Assessment of Plant Species in Colombo District in Sri Lanka as an Air Pollution Mitigation Measure

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Abstract—**Human-induced changes in air composition pose significant threats to both organisms and the environment, emphasizing the urgent need for the adoption of effective nature-based solutions to mitigate these challenges. This study aimed to assess the effectiveness of plants in mitigating air pollution, ultimately identifying tree species suitable for urban forest development by comparing the Air Pollution Tolerance Index (APTI) and Anticipated Performance Index (API) of six tree species: *Azadirachta indica*, *Cassia fistula*, *Filicium decipiens*, *Macaranga peltata*, *Mangifera indica*, and *Terminalia catappa*, all of which are found in the Colombo District, Sri Lanka. The study was conducted in two distinct environmental settings, one classified as least air polluted (located in Padukka) and the other as highly air polluted (situated in Maharagama). Ten individual trees were chosen from each species at every study site, and these trees were treated as replicates for each species. Socio-economic parameters of selected plant species based on a literature survey were used for the study. The study revealed significant variations ($p<0.05$) in biochemical parameters including ascorbic acid content, total chlorophyll content, leaf extract pH, relative water content, and APTI among various tree species and locations. Notably, the highest APTI values were observed in *M. peltata* at both the least polluted (13.35±0.80) and highly polluted (12.17±0.71) sites. The API values indicate that *M. indica* is highly suitable for urban planting ('Very good'), *A. indica* and *M. peltata* are 'good' choices, *F. decipiens* and *T. catappa* are 'moderate', while *C. fistula* is 'poor' in their suitability as tree species for urban landscapes.**

Keywords—**Air pollution, urban planning, air pollution tolerance index, anticipated performance index, biomonitoring**

I. INTRODUCTION

In recent decades, urban areas have witnessed a growing environmental strain, with communities worldwide grappling with crises, predominantly stemming from deteriorating air quality. The primary factors contributing to this issue include the continual expansion of the population, the inappropriate land utilization relative to the population's needs, the congestion triggered by the rising volume of vehicles, and the subsequent escalation in the concentration of harmful gases in the atmosphere. In light of these challenges, the global spotlight has shifted towards green infrastructure, with a particular emphasis on urban forests. Urban forests encompass the collective expanse of trees and shrubbery within city limits, encompassing trees in residential yards, along streets, and within utility corridors, as well as safeguarded natural areas and watersheds. This includes individual trees, street-side plantings, green spaces adorned with trees and their associated vegetation, and even the soil beneath these trees. Presently, a prevailing trend involves the creation of urban forests, urban forest parks, green belts, and green corridors to mitigate the prospective impacts of air pollution, global warming, and climate change. Air pollution affects both plants and humans, with plants undergoing physiological transformations even before observable damage to their leaves occurs. When exposed to airborne pollutants, plants undergo these physiological shifts prior to displaying visible leaf damage. Given that trees play a vital role in their routine functions by removing a substantial amount of pollutants from the environment, they significantly enhance air quality and should thus be deemed an essential component in the broader effort to improve overall air quality [7].

Comprehending the factors that impact sensitivity and tolerance can enhance the understanding of how plants react to pollutants on physiological and biochemical levels. A method was presented, utilizing four biochemical parameters, ascorbic acid, total chlorophyll content, leaf extract pH, and relative water content to evaluate the susceptibility and tolerance of plants to air pollution [12]. This method yields the Air Pollution Tolerance Index (APTI), which characterizes the innate ability of plants to withstand air pollution. The APTI index provides valuable insights into the impact of pollutants, focusing exclusively on biochemical parameters. Nevertheless, the Anticipated Performance Index (API), designed to mitigate air pollution through the promotion of urban forests and green belts, takes into consideration additional socioeconomic and biological factors [11]. API calculations can also determine which plant species are most suitable for environmental management [5], and API proves especially valuable in identifying plant species capable of fulfilling the dual role of enhancing air quality through the removal of atmospheric pollutants and providing recreational benefits [4].

