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Anticipated Performance and Air Pollution Tolerance Indices for the Establishment of Green Belt Development in an Industrial Area

D Gopamma[1], K Jagadeeswara Rao[2], Shaik Riyazuddin[3], K Suresh Kumar[1], N Srinivas[4]*

1 Assistant Professor, Department of Environmental Science, Institute of Science, GITAM (Deemed to be University), Rushikonda, Visakhapatnam, AP, India

2 Research Scholar, Department of Environmental Science, Institute of Science, GITAM (Deemed to be University), Rushikonda, Visakhapatnam, AP, India

3 Junior Research Fellow, Department of Environmental Science, Institute of Science, GITAM (Deemed to be University), Rushikonda, Visakhapatnam, AP, India

4 Professor, Department of Environmental Science, Institute of Science, GITAM (Deemed to be University), Gandhi Nagar Post, Rushikonda, Visakhapatnam, 530 045, AP, India

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* **Corresponding author**.

snamudur@gitam.edu

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Abstract

Background: To identify the plant species tolerance levels in an industrial area by assessing Anticipated Performance Index (API) and Air Pollution Tolerance Index (APTI) to establish a green belt in the industrial area. **Methods:** A survey on local species was conducted in and around the study areas. Seventeen plant species were chosen for an evaluation of tolerant species based on their occurrence and dominance in the study areas. Standard methods were applied for estimation of biochemical parameters such as Cell Sap pH, Relative Water Content (RWC), Total Chlorophyll Content (TCC), and Ascorbic Acid (AA) and were used to compute the APTI. API is assessed based on socioeconomic and biological characteristics. Correlation coefficient test was performed to gain the information about relationship between variables. **Findings:** The results revealed that APTI positively correlated with biochemical parameters in control, negatively correlated with in industrial samples and except ascorbic acid. Ascorbic acid is one of the critical elements in biochemical parameters. It changes plant species sensitivity to tolerance. In API, based on social, biological, and physical characteristics (+, -) codes were used to classify poor, moderate, good, very good, best, and excellent. In the present study *Ficus benghalensis* as excellent (87.25%) in the control area and best (93.75%) in industrial area; *Syzygium cumini* species best (93.75%) in control and excellent (87.25%) in industrial areas. In comparison, *Mimusops elengi* reported moderate (56.25%) to the poor (50) in control and the industrial areas. **Novelty:** This study was carried out to determine the impact of air pollution on plant species which exhibit either sensitivity or tolerance depend on their endurance level. The identified list of the tree species helps to minimize air pollution levels in the industrial area and can be used to establish green belt development.

Keywords: Anticipated Performance Index (API); Air Pollution Tolerance Index (APTI); Tolerance; Green Belt; Biochemical Parameters

1 Introduction

The promising growth of Indian industry with modernization has increased the economy in terms of increased per capita income; infrastructure development, which includes road development, has enhanced people's well-being. But such activities, when they exceed the limits beyond the carrying capacity of an area, cause damage to the natural assets of the environment to a greater or a lesser extent by disturbing the existing ecosystem[1]. Due to the increase in vehicles and their emissions, air pollution has become one of the most severe problems causing threats to flora, fauna, and humans[1,2]. Because of growing urban and industrial activities, air pollution has become a severe issue in nations worldwide[3,4]. Sulfur dioxide (SO_2), Nitrogen dioxide (NO_2), and Particulate Matter (PM) are all found in all types of air pollutants, but they are more common in industrial and urban surroundings[5]. Pollutants can originate from several sources. Due to coal and oil combustion, sulfur dioxide is emitted directly into the atmosphere and oxidized from H_2S produced physiologically[1].

In plants, air pollutants can exert a profound influence on various morphological features, growth, and reproduction, which includes biochemical and physiological parameters such as enzymes, proteins, pigments, Relative Water Content (RWC) and sugar contents, cell sap pH, and Ascorbic Acid (AA), etc.[3,6]. The induced change in plants by the influence of air pollutants results in either sensitivity or tolerance to plant species[7]. Air pollutions negatively impact roadside plants and cause alterations in physiological, morphological, or biochemical characteristics[3,8].

