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Roadside Tree Development Strategies for Air Quality Improvement and Thermal Comfort in Ambon City, Maluku Province

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Abstract

Due to increasing population and vehicle numbers, air pollution and rising temperatures pose significant challenges for cities worldwide. These issues have been shown to impact the health of road users and the surrounding community. Roadside trees offer a potential solution to mitigate air pollution and temperature increase. However, strategic planning is necessary to maximize their benefits. Therefore, this research aims to formulate development strategies for roadside trees to improve air quality and thermal comfort for road users in Ambon City, Maluku Province. The research findings indicate that: firstly, trees should be planted with smaller diameters to maintain effective sidewalk width; secondly, periodic and regular thinning is necessary for densely foliated shade trees; thirdly, the spacing between tree planting points should be carefully considered to avoid large gaps between trees; fourthly, trees should not be planted too close to the road or in the middle of sidewalks to avoid obstructing road users and damaging infrastructure. One recommended tree species is mimusops elengi, which has non-disruptive root systems, provides extensive shade, and acts as a pollution and noise absorber while also serving as a windbreaker.

Keywords: *Roadside Trees, Air Pollution, Thermal Comfort.*

1. Introduction

Pollution and temperature increase are challenges faced by almost all cities worldwide. (Ulpiani, 2021). The pollution level in urban areas is directly proportional to the high traffic congestion experienced in the city. (Nadrian et al., 2020). The increase in population, high motor vehicle ownership, and limited road infrastructure due to land use density are the primary causes of congestion in urban areas. (Mohammed Almatar, 2022). The emission of gases released by vehicles taking a road segment in the form of carbon monoxide (CO), carbon dioxide (CO2), volatile organic compounds (VOCs), hydrocarbons (HC), nitrogen oxides (NOX), sulfur dioxide (SO2), PM10, and methane (CH4), has significant implications for human health. (Hulagu & Celikoglu, 2021). Several diseases caused by air pollution include cardiovascular and respiratory

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conditions, mental and behavioral disorders, eye diseases, digestive system disorders, and musculoskeletal disorders. (Szyszkowicz, 2022).

A study conducted in India indicated that in 2019, approximately 1.67 million people died due to air pollution, with economic losses due to mortality and morbidity amounting to 28.8 billion dollars and 8.0 billion dollars, respectively.(Pandey et al., 2021). The high mortality rate becomes a particular concern for a country that needs to be addressed and improved.

The impacts of air pollution can be minimized by planting trees or vegetation along road segments. The presence of roadside trees along the roadside has been proven to reduce air pollution levels. (Bandara & Dissanayake, 2021; Mukhopadhyay et al., 2021; Zhang et al., 2020; Zheng et al., 2021). This phenomenon can occur because trees function as filters and absorbers of pollutants or harmful emissions through mechanisms such as diffusion, interception, sedimentation, or a combination of these three mechanisms. (Zhang et al., 2020).

In addition to serving as a means to mitigate vehicle emissions, using roadside trees along roadways lowers temperatures and provides moisture, enhancing the microclimate and comfort for road users and the surrounding community, particularly during the dry season. (Cai et al., 2022; Cimburova & Berghauser Pont, 2021; Esperon-Rodriguez et al., 2021).

The trees or clusters of trees along the roadside serve as canopies beneficial in obstructing, reflecting, and absorbing solar radiation. (Cai et al., 2022). Pedestrians will experience greater comfort engaging in activities within greener areas compared to vegetation-free areas, thereby promoting increased pedestrian activity. (Cui et al., 2022; H. Liu et al., 2022).

This is crucial because temperature significantly influences walking activities in tropical regions with high daytime temperatures, such as Indonesia. (H. Liu et al., 2022). In general, increasing physical activities such as walking improves public health and impacts a region's economic development. (Kunaratnam et al., 2022).

Considering the significance of roadside trees, as mentioned previously, it is imperative to strategically plan and efficiently implement policies regarding their availability. The purpose is to attain optimal benefits for the health of the population residing in urban areas.

