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Assessment of the Air Pollution Tolerance Index (APTI) and Anticipated Performance Index (API) of Several Tree Species on Coal Mining Transportation Route: Case at the Air Laya Coal Mine Bukit Asam, South Sumatra, Indonesia

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ABSTRACT

Coal mining transportation activities in the Air Laya coal mine area of Bukit Asam involve the mobilization of vehicles that can potentially increase air pollution due to exhaust emissions and dust particles. This pollution negatively impacts environmental quality and the sustainability of the surrounding vegetation. To mitigate these effects, revegetation is employed as an environmental restoration strategy. This study aims to evaluate the tolerance of several tree species along the Air Laya Mine transportation route using the Air Pollution Tolerance Index (APTI) and Anticipated Performance Index (API) methods. The APTI findings revealed that the four examined tree species demonstrate varying levels of tolerance to air pollution. Chinese Albizia (*Albizia chinensis* (Osbeck) Merr.) recorded the highest APTI score and was categorized as tolerant. Earleaf Acacia (*Acacia auriculiformis* A. Cunn. Ex Benth) and Eucalyptus Tree (*Melaleuca leucadendra* (L.) L.) were classified as having moderate tolerance, while Red Sandalwood (*Pterocarpus indicus* Willd) was identified as sensitive. In terms of the API assessment, *Acacia auriculiformis* was classified as *Excellent*; *Melaleuca leucadendra* and *Albizia chinensis* were rated as *Very Good*, and *Pterocarpus indicus* was categorized as *Good*. These results suggest that species with high APTI and API scores possess significant potential for use as buffer vegetation in green transportation corridors, contributing to sustainable air pollution mitigation.

KEYWORDS: Air Pollution Tolerance Index (APTI), Anticipated Performance Index (API), Air Pollution, Mining Transportation Routes, PT Bukit Asam.

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1. INTRODUCTION

The rapid growth of the mining industry, particularly at the Air Laya Mine within the operational area of PT Bukit Asam, has had a significant impact on the environment. The Air Laya Mine is one of the oldest open-pit mining areas, spanning 7,621 hectares and remaining actively operational. One of the resulting impacts is increased air pollution resulting from mining and transportation activities. According to Juniah *et al*. (2013), coal mining activities cause air pollution. Polluted air can cause the air to become dirty or unclean, leading to public health problems.

Air pollution is the entry or introduction of substances, energy, or other components into the ambient air by human activities or natural processes, resulting in a decrease in ambient air quality to a certain level, causing the air to become less or no longer able to fulfill its intended function (Hasan and Fattah, 2020). The presence of pollutants in the air can be caused by vehicle exhaust from coal transportation activities and coal particles, which contribute to the decline in air quality (Salma, 2024). Mining vehicles and heavy equipment operating on unpaved roads are also sources of mobile air pollution, releasing gases such as N_2O, CO_2, SO_2, and coal dust particles into the atmosphere (Rahma, 2021).

Air pollution impacts plant morphology and physiology. Emissions such as CO_2, NO_x, hydrocarbons, and particulate matter (PM) can induce morphological changes, including chlorosis and necrosis. Physiologically and biochemically, these pollutants can also reduce chlorophyll pigments, carotenoids, and ascorbic acid, disrupt cell membrane permeability, and disrupt stomatal diffusion (Mehmood *et al*., 2024). Tree-like plants play a crucial role in absorbing and retaining air pollutants through their stomata and leaf surfaces. However, not all tree species have the same ability to absorb air pollution. According to Azzahro (2019), environmentally friendly air pollution control efforts can be implemented by increasing the amount of vegetation through the planting of plant species that can adapt and thrive in polluted environments, as well as possess the ability to absorb pollutant gases and trap dust particles, such as those with a dense canopy. Juswardi *et al*. (2024) conducted an Air Pollution Tolerance Index (APTI) assessment to determine the types of trees that are tolerant for use in petrochemical industrial areas. To strengthen the basis for tree selection for transportation route vegetation, an API evaluation is necessary. According to Anake *et al.* (2022), API is an advanced index that considers morphological, ecological, and socio-economic factors that can identify suitable tree species for reforestation in polluted areas.

