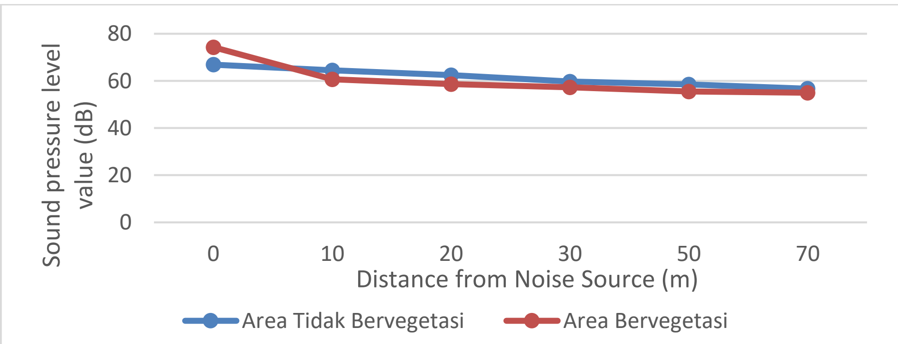

Figure 3Noise Levels in Non-Vegetated and Vegetated Areas

Based on the graph above, it can be seen that the noise level in the vegetated area is lower than in the unvegetated area. Meanwhile, at point 0 m, the vegetated area is noisier because it is located on the side of Jalan Raya Dramaga.

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[17]Vegetation is used as an alternative noise reduction agent. environmentally friendly noise, providing beauty from a visual aspect, capable of absorbs and dissipates sound energy. Noise reduction by vegetation is influenced by the type of vegetation, the level of vegetation density, and the planting combination. Vegetation type is related to the thickness and flexibility of the leaves, which also play a role in reducing noise. Vegetation density is related to the dense leaf mass of vegetation in the form of trees or shrubs. Plants that are tall, wide, and dense enough can reduce noise levels, the effectiveness of which depends on the density of vegetation and leaf density. Leaf density is related to the area of the sound barrier. However, the vegetation planting is not evenly distributed, so its reduction ability is low. Effective noise-reducing plants can reduce noise levels by 10-15 dBA.

These findings demonstrate the important role of plants in reducing air and noise pollution. *Green belt vegetation* consists of several layers of plants, such as tall trees, shrubs, and ground cover, which are able to absorb, reflect, and dampen sound through diffraction, absorption, and reflection mechanisms. Research by [23]shows that vegetation with dense canopies and layers is more effective at absorbing sound due to its ability to better block and absorb acoustic energy. They also further found that vegetation can reduce noise by 6–12 decibels at a distance of 20 meters from the noise source. In line with these findings Chiarini 2020 the greater the distance from the noise source, the higher the level of noise reduction, with a distance of 10 m being set as the minimum limit for an effective green belt.

Furthermore, other research supports these findings, showing that the type and thickness of vegetation play a significant role in sound absorption. Trees with thick, wide leaves are better at dampening noise due to their higher sound absorption capacity [24]. Vegetation can also break up sound waves and scatter them in various directions, thereby reducing the intensity of noise in areas farther from the source. Another study [25]revealed other factors that influence the effectiveness of green belts in absorbing sound, namely humidity levels and soil type.

Some recommendations that urban planners need to consider to improve air quality in locations with high levels of traffic pollution are that urban planners need to consider the rate of vegetation growth and its maintenance so that they can actively maintain the green belt to an ideal height and achieve optimal post-planting pollutant reduction. [10]

4. Conclusion

The plant with the highest dust absorption capacity is the Mango Tree (Mangifera indica) which is 0.531 g/m2. Then the second highest is the Saga Tree (*Adenanthera pavonina*) at 0.224 g/m2. While the lowest dust absorption capacity is the Kaya Tree (*Khaya anthotheca*) which is 0.212 g/m2. The effectiveness of noise reduction by vegetation is influenced by the type of vegetation, the level of vegetation density, and the combination of planting. The results of measurements using an SPL meter show that noise levels in vegetated areas are lower than in areas without vegetation. The ability of plants to absorb and accumulate pollutants is influenced by the morphological characteristics of the leaves, such as: size, shape, and texture of the leaves. In addition, plant growth patterns are also very important to consider when determining vegetation on the roadside to ensure that the plants are maintained through maintenance and pruning to achieve the appropriate barrier height to reduce air pollution and reduce noise effectively. In addition to the type of plants to obtain optimal effectiveness of green belts in absorbing pollution and reducing noise, city planners need to consider the growth rate of vegetation, plant structure, and maintenance techniques so that they can actively maintain green belts to an ideal height and achieve optimal post-planting pollutant reduction.

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