Ambon City, the capital of Maluku Province, is one of the cities located in the eastern part of Indonesia. Ambon City is not exempt from the two aforementioned issues. The increase in the number of vehicles and high population density contribute to congestion at several points in Ambon City, which has the potential to degrade air quality. In addition, the tropical climate leads to high temperatures on the road surface and its surrounding environment. Considering these factors, it is important to conduct research to formulate 'Roadside Tree Development Strategies for Air Quality Improvement and Thermal Comfort in Ambon City, Maluku Province. To address these objectives, it is necessary to undertake (1) monitoring of ambient air pollution levels, (2) evaluation of the roadside tree conditions, and (3) understanding of the public perception of air quality conditions and thermal comfort perception.

2. METHODS

2.1 Research Domain

Ambon City is located on Ambon Island, which is geographically situated in the Maluku Islands and is part of the Unitary State of the Republic of Indonesia. Ambon City is the largest city in Maluku Province and serves as the capital city of Maluku Province. The land area of Ambon City spans approximately 359.45 square kilometers, accommodating a population of 500,000 individuals. The air temperature in Ambon City is generally considered hot, with the lowest, average, and highest temperatures recorded in 2020 being 22.9°C, 27°C, and 33.9°C, respectively (BPS Ambon City, 2021). The number of vehicles in Ambon City has increased from 63,803 vehicles in 2019 to 105,499 in 2020, representing a 65% increase.

This research was conducted on two road segments in Ambon City: Pattimura Street and Diponegoro Street. The selection of these two road segments was determined using the purposive sampling method, considering several factors, including (1) similarity in land use characteristics, (2) similarity in vehicle volume characteristics, and (3) differences in density levels and vegetation density. In order to address the objectives of this research, the analysis employed the methods of documentation and descriptive statistics.

2.2 Data on air quality and temperature.

In this research, air quality and temperature data were collected through on-site surveys and obtained from the 2021 Regional Planning and Development Agency of Ambon City. The field survey for collecting air quality and temperature data on Pattimura Street and Diponegoro Street was conducted by the research team in collaboration with the Ambon Health and Disease Control Technical Center (BTKLPP Ambon). The air quality and temperature data were collected on the same day, specifically November 4, 2011. For Pattimura Street, the data was collected from 12:00 to 13:00 WIT under cloudy weather conditions, while for Diponegoro Street, the data was collected from 14:00 to 15:00 WIT under clear weather conditions. The air quality parameters measured were Nitrite (NO2), Sulfur Dioxide (SO2), Ammonia (NH3), and Ozone (O3). The ambient air measurement locations selected for this research follow the guidelines outlined in the Indonesian National Standard (SNI) 19-7119.9-2005, which pertains to determining sampling locations for roadside air quality monitoring. Figure 1 and Figure 2 illustrate the distance of the sampling points from the road sections and the instruments used for collecting ambient air quality data, while Table 1 provides information on the measured ambient air parameters and the testing methods employed as measurement guidelines.

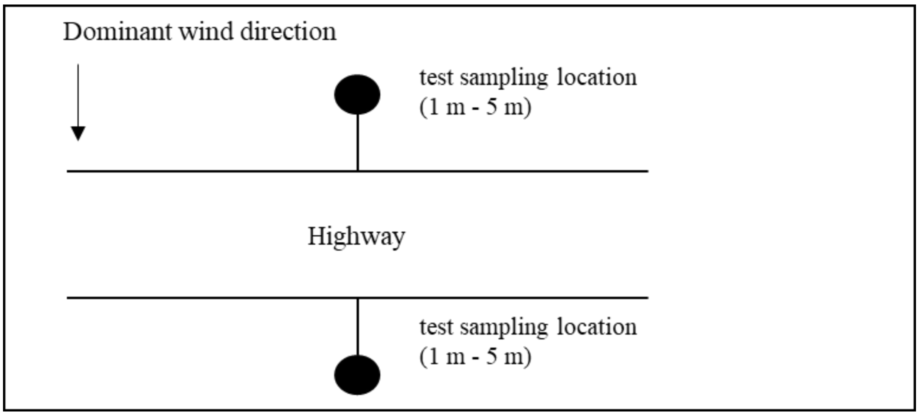

Figure 1. Determination of Roadside Air Quality Monitoring Locations

Figure 2. Air Sampler Impinger

Table 1. Ambient Air Parameters and Testing Methods/Guidelines

No	Parameter	Methods/Guidelines
1	NO_2	SNI 7119-2:2017
2	SO_2	SNI 7119-7:2017
3	NH3	SNI 7119-8:2017
4	O_3	SNI 7119-9:2017