Each plant has a different level of tolerance to air pollution. Plants can survive with varying levels of tolerance to air pollution based on criteria from the APTI assessment, which includes several components such as pH, water content, ascorbic acid, and chlorophyll. Plant tolerance to air pollution is a plant's ability to respond to environmental stressors approaching the minimum or maximum tolerance threshold of normal conditions (Salsabila, 2020). This study specifically aims to evaluate and compare the tolerance of several tree species to air pollution in the green belt area of the PT Bukit Asam Airlaya Mine using the Air Pollution Tolerance Index (APTI) and Anticipated Performance Index (API) methods, thereby identifying species most suitable for enhancing air quality in this environment.

2. MATERIALS AND METHODS

Research Site

The research was conducted on the Air Laya Mine production line (Bang Jo 6), PT Bukit Asam (PTBA) Tanjung Enim, an area with high operational vehicle traffic (Figure 1). Location determination and sampling used a purposive convenience sampling method. Each tree species was made into 3 individual sample repetitions. The selected plant species and their coordinates are presented in Table 1.

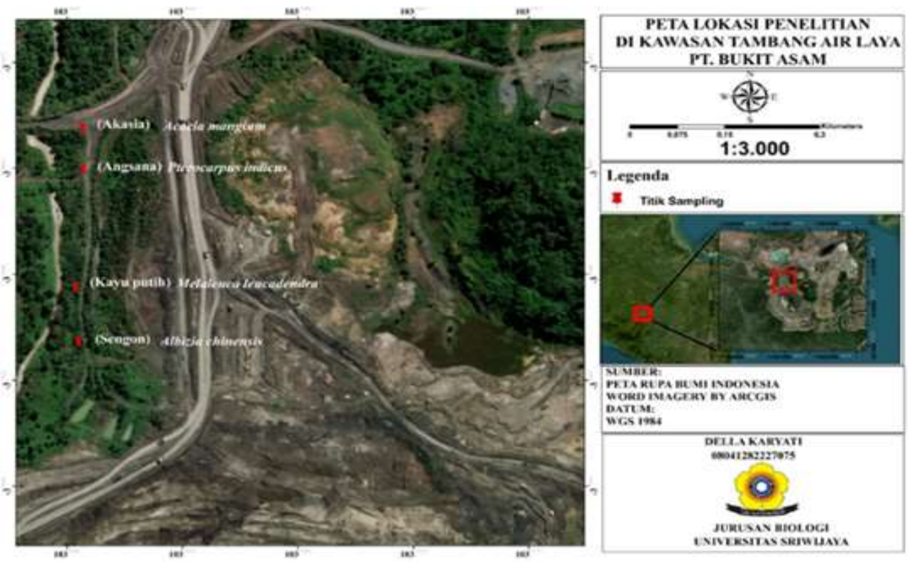

Figure 1. Map of the research location of sampling points in the Air Laya Mining Area of PT Bukit Asam

Table 1. Coordinates of sampling locations in the Air Laya Mining Area of Bukit Asam, South Sumatra

Common name	Scientific name	Coordinates
Earleaf acacia	*Acacia auriculiformis* (A.cunn. Ex Benth)	3.750016°S, 103.760452°E
Red sandalwood	*Pterocarpus indicus* Willd	3.762080°S, 103.765420°E
Eucalyptus tree	*Melaleuca leucadendra* (L.) L.	3.750015°S, 103.760452°E
Chinese albizia	*Albizia chinensis* (Osbeck) Merr	3.750023°S, 103.760450°E

Parameter Observation Procedure

Relative Water Content (RWC): Measured gravimetrically (Agbaire and Esiefarienrhe, 2010; Salsabila *et al*., 2020) using the following formula:

$$\text{Water Content (\%)} = \frac{(\text{wet weight} - \text{dry weight})}{\text{wet weight}} \times 100$$

Leaf Extract pH (pH): 200 mg of fresh leaves were homogenized in 20 ml of deionized water, centrifuged (5,000 rpm, 5 minutes), and measured using a pH meter (Dadkhah-Aghdash *et al*., 2022).