This study aimed to investigate the air pollution tolerance of plant species in the context of establishing urban forests to mitigate air pollution in urban environments. To achieve this, the study encompasses the analysis of various biological and socio-economic parameters and the assessment of the APTI and the API for a specific group of plants in various locations with diverse air pollution profiles. The ultimate goal is to provide practical recommendations to improve air pollution tolerance and the overall performance of plant species in urban forests, thereby contributing to the development of sustainable green spaces that improve not only air quality but also the health and well-being of urban residents. The majority of research on the air pollution tolerance of urban plant species has predominantly concentrated on species located along roadsides, typically utilizing the APTI. However, this study delves into both the APTI and the API to evaluate the tolerance of urban trees to air pollution. Its aim is to pinpoint the most appropriate tree species for the development of urban forests as a strategy to alleviate air pollution.

II. Materials and Methods

A. Experimental Sites

This study was conducted in the Colombo district of Sri Lanka, a tropical island situated to the south of the Indian subcontinent. The selection of study sites in Colombo was based on the ambient air levels of SO_2, NO_2, PM2.5, and PM10, categorizing them into two distinct categories: "control site" (CS) and "polluted site" (PS). Consequently, the premises of Sri Lanka Technological Campus (SLTC Research University) were designated as the control site, while Maharagama was identified as the polluted site. In the selection of study sites, the control site was primarily selected systematically. Polluted sites were then selected based on precise analysis of air quality data, facilitating a comprehensive comparison with the control site. Sri Lanka Technological Campus, located in the biodiverse region of Padukka, was chosen as the control site for sampling due to its remote location, away from the city. The average ambient air levels of SO_2, NO_2, PM2.5, and PM10 around the area were recorded as 11 $\mu g/m^3$, 4 $\mu g/m^3$, 22 $\mu g/m^3$, and 30 $\mu g/m^3$, respectively [2]. In contrast, Maharagama is a city characterized by rapid housing development and urbanization and is renowned for having some of the highest air pollution levels, largely attributable to heavy traffic. In Maharagama, the average ambient air levels of SO_2, NO_2, PM2.5, and PM10 around the area were measured at 24 $\mu g/m^3$, 15 $\mu g/m^3$, 60 $\mu g/m^3$, and 43 $\mu g/m^3$, respectively [2], thus making it a suitable site for sampling. It's worth noting that the soil condition was consistent across all the studied zones.

B. Sample Collection

A preliminary field study was carried out to collect data regarding a variety of urban trees and their locations because there are no existing records of their locations or species. Plant species were selected considering the study of the abundance of plant species in the selected areas and being indigenous/ native species. Selected plant species (Fig. 1) were *Azadirachta indica* (Neem tree), *Cassia fistula L.* (Golden shower tree), *Filicium decipiens* (Fern tree), *Macaranga peltata* (Chandada or Kenda tree), *Mangifera zeylanica* (Mango tree), and *Terminalia catappa L.* (Indian almond tree).

A. indica *C. fistula* *F. decipiens*

M. peltata *M. zeylanica* *T.catappa*

Fig. 1. Selected plant species for analysis

Ten individual trees were selected from each species at every study site, and these trees were considered replicates for each respective species. All chosen tree specimens were within the age range of 5 to 10 years. Given the absence of documented records regarding the trees' ages or planting years, we relied on oral accounts provided by neighboring residents of the study sites to estimate the trees' ages, thereby integrating this qualitative data into this study. Mature leaves from chosen individuals of each species were randomly gathered in the morning, specifically between 7:00 am and 9:00 am, to minimize exposure to dust and other potential obstacles. This timing is crucial to obtain the fresh weight of the leaves. Leaf samples were obtained from the lowermost part of the canopy, approximately at a height of 1.8 to 2 meters above the ground surface. Sampling was conducted during August and September, coinciding with the southwest monsoon season (also known as the wet season). The collected samples were meticulously sealed in individual polythene bags and transported to the laboratory. Upon reaching the laboratory, the fresh weight of the leaves was documented, and the samples were then stored at 4 °C. To facilitate further analysis, a composite leaf sample was generated from each individual.