2.3 Vegetation Data

The vegetation data were collected through field surveys along Pattimura Street and Diponegoro Street. The vegetation data collection utilized two methods, namely the census method and the documentation method. The census method was employed to determine the vegetation types, composition, and density. In contrast, the documentation method was used to record the existing vegetation condition in relation to its impact on facilities such as sidewalks and road infrastructure, as well as any misplacement of tree planting.

In addition to the field survey data described above, this research obtained vegetation condition data in Ambon City from the 2021 Regional Development Planning Board of Ambon City Research and Development.

2.4 Traffic Volume Data

Traffic volume data is necessary to determine the number and types of vehicles taking Pattimura Street and Diponegoro Street. The collection of traffic volume data was conducted simultaneously with the collection of ambient air quality data. The guidelines used were the manual traffic counting survey guidelines with the code Pd. T-19-2004-B. The data was collected manually by 8 surveyors, with 4 assigned to Pattimura Street and 4 to Diponegoro Street.

The traffic counting data collection was conducted on a working day, specifically Friday, November 4, 2022. The data collection was conducted on working days due to the land use characteristics of the research area, which comprise office, educational, and commercial zones. These areas exhibit higher traffic volume during weekdays compared to weekends. The data collection started from 07:00 AM until 07:00 PM for both selected road sections. However, for data analysis, the vehicle volume data presented correspond only to the same time period as the air quality data collection.

2.5 Public Perception Data

The collection of public perception data aims to determine the level of satisfaction and comfort of pedestrians or individuals engaging in activities along Pattimura Street and Diponegoro Street regarding air pollution levels and exposure to sunlight radiation. The technique for collecting public perception data involved using a questionnaire consisting of closed-ended questions with a 5-point Likert scale. The questionnaires were distributed to the public or road users engaged in activities along both road sections.

The selection of respondents in this research utilized the accidental sampling technique, where respondents who coincidentally encountered the researchers and were engaged in activities around Pattimura Street and Diponegoro Street road sections were asked for their willingness to participate in filling out the questionnaire. The data obtained from the questionnaires are considered ordinal data, and therefore, they were analyzed using descriptive statistical methods.

3. RESULTS

3.1 Air pollution and temperature condition

The field survey for collecting air quality and temperature data on Pattimura Street and Diponegoro Street was conducted by the research team in collaboration with the Ambon Class II Health and Disease Control Technical Office (BTKLPP). The air quality and temperature data were collected on the same day. For Pattimura Street, the data was collected from 12:00 to 13:00 WIT under cloudy weather conditions, while for Diponegoro Street, the data was collected from 14:00 to 15:00 WIT under clear weather conditions. The air quality parameters measured were Nitrite (NO2), Sulfur Dioxide (SO2), Ammonia (NH3), and Ozone (O3).

As is well known, one of the sources of air pollution in Ambon City originates from the transportation sector. Thus, the collection of air quality data is also accompanied by the collection of data on the number of vehicles taking Pattimura Street and Diponegoro Street. Table 2 presents the results of ambient air testing, temperature, and volume of vehicle traffic on Pattimura Street and Diponegoro Street, respectively.

Table 2. The Results of Ambient Air Testing and Temperature on Pattimura Street.

Pattimura Street					
No	Parameter	Unit	Test /Survey Result	Limit Detection	Quality standard
1	NO_2	μg/Nm^3	69.422	5.22	200
2	SO_2	μg/Nm^3	< 32.18	32.18	150
3	NH3	Ppm	< 0.04	0.04	2
4	O_3	μg/Nm^3	< 17.16	17.16	150
5	Air temperature	°C	32		
6	Vehicle Volume	Vehicle/hour	2303		
Diponegoro Street					
No	Parameter	Unit	Test /Survey Result	Limit Detection	Quality standard
1	NO_2	μg/Nm^3	79.417	5.22	200
2	SO_2	μg/Nm^3	< 32.18	32.18	150
3	NH3	Ppm	< 0.04	0.04	2
4	O_3	μg/Nm^3	< 17.16	17.16	150
5	Air temperature	°C	33.8		
6	Vehicle Volume	Vehicle/hour	2392		