Air pollution, including acid rain, interfere with the physiological mechanism of plants and cause acidification of soils. This results in contaminants' dissolvability, such as heavy metals, which induces various morphological and anatomical changes in plant species. Such plants can act as pollution indicator species[9–11].

Meanwhile, some other plant species are more resistant to the above conditions or air pollution and more popular to be planted in air pollution areas[12,13]. The more sensitive plant species serve as biological sensors of air pollution based on plants' physiological and biochemical responses to air pollution[1,6,14].Kaur and Kaur[2] developed APTI indices based on four physiological characteristics: Total Chlorophyll Content (TCC), Relative Water Content (RWC), the cell sap pH, and Ascorbic Acid (AA) to assess the tolerance of plant species[15]. Ascorbic acid acts as a co-enzyme, metabolizes proteins, lipids, and carbohydrates to produce RNA. Ascorbic acid is also valuable for plant photosynthesis and stimulates plant development[16]. Furthermore, ascorbic acid is strongly resistant to toxic contaminants in plants by lowering SO_2 content[2]. Total chlorophyll concentration directly indicates plant health since it is one of green plants' most crucial energy generation components[17]. Environmental factors have a considerable impact on its composition[18]. As a result, plants with greater relative water content levels may be more resistant to contaminants[19]. The pH of plants is strongly related to air pollution, particularly SO_2. It has been found in cell sap pH plays a vital role in the identification of plants as sensitive (pH less than 7) or tolerant (pH near 7)[20].

As a result, the role of plants in assessing air pollution is becoming more critical. In this context, API expresses the plant's inherent ability to encounter stress caused by air pollution and aids in identifying tolerance levels of plant species based on biochemical parameters[21]. Plants with higher APTI scores are less vulnerable to pollution and reduce air pollution. However, those with low index values show less tolerance and can be used to detect levels of air pollution[22]. The APTI index considers just the influence of pollutants on biochemical indicators. Still, to combat air pollution through green belt development, different biological and socioeconomic factors are considered and used to generate the Anticipated Performance Index (API)[23]. The present study represents the research content to evaluate the parameters of the Anticipated Performance Index (API) and Air Pollution Tolerance Index (APTI) by using biochemical parameters of cell sap, pH, relative water content, and ascorbic acid and total chlorophyll content analyzed in control and industrial areas in Visakhapatnam.

2 Materials and Methods

2.1 The research area (Visakhapatnam)

The present research conducted in control area was free from pollution (Rushikonda) and the industrial areas (BHPV, Gnanapuram, Parawada) of Visakhapatnam in Andhra Pradesh, India, which is popularly known as the city of destiny. The topography of this area is like a spoon-shaped basin, which covers three sides hills and one side sea, which makes the pollutants remain in the bowl area for a more extended period and cause inversion conditions, especially in the winter season. The monsoon in Visakhapatnam begins in June that lasts till the end of September. In this city, the average temperature in the winter season is 29°C, summer season 39°C to 40°C. The hill regions surrounded this area on the northeast side of Simhachalam hills (one of Eastern Ghats) and another side of the Bay of Bengal. The tree species that grow in this area play an essential role in mitigating air pollutants.