C. Biochemical Analysis

Laboratory analysis was performed to evaluate the Air Pollution Tolerance Index (APTI) by examining four crucial biochemical parameters: Ascorbic Acid Content (AAC), Relative Water Content (RWC), Total Chlorophyll Content (TChC), and pH. The measurement of AAC was carried out using the spectrophotometric method [3]. A fresh leaf sample weighing one gram was extracted using a solution comprising Oxalic acid – EDTA (4 mL), orthophosphoric acid (1 mL), 5% (v/v) sulfuric acid (1 mL), 5% (m/v) ammonium molybdate (2 mL), and water (3 mL). Following a 15-minute incubation period, the absorbance of the solution was measured at 520 nm and 760 nm using a UV-visible spectrophotometer. The concentration of ascorbic acid in the sample was extrapolated from a standard ascorbic curve, and the results were duly recorded. The gravimetric method was employed to ascertain the RWC of the leaves [9]. A quantity of 30 grams of fresh leaves was acquired from each sample as the initial fresh weight. These leaves were immersed in water overnight, subsequently dried and weighed to establish the turgid weight. Following this, the leaves were subjected to drying in an oven at 70 °C for a day, and the resulting weight provided the dry weight. Equation (1) was applied in the calculation process.

$$RWC = \frac{(FW - DW)}{(TW - DW)} \times 100 \qquad (1)$$

Where, RWC = Relative Water Content (%), FW = Fresh Weight (g), DW = Dry Weight (g), and TW = Turgid Weight (g)

The determination of TChC followed the spectrophotometric method outlined by [3]. Three grams of fresh leaves were blended and extracted with 10 mL of 80% acetone, followed by a 15-minute incubation period. The liquid portion underwent decantation and centrifugation at 2500 rpm for 3 minutes. The resulting supernatant was collected, and the absorbance at 645 nm and 663 nm was recorded. Equations (2), (3), and (4) were applied for subsequent calculations.

$$Chlorophyll\ a = \frac{12.7Dx_{663} - 2.69Dx_{645} \times V}{1000W} (mg/g) \qquad (2)$$

$$Chlorophyll\ b = \frac{22.9Dx_{645} - 4.68Dx_{663} \times V}{1000W} (mg/g) \qquad (3)$$

$$TChC = Chlorophyll\ a + Chlorophyll\ b\ (mg/g) \qquad (4)$$

Where, D_x= Absorbance of the extract at the wavelength X nm, V = Total volume of the chlorophyll solution (mL), W = Weight of the tissue extract (g), Leaf extract pH

The pH of leaf extracts was determined by homogenizing 5 grams of leaf samples with 50 mL of deionized water, and the resulting leaf extract's pH was measured using a pH meter calibrated with pH 4 and 9 buffer solutions. Carbonic acid and sodium bicarbonate served as the buffer solutions [3, 9].

D. Socio-Economic Parameters

Traditional criteria for choosing plants for urban vegetation usually concentrate on a limited set of observable characteristics, including color, shedding, shape, size, plant habit, leaf structure, and canopy structure. The most dependable sources of information include a review of published literature and several official websites that were consulted to identify relevant socio-economic parameters of the selected plant species [4].

E. APTI and API Determination

APTI only gives the effect of pollutants on biochemical parameters. This expresses the ability of a plant to fight air pollution. APTI was calculated using the following equation (5) [3].

$$APTI = \frac{A(P + T) + R}{10} \qquad (5)$$

Where; A = Ascorbic Acid (mg/g), T = Total Chlorophyll (mg/g), P = Leaf Extract pH, R = Relative Water Content (%), APTI = Air Pollution Tolerance Index

Tab. 1 [3] provides the categorization of APTI results for various plants into different tolerance levels. Plants exhibiting higher APTI values demonstrate greater tolerance to air pollution, whereas those with lower APTI values indicate lower tolerance.