Ascorbic Acid (AsA): Measured using a spectrophotometer (wavelength 270 nm) from leaf extracts in CO_2-free distilled water. Ascorbic acid levels were calculated by comparing the sample absorbance value to a standard ascorbic acid solution using the established formula (Juswardi *et al*., 2022):

$$\text{AsA content (equivalent AsA ppm)} = \frac{\textbf{Sample Absorbance}}{\textbf{Standard Absorbance}} \times \text{Standard AsA}$$

Total Chlorophyll (TC): Extracted with 80% acetone and measured at wavelengths of 645 nm and 663 nm (Fred Chibuisi *et al*., 2014). Chlorophyll levels can be determined using the formula (Arnon, 1949) in (Robika and Sari, 2019):

$$\text{Chlorophyll a} = (12.7 \times D663 - 2.69 \times D645)$$

$$\text{Chlorophyll b} = (22.9 \times D645 - 4.68 \times D663)$$

$$\text{Total Chlorophyll} = (20.2 \times D645 + 8.02 \times 663)$$

Stomata Density (SDS): Using the epidermal print method (clear nail polish) on the abaxial surface of the leaf, observed under a microscope at 40x10 magnification. (Khoiroh *et al*., 2014). Stomatal density can be calculated using the formula from Wilmer and Fricker (1996):

$$\text{Stomatal Density (mm}^2) = \frac{\textit{Number of Stomata}}{\textit{Field of View } (1mm^2)}$$

Analysis of Air Pollution Tolerance Index (APTI):

The Air Pollution Tolerance Index (APTI) was determined using the method provided by Singh and Rao (1983) using the formula (Maheswari and Nagajoth, 2020):

$$\text{APTI} = \frac{[A(T+P)+R]}{10}$$

Information;

A: Ascorbic Acid Content (mg/g)

T: Total Chlorophyll (mg/g)

P: Leaf Extract pH

R: Relative Leaf Water Content (%)

Table 2: Air Pollution Tolerance Index (APTI) Criteria in Plants

Value of APTI	Criteria
APTI Value > Average APTI + SD	Tolerant
Average APTI < APTI Value > Average APTI + SD	Moderate
Average APTI - SD < APTI Value > Average APTI	Moderate
APTI Value < Average APTI – SD	Sensitive

Source : Liu and Ding (2008)

Analysis of Anticipated Performance Index (API)

API Calculation:

The APTI value is calculated by combining several related biological and socio-economic characteristics, including plant habitus, canopy structure, plant species, and economic value. Based on these characteristics, selected plants are assigned different values (+ or -) and scored accordingly (Maheswari and Nagajoth, 2020). The API uses the formula according to Govindaraju *et al*. (2012), as follows:

$$\textbf{API} = \frac{\textbf{Number of plant scores (+)}}{\textbf{Maximum score (16)}} \times \mathbf{100\%}$$

Table 3. Anticipated Performance Index (API) assessment parameters

Character Assessment		Assessment Pattern	Grade Given
Tolerance	APTI	12.0-16.0	+
		16.1-20.0	++
		20.1-24.0	+++
		24.1-28.0	++++
		28.1-32.0	+++++
		32.1-36.0	++++++
Biology	Plant Habits	Small	-
		Medium	+
		Large	++
	Canopy structure	Sparse/Irregular/round	-
		Dispersed/Open/semisolid	+
		Spread densely	++
	Types of Plants	Deciduous Plants	-
		Evergreen	+
	Leaf structure	Leaf Size	
		Small	-
		Medium	+
		Large	++
		Leaf Texture	
		Smooth	_
		Rough	+
		Leaf Hardness	
		Soft	-
		Hard	+
Socio-Economic	Economic Value	< 3 utility	-
		3 – 4 utility	+
		> 5 utility	++

Table 4. Anticipated Performance Index (API) table of plant species

Value	% Score	Assessment Categories
0	< 30	*Not Recommended*
1	31-40	*Very poor*
2	31-50	*Poor*
3	51-60	*Moderate*
4	61-70	*Good*
5	71-80	*Very Good*
6	81-90	*Excellent*
7	91-100	*Best*

Source: Maheswari dan Nagajoth (2020).