Source: Calculation Results (2022)

Based on Table 2, with a similar volume of traffic, it can be concluded that the air quality on Pattimura Street and Diponegoro Street, based on parameters such as Nitrite (NO_2), Sulfur Dioxide (SO_2), Ammonia (NH_3), and Ozone (O_3), is classified as good and with minimal pollutants. The threshold values for each parameter are lower than the detection limit, except for the NO_2 pollutant, with a parameter value of 69.442 for Pattimura Street and 79.417 for Diponegoro Street. However, the parameter value for the pollutant NO_2 falls into the low category. These findings are consistent with the monitoring results of the 2021 Regional Development Planning Agency, Research and Development of Ambon City.

The temperature data on Pattimura Street from 12:00 to 13:00 WIT was recorded at 32 °C, while the temperature on Diponegoro Street from 14:00 to 15:00 WIT was recorded at 33.8 °C. The high air temperature during the daytime causes discomfort for road users, especially pedestrians taking both streets. Based on the recorded data from the Meteorology, Climatology, and Geophysics Agency (BMKG) of Ambon City from September to November 2021, there was an increase in the annual average temperature from 29.25 °C to 33.00 °C. There is a need for serious efforts from the Ambon City Government in the development of green open spaces to mitigate the increasing trend of air temperature.

3.2 Vegetation condition

3.2.1 Types of Vegetation

Based on the research conducted on two roadside trees in Ambon City, namely Diponegoro Street and Pattimura Street, the types of vegetation planted by the Sanitation and Landscaping Office of Ambon City are identified. The research findings indicate that there are 12 types of shade tree vegetation that can grow quickly and have strong resilience. However, some shade tree vegetation may be prone to breakage if the canopy is dense, especially under unfavorable weather conditions. To address this issue, thinning practices are implemented as a preventive measure. The types of vegetation found along the roadside trees can be observed in Table 3.

Table 3. Types of Vegetation along the roadside trees of Pattimura Street and Diponegoro Street

No	Local Name	Latin name	Total number	(%)
1	Mahoni daun Kecil	Switenia mahagoni	21	14.58
2	Mahoni daun besar	Switenia macrophily	5	3.47
3	Lenggua	Pterocarpus indicus	41	28.47
4	Trembesi	Samanea saman	26	18.05
5	Tanjung	Mimusops elegy	15	10.41
6	Beringin	Ficus benjamina	7	4.86
7	Nangka	Artocarpus heterophillus	4	2.7
8	Palem Raja	Oreodoxa regia	11	7.6
9	Mangga	Mangifera indica	2	1.3
10	Bunga Kupu - kupu	Bauhinia purpurea	1	0.69
11	Glodokan /Janda Merana	Polyanthia longifoli	8	5.55
12	Kirai payung	Filicium decipient	3	2.08

Source: Calculation Results (2022)

Table 3 shows that the planted vegetation is dominated by Pterocarpus indicus (locally known as lenggua), accounting for 28.47% of the total identified vegetation types. It is followed by Samanea saman (trembesi) at 18.05%, Swietenia mahagoni (mahoni daun kecil) at 14.58%, and Mimusops elengi (tanjung) at 10.41%. The vegetation planted by the Sanitation and Landscaping Office of Ambon City consists of fast-growing species with aesthetic value and sufficient strength.

3.2.2 The existing condition of vegetation in relation to road infrastructure damage

The existing condition of roadside trees was obtained through field surveys conducted by the research team, documenting vegetation or trees that cause damage to surrounding infrastructure or discomfort to users in the two research locations. The existing condition of roadside trees on Pattimura Street and Diponegoro Street can be seen in Table 4 and Table 5, respectively.

Table 4. The Existing Condition of Vegetation on Diponegoro Street

No	Documentation	Type of Damage
1		Damage to sidewalk facilities caused by tree roots.
2		A significant gap or distance between tree planting points.
3		The trees are in the middle of pedestrian facilities, with large-diameter trunks obstructing pedestrians.

No	Documentation	Type of Damage
4		The planting distance is too close to the road.