Seventeen tree species selected for the present study which are common to two study areas. Among seventeen species eight tree species are native, and the remaining were naturalized introduced species. The selected tree species are 1. *Acacia auriculiformis* (Fabaceae), 2. *Albizia lebbeck* (Fabaceae), 3. *Artocarpus heterophyllus* (Moraceae) 4. *Azadirachta indica* (Meliaceae) 5. *Bauhinia purpurea* (Fabaceae), 6. *Cassia fistula* (Fabaceae) 7. *Delonix regia* (Fabaceae), 8. *Eucalyptus citriodora* (Myrtaceae), 9. *Ficus benghalensis* (Moraceae), 10. *Mangifera indica* (Anacardiaceae), 11. *Mimusops elengi* (Sapotaceae), 12. *Nerium oleander* (Apocynaceae) 13. *Polyalthia longifolia* (Annonaceae) 14. *Pongamia pinnata* (Fabaceae), 15. *Syzygium cumini* (Myrtaceae), 16. *Tamarindus indica* (Fabaceae), 17. *Terminalia catappa* (Combreataceae). The species are selected from the respective selected areas such as control (Rushikonda) and industrial (Gnanapuram, Parawada, and BHPV) area. Figure 1 provide locations in Visakhapatnam and tree species.

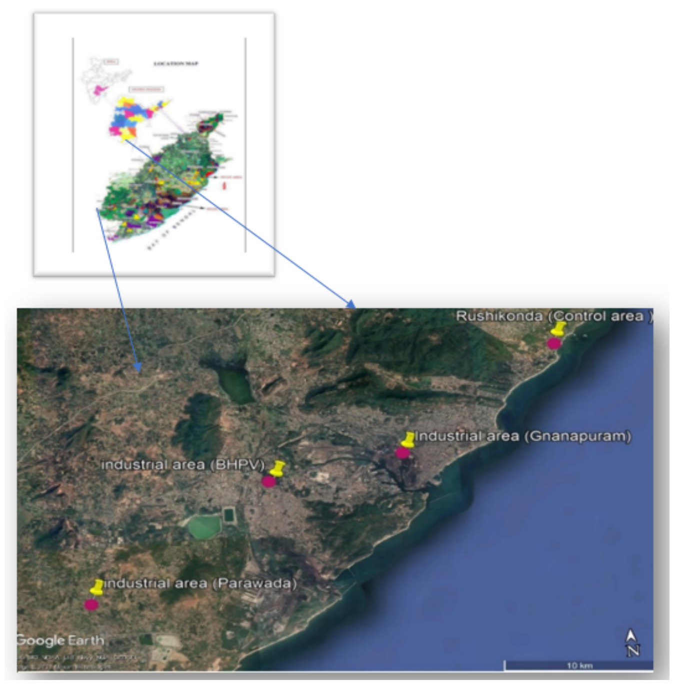

Fig 1. Map showing the study areas of Visakhapatnam.

2.2 Methods

2.2.1 Sampling Methods

A survey was conducted and identified seventeen species for assessment based on their occurrence and dominance in that area[24]. The study was conducted for one year, covering all seasons. The selected tree species were monitored and analyzed for various parameters to ensure uniformity throughout the study. Five exposed leaves in triplicates from each tree species were taken for analysis. The collected leaf samples were wrapped in a polythene sheet and immediately placed in an icebox for further analysis.[24].

2.2.2 Biological examination of leaf samples, Calculation of APTI and API

The leaf samples were washed using ordinary tap water, removed the dust particles on the leaf, and used the leaf samples for estimation of biochemical parameters such as cell sap pH, relative water content, chlorophyll content and ascorbic acid using standard methods[24,25].

Based on the above four biochemical parameters the APTI for the chosen plants was calculated using the formula given below[1,24].

APTI =[(A(T+P) +R)/10]

Where A=Ascorbic acid content (in milligrams/ gram of fresh wt.); T=Total chlorophyll content (in milligrams/ gram of fresh wt), P = pH of fresh leaf extract; R= Relative water content (%).

2.2.3 Estimation of API in tree species

It is assessed based on the grading criteria Table 1, and on grade allotment, API is calculated using the following formula[14,16].

$$\text{Anticipated Performance Index (API)} = \frac{\text{Number of `+' grades obtained}}{\text{Total no. of `+' grades of any species}} \text{ x } 100$$

Total no. of '+' grades of any species

The final percentage score of API is assigned to each plant species and further assigned assessment categories.[19].