3. RESULTS AND DISCUSSION

Based on research on the Assessment of the Air Pollution Tolerance Index (APTI) and Anticipated Performance Index (API) of several tree species along the Air Laya coal mine transportation route in Bukit Asam, the following results were obtained.

Table 5. Biochemical Parameter for of Several Tree Species along the Air Laya Bukit Asam Coal Mine Transportation Route

Species	Ascorbic acid (eq. AsA ppm)	Total chlorophyll (mg/g)	pH leaf	Relative water content (%)
Acacia auriculiformis	37.16±12.15	0.27±0.02	5.73±0.09	63.87±2.54
Melaleuca leucadendra	41.98± 2.11	0.27±0.01	4.96±0.26	69.33±2.23

Albizia chinensis	40.37±10.31	0.29±0.02	7.18±0.12	64.40±1.65
Pterocarpus indicus	28.02± 1.40	0.29±0.03	5.67±0.84	72.13±1.17

Relative Water Content (RWC), Variations in relative water content (RWC) were found across the four species, with *P. indicus* having a higher RWC (72.13±1.17%) and *A. auriculiformis* having a lower RWC (63.87±2.54%). Despite exposure to pollutants, all species were able to maintain RWC above 60%, which, according to Yazdani *et al*. (2024), indicates a positive response and plant adaptability to polluted locations. This ability reflects the balance between water supply and loss through transpiration, where RWC is directly related to cell volume and turgidity (Rajiman *et al*., 2024). This physiological stability is likely supported by effective stomatal regulatory mechanisms and leaf anatomical structures capable of suppressing excessive water loss under environmental stress.

Leaf Extract pH, The pH values of leaf extracts ranged from neutral in *P. indicus* (7.18± 0.84) to acidic in *M. leucadendra* (4.96±0.26), reflecting the species' tolerance level to air pollution. According to the classification of Asif and Ma (2024), the pH range of 4.4 to 8.8 encompasses plants with intermediate to tolerant sensitivity. A decrease in pH toward acidic conditions, as seen in the majority of sampled species, is an indicator of stress due to sulfur dioxide (SO_2) and nitrogen oxide (NO_x) pollutants entering leaf tissue (Kazi *et al*., 2021; Mehmood *et al*., 2024). A lower pH tends to reduce photosynthetic efficiency, while a higher or neutral pH in *P. indicus* indicates greater resistance to airborne contaminants.

Ascorbic Acid Content, Analysis of ascorbic acid content showed that *M. leucadendra* (41.98±2.11ppm) had the highest antioxidant capacity, followed by *A. chinensis*, *A. auriculiformis*, and *P. indicus*. This variation reflects each species' antioxidant defense strategies to counteract oxidative stress caused by pollution (Venkatesh & Park, 2014). The high ascorbic acid content in *M. leucadendra* and *A. chinensis* indicates a more effective cellular protection mechanism, where ascorbic acid acts as a strong reducing agent to prevent oxidation (Putri *et al*., 2023). Conversely, lower values indicate a higher level of susceptibility or sensitivity to airborne pollutants at the study site.

Total Chlorophyll Content, Total chlorophyll content showed relatively uniform values among the four species, ranging from 0.265 to 0.289 mg/g, indicating that the photosynthetic system was still functioning quite well despite exposure to pollutants. Decreased chlorophyll levels often occur as a result of pigment degradation and chloroplast disruption by pollutants such as SO_2, NO_2, and particulate matter (PM2.5 and PM10) (Hamid *et al*., 2022). Although the results of this study showed lower values than those of Rizkiaditama *et al*. (2017) on *P. indicus* in industrial areas (2.610 mg/g), the stability of chlorophyll values between species indicates a sustainable photosynthetic capacity to support plant metabolism in polluted environments (Zahara *et al*., 2025).