TABLE 1. CLASSIFICATION OF APTI VALUES IN TREE SPECIES INTO DISTINCT TOLERANCE LEVELS

Range of APTI		Tolerance Level
a)	Tree species with APTI higher than mean APTI+SD	Tolerant
b)	Tree species with APTI value between mean APTI and mean APTI+SD	Moderately Tolerant
c)	Tree species with APTI value between mean APTI-SD and mean APTI	Intermediate
d)	Tree species with APTI lower than mean APTI+SD	Sensitive

As described by [4] the key criteria and corresponding grades for API determination using plus (+) and minus (-) marks. The key criteria are APTI, plant habitat, canopy structure, plant type, size, texture, and hardiness of the lamina and economic value of the species. Assessment of API was done using equation 5 after obtaining the total score. There are eight grades from 0 to 7, indicating plants unsuitable for urban forest development to excellent plants. An API value below 50% is a poor and not recommended plants and above 50% varies from moderate to excellent plants with good API score.

$$API = \frac{No\ of\ '+'obtained}{16} \times 100 \qquad (6)$$

F. Statistical Analysis

The study utilized a two-sample t-test to assess the significance of variations in selected biochemical parameters and the resulting APTI values for each species between the sites with the lowest and highest pollution levels. Additionally, a standard one-way analysis of variance (ANOVA) was performed to examine the significance of differences in APTI values among the six chosen urban tree species at each site.

III. RESULTS AND DISCUSSION

A. Biochemical Parameters and APTI Comparison

The resistivity and susceptibility of tree species are predominantly influenced by the biochemical parameters investigated for APTI. Tab. 2 displays the biochemical result of calculating the APTI for six tree species growing in polluted and control sites. Based on the mean RWC results, in the control site, *M. peltata* exhibited a significantly higher relative water content at 93.70±0.01%, whereas *C. fistula* recorded the lowest value at 84.05±0.03%. In the polluted site, *F. decipiens* displayed a significantly higher relative water content at 89.63±0.03%, while *T. catappa* registered the lowest value at 71.92±0.03%. A plant's ability to withstand and maintain its physiological balance under stressful conditions, including drought, is improved when it has a higher relative water content in its tissues [4].

TABLE 2. ASSESSMENT OF AIR POLLUTION TOLERANCE INDEX (RESULTS ARE PRESENTED AS MEAN ± SEM (N =10)

Species	**Site**	**RWC (%)**	**TChC (mg/g)**	**AAC (mg/g)**	**pH**	**APTI**
A. indica	CS	86.26 ±0.03	0.24 ± 0.04	4.75 ±0.32	6.70 ±0.38	12.80 ±0.31
	PS	82.95 ±0.05	0.22 ± 0.04	6.22 ±0.33	6.44 ±0.12	11.42 ±0.59
C. fistula	CS	84.05 ±0.03	0.34 ± 0.03	6.14 ±0.48	6.74 ±0.51	12.14 ±0.50
	PS	82.24 ±0.03	0.34 ± 0.02	2.58 ±0.76	5.76 ±0.44	10.06 ±0.66
F. decipiens	CS	90.82 ±0.03	0.23 ± 0.03	4.28 ±0.57	6.66 ±0.41	11.94 ±0.68
	PS	89.63 ±0.03	0.23 ±0.03	3.20 ±0.66	6.35 ±0.44	11.18 ±0.77
M. peltata	CS	93.70 ±0.01	0.37 ±0.03	5.39 ±0.52	5.71 ±0.33	13.35 ±0.80
	PS	83.40 ±0.02	0.36 ±0.03	8.12 ±1.94	4.58 ±0.31	12.17 ±0.71
M. indica	CS	85.75 ±0.03	0.35 ±0.05	5.43 ±0.32	5.72 ±0.53	11.69 ±0.41
	PS	79.30 ±0.04	0.36 ±0.06	4.41 ±0.26	5.38 ±0.30	10.62 ±0.52
T. catappa	CS	85.38 ±0.07	0.29 ±0.04	7.52 ±0.39	4.98 ±0.48	12.16 ±0.49
	PS	71.92 ±0.03	0.28 ±0.04	6.20 ±0.65	4.52 ±0.24	10.44 ±0.50