Table 1. Grading Criteria used for Anticipated Performance Index

Grading Character		Pattern of assessment	Grade allotted
Tolerance	APTI	9.0–12.0	+
		12.1–15.0	++
		15.1–18.0	+++
		18.1–21.0	++++
		21.1–24.0	+++++
	Plant habit	Small	–
Biological and socio- economic	Canopy structure	Medium	+
	Type of plant	Large	++
		Sparse/irregular/globular	–
		Spreading crown/open/semi-	+
		dense	++
		Spreading dense	
		Deciduous	–
		Evergreen	+
	Leaf size	Small	–
Laminar structure	Texture	Medium	+
	Hardiness	Large	++
	Economic value	Smooth	–
		Coriaceous	+
		Delineate	–
		Hardy	+
		Less than three uses	–
		Three or four uses	+
		Five or more uses	++

Grade	Score (%)	Assessment category
0	Up to 30	Not recommended
1	31–40	Very poor
2	41–50	Poor
3	51–60	Moderate
4	61–70	Good
5	71–80	Very good
6	81–90	Excellent
7	91–100	Best

2.3 Statistical analysis

Correlation coefficient performed to identify the relation between the biochemical parameters.

3 Result and Discussion

The impacts of different pollutants on various individual species have been extensive, while most of these studies were based on control studies. Plants' responses to pollution differ depending on the contaminant [23]. Most studies have studied the impacts of air pollution, especially by SO_2 and NOx air pollutants [26]. Physical and chemical measurements of air pollutants help estimate the biological impacts [26]. Plants act as biological indicators to assess air quality throughout the exposure, and at various levels, the effect of air pollution on plants was investigated [27]. The response of plants towards air pollution varies from plant to plant [27].

3.1 Air Pollution Tolerance Index (APTI)

The APTI of tree species indicates its tolerance to air pollution. In the present study, APTI was reported in seventeen species in the range of 13.77±0.61 to 25.05±0.95. *Albizia lebbeck* is reported with a minimum value of 13.77±0.61, and *Terminalia catappa* with a maximum value of 25.05±0.95 is recorded in the control area. In contrast, APTI in the industrial area varied from 13.69±0.53 to 19.04±0.72. *Terminalia catappa* has the lowest minimum value of 13.69±0.53, and *Cassia fistula* has the highest maximum value of 19.04±0.72 Table 2. The obtained APTI values were further used to classify the plants into four groups. If APTI < 1 Highly sensitive, 1-16 sensitive, 17-19 intermediate tolerance, 30-100 tolerant [19]. It controls area species like *Albizia lebbeck; Artocarpus heterophyllus; Acacia auriculiformis; Mangifera indica; Azadirachta indica, Cassia fistula; Mimusops elengi; Bauhinia purpurea; Eucalyptus citriodora; Delonix regia* reported in the sensitivity range turned into intermediate tolerance in the industrial area. Similarly, two tree species, *Terminalia catappa* and *Tamarindus indica* showed tolerance in the control area and turned into a sensitive an industrial area. A previous study had revealed that changes in environmental parameters such as temperature, water content, relative humidity, soil acidity, and other factors might influence plant tolerance behavior [28].

Table 2. Biochemical parameters of Leaf cell sap of pH, Total Chlorophyll Content (mg/g), Ascorbic Acid (mg/g), Relative Water Content (RWC), APTI in tree species of two environmental backdrops of control and industrial areas