Stomatal Density

Based on observations of leaf stomatal density, the following results were obtained:

Table 6. Stomatal Density of Several Tree Species along the Air Laya Bukit Asam Coal Mine Transportation Route

Species	Stomata Density (mm^2)
Acacia auriculiformis	422.52
Melaleuca leucadendra	393.04
Albizia chinensis	485.69
Pterocarpus indicus	120.72

As shown in Table 6, observations of stomatal density on the underside of leaves revealed differences between species. The average stomatal density in *A. chinensis* was 485.69 mm^2, *A. auriculiformis* 422.52 mm^2, and *M. leucadendra* 393.04 mm^2, all categorized as medium density. Meanwhile, *P. indicus*, with a stomatal density of 120.72 mm^2, is classified as low density, as it is below 300 mm^2.

Karubuy *et al*. (2018) stated that stomatal density can be classified into three categories: low density (<300/mm^2), medium density (300–500/mm^2), and high density (>500/mm^2). Plants with a high average stomatal density, such as *A. chinensis*, have a larger gas diffusion area, potentially absorbing greater amounts of gaseous pollutants. Conversely, plants with lower stomatal densities, such as *P. indicus*, tend to have a more limited gas exchange capacity, resulting in a relatively smaller pollutant absorption capacity. Stomatal density thus indicates a plant's ability to absorb pollutants or act as a bioindicator. According to Prithviraj and Reshmi (2025), a lower stomatal count is an adaptive mechanism to minimize the absorption of gaseous pollutants in the air.

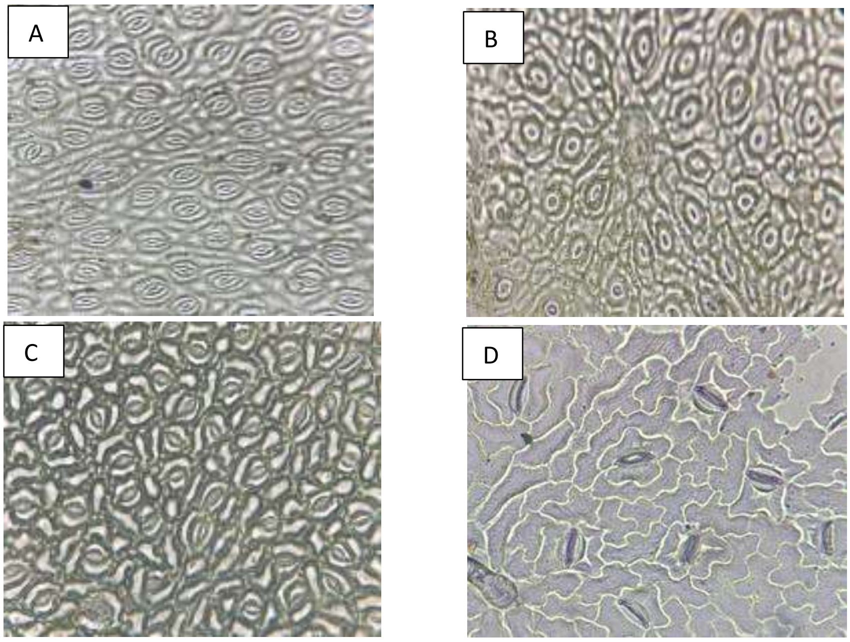

Figure 2. Stomata Density: (A) *Acacia auriculiformis*, (B) *Melaleuca* leucadendra, (C) *Albizia chinensis*, and (D) *Pterocarpus indicus*.