Source: Research Documentation (2022)

Table 5. Existing Condition of Vegetation on Pattimura Street

No	Documentation	Type of Damage
1		Damage to sidewalk facilities caused by tree roots.
2		The type of tree canopy is vertically shaped, thus not providing extensive shade.

Source: Research Documentation (2022)

Tables 4 and 5 present the issues caused by trees/vegetation along the roadside trees of Diponegoro Street and Pattimura Street. The tree planting along Diponegoro Street is not well organized compared to Pattimura Street. This can be observed from the irregular spacing between tree planting points along Diponegoro Street, the proximity of tree planting to the roadside, and the placement of trees in the middle of the sidewalk facility. In general, the level of damage caused by tree roots on Pattimura Street is less significant compared to Diponegoro Street. However, several trees on Pattimura Street with vertical canopy shapes still do not provide extensive shade.

3.3 Public Perception of Air Pollution and Temperature

The number of respondents who filled out the questionnaire amounted to 99 individuals, with 51 respondents on Pattimura Street and 48 on Diponegoro Street. Diponegoro. The data collection was conducted during the daytime, approximately from 11:00 AM to 2:00 PM local time. Table 6 presents the characteristics of the participants who completed the questionnaire in this research.

Table 6. Participant Characteristics

Personal Characteristics		Percentage (%)
Gender	Male	40
	Female	60
Age	≤15	11
	15 to 30	71
	30 to 50	14
	≥ 50	4
Occupation	Civil Servant	4
	Private Employee	4
	Student	78
	Unemployed	5
	Housewife	1
	Others	8
Primary Purpose of Travel	Shops	6
	Office	4
	School	78
	Market	3
	Meet people	4
	Others	4
The frequency of taking the road	Every day	82
	Several times a week	15
	Several times a month	2
	Seldom	1
	First time	0

Source: Calculation Results (2022)

From the questionnaire analysis results, as shown in Table 6, it can be observed that the participants were predominantly female, with 59 individuals (60%). The age group between 15 and 30 comprised 70 individuals (71%), and 77 participants (78%) were high school students. Furthermore, the most common purpose among the respondents was for educational purposes, with 78 individuals (79%) and 81 individuals (82%) reporting taking the research area on a daily basis.

The results of the descriptive statistical analysis regarding the public perception of air pollution and temperature comfort using a bipolar scale on Pattimura Street and Diponegoro Street are presented in Table 7 and Table 8, respectively.

Table 7. The results of the analysis of public perception regarding air pollution

Question	Strongly Agree (%)	Agree (%)	Neutral (%)	Disagree (%)	Strongly Disagree (%)	Perception Index (%)	Perception
Is the air in this area polluted?	0[a] 2[b] 1[c]	21[a] 43[b] 32[c]	60[a] 39[b] 49[c]	17[a] 16[b] 16[c]	2[a] 0[b] 1[c]	60[a] 66[b] 63[c]	Agree Agree Agree
In your opinion, is air pollution in this area caused by vehicles taking the streets?	4[a] 12[b] 8[c]	27[a] 47[b] 37[c]	48[a] 25[b] 36[c]	19[a] 14[b] 16[c]	2[a] 2[b] 2[c]	63[a] 71[b] 67[c]	Agree Agree Agree
In your opinion, can air pollution cause health problems?	29[a] 53[b] 41[c]	52[a] 35[b] 43[c]	17[a] 8[b] 12[c]	0[a] 4[b] 2[c]	2[a] 0[b] 1[c]	81[a] 87[b] 84[c]	Strongly Agree Strongly Agree Strongly Agree
In your opinion, can planting trees alongside roads reduce air pollution levels	21[a] 33[b] 27[c]	56[a] 47[b] 52[c]	19[a] 10[b] 14[c]	4[a] 6[b] 5[c]	0[a] 4[b] 2[c]	79[a] 80[b] 79[c]	Agree Strongly Agree Agree

Note: a represents the analysis results for Diponegoro Street; b represents the analysis results for Pattimura Street; c represents the total analysis results.