Name of the tree species		Cell sap pH	Total Chlorophyll Content (TCC) (mg/g)	Ascorbic Acid (AA) (mg/g)	Relative Water Content (RWC) (%)	APTI
Acacia auriculiformis	C	6.06±0.59	1.47±0.79	9.93 ± 0.86	69.78±0.95	14.45±0.94
	I	6.30±0.09	0.61±3.31	17.20±0.05	67.94±0.09	17.74±0.86
Albizia lebbeck	C	6.25±0.54	1.20±0.30	9.03 ±0.69	70.52±0.74	13.77±0.6
	I	6.02±0.23	0.56±2.29	17.65±0.06	65.78±0.23	17.64±0.44
Artocarpus heterophyllus	C	6.38±0.50	1.23±0.75	8.91±0.98	70.67±0.88	13.98±0.96
	I	5.61±0.26	0.65±5.09	16.32±0.09	67.84±0.26	16.53±1.27
Azadirachta indica	C	6.35±0.98	1.42±0.75	9.54 ±0.87	71.94±0.97	14.99±0.92
	I	6.25±6.25	0.66±2.46	16.33±0.09	68.73±0.60	17.24±3.13
Bauhinia purpurea	C	6.44±0.82	1.78±0.95	10.33±0.92	71.24±0.84	15.68±0.82
	I	5.97±0.45	0.62±3.07	18.52±0.14	68.58±0.45	18.22±0.32
Cassia fistula	C	6.53±0.67	1.83±0.89	9.69±0.90	72.52±0.95	15.27±0.73

Continued on next page

Table 2 continued

	I	6.19±0.16	0.63±1.23	19.30±0.09	64.58±0.16	19.04±1.88
Delonix regia	C	6.55±0.40	2.21±0.51	9.77±0.94	78.22±0.87	16.21±0.90
	I	6.20±0.37	0.55±2.89	14.63±0.08	67.64±0.37	18.42±4.34
Eucalyptus citriodora	C	6.92±0.56	2.53±0.68	10.00 ±0.79	78.10±0.83	17.40±0.88
	I	5.79±0.22	0.57±3.17	15.15±0.08	66.82±0.22	15.72±4.29
Ficus benghalensis	C	6.89±0.53	2.03±0.92	9.84±0.72	71.00±0.87	16.53±0.92
	I	6.07±0.13	0.64±3.41	12.21±0.04	65.52±0.12	13.81±5.71
Mangifera indica	C	6.75±0.32	2.85±0.88	10.36 ±0.89	76.59±0.89	17.55±0.97
	I	5.39±0.75	0.60±4.54	14.98±0.04	62.83±0.75	14.63±4.52
Mimusops elengi	C	6.90±0.59	3.43±0.93	11.99±0.99	75.56±0.85	20.59±0.93
	I	5.85±0.48	0.58±5.58	14.48±0.12	67.43±0.69	15.48±4.64
Nerium oleander	C	6.84±0.34	3.25±0.96	10.69±0.80	76.11±0.65	19.83±0.89
	I	6.05±0.48	0.64±0.11	15.22±6.82	61.68±6.52	17.07±2.91
Pongamia pinnata	C	6.79±0.60	3.65±0.91	11.58±0.74	70.49±0.87	19.88±0.99
	I	5.74±0.93	0.71±4.57	17.34±0.16	67.76±0.93	17.29±3.38
Polyalthia longifolia	C	6.88±0.65	2.64±0.96	10.64±0.90	79.61±0.78	19.37±0.97
	I	6.04±0.46	0.49±1.94	16.69±0.07	67.27±0.46	17.31±4.30
Syzygium cumini	C	6.90±0.74	3.64±0.90	12.98±0.94	79.81±0.97	21.99±0.94
	I	6.28±0.55	0.73±6.08	16.31±0.36	67.57±0.55	17.48±1.88
Tamarindus indica	C	6.87±0.54	3.14±0.94	13.68 ±0.97	80.45±0.98	22.95±0.96
	I	5.85±0.45	0.59±4.37	14.84±0.12	63.98±0.45	14.96±3.87
Terminalia catappa	C	7.06±0.42	4.49±0.80	14.59±0.68	77.99±0.88	25.05±0.95
	I	5.89±1.44	0.65±8.16	12.23±0.06	61.54±1.45	13.69±5.46