Based on Figure 2, it is visually apparent that the size of stomata in the four observed species exhibits an inverse relationship with stomatal density on the leaf surface. Larger stomata tend to be fewer in number, whereas smaller stomata are usually more numerous. According to Siahaan and Lestari (2023), larger stomata generally correspond to lower density compared to smaller stomata. Stomata with higher density tend to have increased transpiration rates compared to those with lower density.

APTI Analysis

Based on plant biochemical parameters—including relative water content, leaf extract pH, ascorbic acid content, and total chlorophyll content—the Air Pollution Tolerance Index (APTI) was determined. The results are as follows:

Table 7. Air Pollution Tolerance Index (APTI) values for various tree species along the Air Laya mine, Bukit Asam transport route.

Species	APTI	Category
Acacia auriculiformis	28.66	*Moderate*
Melaleuca leucadendra	28.88	*Moderate*
Albizia chinensis	36.58	*Tolerant*
Pterocarpus indicus	23.91	*Sensitive*

Based on Table 7, the results indicate that the species with the highest APTI value, categorised as tolerant, is *A. chinensis*, with an APTI of 36.58. *M. leucadendra*, with an APTI of 28.88, and *A. auriculiformis*, with an APTI of 28.66, fall within the medium APTI category. *P. indicus*, with an APTI of 23.91, is classified as sensitive. Plants identified as sensitive to air pollution can serve as indicator species for polluted environments due to their rapid physiological response to elevated levels of environmental pollutants. Conversely, plants categorised as tolerant are utilised as buffer vegetation in pollution mitigation efforts, such as the establishment of green belts in areas with high air pollution levels. According to Saptoka and Shresta (2024), APTI is employed to assess plants either as pollution indicators (sensitive) or as tolerant vegetation suitable for green belts.

API Analysis

Biological and socio-economic characteristics, including plant habitus, canopy structure, plant species, by combining APTI value the results were obtained on Table 8.

Table 8. Anticipated performance index (API) values for various tree species along the Air Laya mine Bukit Asam transportation route.

Spesies	APTI	API	Total (+)	*Grade total* Score (%)	Category
Acacia auriculiformis	5	8	13	81.25	*Excellent*
Melaleuca leucadendra	5	7	12	75.00	*Very Good*
Albizia chinensis	6	6	12	75.00	*Very Good*
Pterocarpus indicus	3	8	11	68.75	*Good*

Based on Table 8, the results of the API calculation indicate that *A. auriculiformis* falls into the Excellent category, demonstrating that the plant is not only tolerant of air pollution but also highly adaptable to it. *M.. leucadendra* and *A. chinensis* were classified as Very Good, reflecting a favourable combination of physiological tolerance to APTI alongside supportive morphological and ecological characteristics. Meanwhile, *P. indicus* was assigned a Good category, indicating reasonably good survival but with a more limited level of tolerance. According to Hanif *et al*. (2025), the Anticipated Performance Index (API) assessment aims to qualitatively evaluate and recommend the most suitable tree species for planting in polluted areas. For instance, an API score of 90% or above identifies a species as an excellent performer, highly recommended due to its dense canopy's ability to reduce air pollutants.

The API assessment category is determined based on a combination of APTI values and the plant's morphological, biological, and socioeconomic characteristics. The assessment results indicated that species with large tree habitats, dense canopy structures, evergreen foliage, broad leaves with rough surfaces, and high socio-economic value tended to achieve higher API scores and were most recommended for reforestation activities.

4. CONCLUSION

The four tree species exhibited different responses to air pollution stress. *Albizia chinensis* had the highest APTI score and was classified as tolerant to air pollution, making it potentially suitable for use as buffer vegetation. *Acacia auriculiformis* and *Melaleuca leucadendra* were placed in the medium tolerance category. Meanwhile, *Pterocarpus indicus* had the lowest APTI score and was classified as sensitive to air pollution, making it more appropriate for use as an air quality bioindicator. The Anticipated Performance Index (API) values indicated that *A. auriculiformis* was rated as Excellent, while *M. leucadendra* and *A. chinensis* were rated as Very Good and could be recommended. *P. indicus*, meanwhile, was rated as Good.

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