The analysis results pertaining to public perception of air pollution conditions, as depicted in Table 7, indicate that: firstly, both Diponegoro Street and Pattimura Street have been subjected to air pollution. This is evident from the 60% and 66% perception index values obtained for Diponegoro Street and Pattimura Street, respectively. Secondly, the respondents said air pollution in the studied area is attributed to the vehicles taking the streets. This is evident from the perception index values for Diponegoro Street, which amounted to 63%, and Pattimura Street, which amounted to 71%. Thirdly, the respondents strongly agreed that air pollution could have adverse effects on health. The perception index values for Diponegoro Street were found to be 81%, while for Pattimura Street, the value was 87%. Fourthly, the respondents expressed the belief that planting trees alongside the road can effectively mitigate the levels of air pollution. The index values for Diponegoro Street were determined to be 79%, while for Pattimura Street, the value was 80%.

Table 8. The Results of the Analysis on Public Perception Regarding Temperature Comfort

Question	Response					Index Perception (%)	Perception (%)
How long have you been engaging in activities in this area?	> 90 minutes (%)	60 to 90 minutes (%)	30 to 60 minutes (%)	15 to 30 minutes (%)	< 15 minutes (%)		
	38[a] 35[b] 36[c]	6[a] 4[b] 5[c]	15[a] 10[b] 12[c]	23[a] 29[b] 26[c]	19[a] 22[b] 20[c]	64[a] 60[b] 62[c]	
How would you describe the sensation of temperature you are currently experiencing?	Very hot (%)	Hot (%)	Neutral (%)	Cold (%)	Very cold (%)		
	15[a] 16[b] 15[c]	50[a] 55[b] 43[c]	35[a] 24[b] 29[c]	0[a] 6[b] 3[c]	0[a] 0[b] 0[c]	76[a] 76[b] 76[c]	Hot Hot Hot
How would you describe the sunlight exposure you are currently experiencing?	Very high (%)	High (%)	Neutral (%)	Low (%)	Very low (%)		
	4[a] 0[b] 2[c]	31[a] 22[b] 26[c]	48[a] 63[b] 56[c]	13[a] 16[b] 14[c]	4[a] 0[b] 2[c]	70[a] 72[b] 71[c]	High High High
In your opinion, can planting trees along the roadside improve comfort due to high-temperature conditions?	Strongly Agree (%)	Agree (%)	Neutral (%)	Disagree (%)	Strongly Disagree (%)		
	15[a] 18[b] 16[c]	48[a] 59[b] 54[c]	31[a] 18[b] 24[c]	6[a] 4[b] 5[c]	0[a] 2[b] 1[c]	74[a] 77[b] 76[c]	Agree Agree Agree

Note: a represents the analysis results for Diponegoro Street; b represents the analysis results for Pattimura Street; c represents the total analysis results.

The results of the analysis of public perception regarding temperature comfort, as shown in Table 8, indicate the following: first, respondents on Diponegoro Street and Pattimura Street; second, both on Diponegoro Street and Pattimura Street, respondents experienced a sensation of hot temperature. This is evident from the perception index of 76% on both Diponegoro Street and Pattimura Street; third, respondents perceived that the exposure to sunlight on the sections of Diponegoro Street and Pattimura Street was relatively high. This can be observed from the perception index values of 70% for Diponegoro Street and 72% for Pattimura Street; fourthly, respondents tend to agree that planting trees in intersection areas can enhance comfort, with perception index values of 74% for Diponegoro Street and 77% for Pattimura Street.

4. DISCUSSION

4.1 Findings

Generally, this research aims to develop roadside tree development strategies to enhance air quality and reduce the temperature in Ambon City, thereby improving the comfort of road users, especially pedestrians and the public engaged in activities within the road environment. For this purpose, the research was conducted by: (1) monitoring ambient air pollution levels; (2) evaluating the condition of roadside trees; (3) assessing the public perception of air quality conditions and their perception of temperature comfort. These three outcomes then serve as the basis for formulating strategies for developing roadside trees in the surveyed locations.