TChC in plants significantly influences photosynthetic activity and biomass growth [2]. At the control site, *M. peltata* exhibited a significantly higher TChC at 0.37±0.03 mg/g, whereas *F. decipiens* registered the lowest value at 0.23±0.03 mg/g. In the polluted site, *M. peltata* and *M. indica* (0.36±0.03 mg/g and 0.36±0.06) recorded significantly higher TChC, while *A. indica* (0.22±0.04 mg/g) recorded the lowest value. It can be triggered by the deposition of dust on the leaf surface and exposure to air pollution [7]. Tolerant plants make an effort to maintain higher TChC as a defense mechanism against air pollution. This is supported by the observation that *M. peltata*, which demonstrated the highest TChC in the control site, is documented as being tolerant according to its APTI. As an antioxidant, AAC plays a pivotal role in shaping the resilience of plants against adverse environmental factors, especially air pollution [4]. In the control site, *T. catappa* (7.52±0.39 mg/g) recorded significantly higher AAC while *F. decipiens* (4.28±0.57 mg/g) recorded the lowest value. In the Polluted site, *M. peltata* (8.12±1.94 mg/g) recorded significantly higher AAC while *C. fistula* (2.58±0.76 mg/g) recorded the lowest value. A defensive system of plants in an environment is favored by a high concentration of ascorbic acid [3]. The pH acts as an indicator of sensitivity to air pollution. In the control site, *C. fistula* (6.74±0.51), *A. indica* (6.70±0.38), and *F. decipiens* (6.66±0.41) recorded significantly higher pH while *T. catappa* (4.98 ± 0.48) recorded the lowest value. In the polluted site, *A. indica* (6.44±0.12) recorded significantly higher pH value while *T. catappa* (4.52±0.24) recorded the lowest value. All the leaf extracts of the plant species collected from the polluted site were observed to be more acidic than the control site. According to [3, 1]. the acidic pH observed in leaf extracts of tree species is likely attributed to high levels of SO_2 and NO_2 in the ambient air.

For each of the six selected tree species, a decrease in APTI was observed at the polluted location compared to the control site. This decline is evident from the reduction in all biochemical parameters when moving from the least to the polluted site. In the control site, *M. peltata* (13.35±0.80) recorded significantly higher APTI value while *M. indica* (11.69±0.41) recorded the lowest value. In the polluted site, *M. peltata* (12.17±0.71) recorded a significantly higher APTI value while *C. fistula* (10.06±0.66) recorded the lowest value.

TABLE 3. TREE SPECIES CATEGORIZATION INTO DISTINCT TOLERANCE LEVELS BASED ON APTI VALUES

Species	Site	APTI	Mean APTI	Category
A. indica	CS	12.80	11.74	Tolerant
	PS	11.42	10.98	M. Tolerant
C. fistula	CS	12.14	11.74	M. Tolerant
	PS	10.06	10.98	Intermediate
F. decipiens	CS	11.94	11.74	M. Tolerant
	PS	11.18	10.98	M. Tolerant
M. peltata	CS	13.35	11.74	Tolerant
	PS	12.17	10.98	Tolerant
M. indica	CS	11.69	11.74	Intermediate
	PS	10.62	10.98	Intermediate
T. catappa	CS	12.16	11.74	M. Tolerant
	PS	10.44	10.98	Intermediate

Tab. 3 illustrates the classification of tree species into different tolerance levels, determined by their APTI values and standard deviation (SD). The SD value for the polluted site and the control site was 0.93 and 0.61 respectively. The tolerance category of each species was different in the two sites. *A. indica* and *M. peltata* were categorized as tolerant species in the control site while in the moderately tolerant category in the polluted site. *C. fistula* and *T. catappa* are in the moderately tolerant category in the control site and in the polluted site are classified as intermediately tolerant species. The tolerance of *F. decipiens* is categorized as moderately tolerant in both sites. The tolerance category of *M. indica* remains unchanged in both sites and categorized as an intermediate species.