3.1.1 Cell sap pH

pH plays a vital physiological role in living organisms. The enzyme activity of living things is given a small range of the pH values of their environment. In the industrial area, the pH was between 5.39 and 6.28. The minimum cell sap pH value for *Mangifera indica* was 5.39, while the maximum cell sap pH value for *Syzygium cumini* was 6.28. The cell sap pH in the control region ranged from 6.06 to 7.06. *Acacia auriculiformis* has the lowest score of 6.06, and *Terminalia catappa* has the highest value of 7.06 Table 2. The cell sap pH of a plant is essential in its physiological functions [28].Most enzymes engaged in biological processes require a relatively high pH to function correctly. The presence of SO_2 and NO_x in the ambient air causes a change in the cell sap pH toward an acidic value owing to SO_2 diffusion through stomata. Gaseous SO_2 dissolves in water, generating sulfates, bisulfate, and their ionic species, and the production of protons raises the cellular pH [29].A high pH may enhance the conversion of hexose sugar to ascorbic acid [30]. On the other hand, low cell sap pH extract is associated with pollution sensitivity and reduces plant photosynthetic activity. Low cell sap pH plants are more sensitive, whereas plants with 7 or higher are more resistant [30].

3.1.2 Relative Water content (RWC)

Plant weight depends on the water content and stores massive amounts of water to grow [31]. Water controls plant metabolism, growth, production, and photosynthesis. Gaseous contaminants can decrease carbon growth, water capacity, and nutrient absorption [28]. Reducing water content may cause stress. While a high-water content in plant bodies would help plants maintain their physiological homeostasis under stress, transpiration is high when exposed to air pollution. Water content in the industrial area ranges from 61.54 % to 68.74 %. *Terminalia catappa* has the lowest range of 61.54 %, whereas *Azadirachta indica* and Nerium oleander has the highest range of 68.74 %. Relative water content ranged from 69.78 % to 80.45 % in the control region. *Acacia auriculiformis* has the lowest percentage at 69.78 %, while *Tamarindus indica* has the highest percentage at 80.45 % Table 2. The water contained in a leaf relative to its full turgidity is its relative water content. High water content inside the plant body aids in the maintenance of physiological balance during stressful situations such as exposure to air pollution when transpiration rates are typically high [31]. A decrease in transpiration rate and damage to the leaf mechanism causes water to be drawn up from the roots because of air pollution (1-2 percent of the total) [31]. As a result, the plants do not provide nutrients or chill the leaf[31]. Pollutants' influence on transpiration rate in leaves causes a reduction in relative water content in plant species [32].

3.1.3 Total Chlorophyll Content (TCC)

The chloroplasts of photosynthetic plants contain the green pigment chlorophyll (green plastid organelles). It is the molecule that absorbs sunlight and converts its energy into carbs by combining CO_2 and water. Photosynthesis happens when chlorophyll converts radiant energy (from sunlight) into chemical energy owing to its intrinsic capacity (ATP). The molecules are carefully organized in and around pigment-protein complexes called photosystems embedded in chloroplast thylakoid membranes. Total Chlorophyll content plays a vital role in APTI[19]. Reducing chlorophyll content instantly causes a decrease in the productivity of plants. The Total Chlorophyll Content (TCC) of plants concentration ranges from 0.49 milligram/gram to 0.73 milligram/gram. *Pongamia pinnata* has the lowest concentration at 0.49 milligram/gram, while *Syzygium cumini* has the highest concentration at 0.73 milligram/gram. Total chlorophyll content in the control region varied from 1.20 milligram/gram to 4.49 milligram/gram. *Albizia lebbeck* has the lowest concentration at 1.20 milligram/gram, while *Terminalia catappa* has the highest concentration at 4.49 milligram/gram Table 2. The degradation of photosynthetic pigments has long been considered an indication of air pollution. The chloroplast is constantly the target of airborne pollutants. Pollutants in the air enter tissues through the stomata, causing partial denaturation of the chloroplast and reducing the pigment content of polluted leaf cells. The alkaline condition produced by the breakdown of compounds in dust particles, including as metals and polycyclic aromatic hydrocarbons, may be responsible for the decrease in chlorophyll content of leaves. The decrease might be explained by an alkaline state generated by the breakdown of chemicals in dust particles, such as metals and polycyclic hydrocarbons in the leaf cell sap.[33].