The findings of this research indicate the following aspects: firstly, the air quality along Pattimura Street and Diponegoro Street is classified as good and safe, as evidenced by the low levels of pollutants such as Nitrite, Sulfur Oxides, Ammonia, and Ozone; secondly, the vegetation conditions observed on both road sections are diverse, consisting of fast-growing and robust vegetation types. However, there are still several issues caused by the planted trees, such as damage to sidewalk facilities due to tree roots, significant gaps between trees, obstruction of pedestrians due to large tree trunk diameters, the proximity of tree planting points to the road, and the vertical shape of tree canopies. Thirdly, the public perception of air pollution conditions indicates a tendency that the air along both road sections assessed has been polluted, with vehicular traffic identified as the main contributor to pollution. These findings contradict the results of ambient air quality monitoring. Although public perception in evaluating air quality is subjective, it is advisable to take mitigation measures for sustainable development to reduce air pollution. The increase in the number of vehicles by 65% from 2019 to 2020 is one of the factors that need to be taken into consideration. In addition, the respondents agreed that air pollution could lead to health issues and expressed their agreement that planting trees along the roadside can reduce air pollution levels. The results of the public perception regarding temperature comfort in both research locations indicate that respondents tend to perceive a sensation of heat due to the significant exposure to sunlight. In addition, the respondents agreed that planting trees along the roadside can enhance comfort due to high-temperature conditions.

Several studies have demonstrated the benefits of roadside trees as a mitigation strategy for air pollution (Baldauf, 2017; H. S. Chen et al., 2022; X. Chen et al., 2015; Ghasemian et al., 2017; Kang & Kim, 2023; X. Liu et al., 2023; Ottosen & Kumar, 2019; Xue & Li, 2017) and how roadside trees can reduce air temperature, thus enhancing the comfort of road users.(Cai et al., 2022; Elsadek et al., 2019; Kong et al., 2017; Li et al., 2023; Mohammad et al., 2021; Park et al., 2012; Tan et al., 2017) These findings are consistent with the results of the current research.

4.2 Green belt strategies

Based on the aforementioned research findings, several factors highlight the importance and urgency of implementing roadside tree development strategies on Pattimura Street and Diponegoro Street. These factors include:

1) Some current vegetation/tree species are unsuitable for their intended purposes. This can be observed through the damage to the sidewalks and roads caused by tree roots, both on Pattimura Street and Diponegoro Street. In addition, there are also shade trees that can break if their canopy is dense, especially under unfavorable weather conditions.

2) The high temperatures during the daytime can cause discomfort for road users, especially pedestrians and individuals engaged in various activities along the surveyed road sections. This is evident from the lack of continuity in roadside trees, resulting in areas alongside the road being exposed without the protection of tree canopies.

The following are several strategies that can be implemented to maximize the roadside trees along the studied road sections:

1) Planting trees with smaller diameters is recommended to maintain the effective width of the sidewalk facilities. Furthermore, tree roots should be of taproot type as fibrous roots can damage sidewalk facilities and even the functional lane of the road. Moreover, the research findings reveal the presence of 12 types of shade tree vegetation that exhibit rapid growth and strength. However, some shade tree species are prone to breakage when their canopy becomes dense, particularly in unfavorable weather conditions. To address this issue, periodic and regular thinning practices are implemented as a precautionary measure.

2) The planting of trees or vegetation should be done continuously, taking into consideration the spacing between planting points to avoid gaps or excessive distances between trees. A large gap causes inconvenience and discomfort for individuals engaging in activities as they are not adequately protected from direct sunlight exposure. In addition to the spacing between tree planting points, it is also important to consider the distance between trees and road infrastructure and avoid planting trees in the middle of pedestrian walkways. The planting process should consider functionality, coherence, harmony, aesthetics, and safety.

Based on the issues and strategies provided, the most suitable vegetation or tree for the two researched locations is the tanjung tree (Mimusops elengi). This is because the root structure of the tanjung tree (Mimusops elengi) does not cause damage to the surrounding sidewalks, roads, or buildings. In addition, based on its functions, the tanjung tree serves as a shade provider with its wide canopy, a pollutant absorber, a noise absorber, and a windbreaker (Bina Marga, 2018).

4.3 Strength, limitations and recommendations

This research was conducted only on two road sections in Ambon City with 99 respondents. Further research should be conducted on more road sections in Ambon City with more respondents to make the roadside tree strategies more comprehensive and effective. Furthermore, the findings of this research can also serve as a reference for future development by the government of Ambon City.

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