The statistical analysis identified a significant difference ($p < 0.05$) in APTI values among the six chosen urban tree species at each site. Based on an ANOVA performed, there was no significant difference between the RWC of the test species at both sites. There was a significant difference in the AAC in all plants at both sites. This implies that a plant's ability to withstand air pollution differs depending on its site. With the exception of *M. peltata*, all plant species showed significant differences in pH. A significant difference in TChC was found for *M. indica* species. In terms of APTI values, *C. fistula*, and *T.catappa* were statistically significant. It can be said that those species have the adaptability to combat stress under different environmental conditions.

B. *Assessment of API*

Tab. 4 summarizes API of different plant species. It reveals that *M. indica* performed as 'very good' for urban forest developments. According to the grading of two sites *T. catappa*, *A. indica*, and *M. peltata* performed as 'good' plant species and *F. decipiens* is a 'moderate' performer. *C. fistula* is recorded as a 'poor' performer in order to urban forest development. According to the findings of this study, certain plants, such as *M. indica, F. decipiens, and T. catappa*, exhibit low APTI values while demonstrating excellent API. This could be ascribed to advantageous socio-economic factors that boost the phytoremediation capabilities of these plants. Moreover, these species possess significant economic and aesthetic value [4]. It was followed by the maximum API of *A. indica* and *M. peltata* may be due to its high APTI. API value is more for the species with higher APTI having better plant and leaf characteristics[6].

TABLE 4. ASSESSMENT OF ANTICIPATED PERFORMANCE INDEX

Species	Grade Allocated		API Grade	API Assessment
	Total Plus	Percentage		
A. indica	9	56	4	Good
C. fistula	8	50	2	Poor
F. decipiens	11	69	4	Good
M. peltata	11	69	4	Good
M. indica	12	75	5	Very Good
T. catappa	10	63	4	Good

A thorough examination of the findings indicates diverse responses among different plant species to air pollution. Furthermore, the study underscores the influence of air pollution on crucial factors such as total chlorophyll content, ascorbic acid content, relative water content, and leaf extract pH. Plants exhibiting lower index values indicate diminished tolerance and can function as indicators of the degree of air pollution [12]. On the other hand, higher Air Pollution Tolerance Index values are indicative of plant species' resilience to air pollutants [8]. It is crucial to emphasize that a plant's capacity to withstand air pollutants is contingent on the specific site conditions, including the nature and concentration of the pollution [10].

IV. CONCLUSION

A consistent pattern of declining APTI values was observed from the polluted site to the control site for all chosen tree species. In terms of air pollution tolerance, *Macaranga peltata* stood out as the most resilient tree species in both sites. Plants characterized by low APTI index values exhibit low tolerance, while those with high APTI values demonstrate a high tolerance to air pollutants. The capability of plants to withstand air pollutants is specific to the site and relies on the type and concentration of pollution. The API scores indicated that among the tested tree species, *Mangifera indica* was categorized as 'very good' in terms of suitability for planting in urban forests due to its highest API score. Based on the outcomes obtained through the API assessment, it is recommended that all plant species, except for *Cassia fistula*, exhibit suitability for urban environments. Certain species demonstrate the highest APTI grades, while in other cases, factors like canopy structure and economic value also play a role. APTI and API have gained broad acceptance as reliable methods for assessing plant tolerance to air pollution. They are valuable tools for designing urban forests and landscapes that are visually appealing and environmentally sustainable. Future studies should delve into the tolerance of additional tree species to urban environments characterized by air pollution. Furthermore, considering the relevant parameters for these trees across various age groups and over extended periods, during both wet and dry seasons, would be valuable for evaluating crop productivity in the face of air pollution across different seasons.

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