Furthermore, it has been discovered that pollution caused by vehicles is one of the primary causes of decreased chlorophyll content in plants growing near roadsides[26].As a result, the decline in chlorophyll content of contaminated site roadside plants is associated with high levels of vehicle air pollution[34]. The chlorophyll concentration of plants alters with species, leaf age, and pollution level[34]. The tolerant nature of plants may explain their more significant levels of total chlorophyll concentration[33]. As a result, plants that retain their chlorophyll concentration even in polluted environments are tolerant[34].

3.1.4 Ascorbic Acid content (AA)

Ascorbic acid content is a stress indicator of plants. It decides the plant's tolerance to air pollution due to its antioxidative properties. It also plays a vital role in photosynthesis during the light reaction and activates plant defines a mechanism[35]. Under stress conditions, it can replace water from the light response[35]. The mean concentration of ascorbic acid in the industrial area plant samples ranged between 12.21 milligram/gram and 19.30 milligram/gram. *Ficus benghalensis* has the lowest amount of 12.21 milligram/gram, whereas *Cassia fistula* has the highest value of 19.30 milligram/gram. The control area ranges from 8.91 milligram/gram to 14.59 milligram/gram. In *Artocarpus heterophyllus*, a minimum value of 8.91 milligram/gram was found. *Terminalia catappa* has the highest maximum value of 14.59 milligram/gram [Table 2]. Ascorbic acid has been linked to cell wall production, photosynthetic carbon fixation, and cell division[22]. It is also a natural antioxidant that has been shown to protect plant tissue from the harmful effects of air pollutants[23]. The reducing power of this compound is related to its concentration[36]. The high concentration of ascorbic acid aids in the increase of pollution tolerance in plants. A significant pollution indicator is given utmost importance and is thus utilized as a multiplication factor in the APTI calculation[36]. The antioxidant ascorbic acid concentration rises when overall chlorophyll levels fall to fight stress. According to Gadallah[37], ascorbic acid preserves the integrity of the chloroplast membrane and the breakdown of chlorophyll. It has also been observed that increased dehydroascorbate reductase in plants maintains photosynthetic performance stability[38]. Even the APTI value rises as the ascorbic acid concentration increases, suggesting a fundamental component that confers tolerance on plants. *Terminalia catappa* (control) and *Cassia fistula* (industrial) has the greatest ascorbic acid concentration, demonstrating the plant's ability to increase tolerance through ascorbic acid content in both areas. Ascorbic acid (AA), one of the necessary vitamins for humans, also plays key functions in growth and development[39]. As the most abundant antioxidant in plants, AA plays a significant role in scavenging Reactive Oxygen Species (ROS) during photosynthetic electron transport and stress reactions[40]. As a result, AA synthesis is tightly linked to environmental stressors[40]. AA has widely engaged in scavenging ROS in plant responses to different environmental stressors via direct or indirect routes[41]. Plants develop excess ROS under stress circumstances, leading to the peroxidation of plant lipids, proteins, and other components. The accumulating ROS disturbs the normal physiological processes of plants and causes significant harm to them. Thus, ascorbic acid is crucial for scavenging ROS under stressful circumstances[42].

3.2 Anticipated Performance Index (API)

Each plant species is assigned an API value to classify into different performance levels for use in greenbelt development[19]. In the present study, among the seventeen species *Syzygium cumini* reported under best category with high API score of 93.75% in the control area and reported under the excellent category in an industrial area. Similarly, Ficus benghalensis showed excellent control and was best in the industrial area. Species such as *Bauhinia purpurea, Artocarpus heterophyllus, Terminalia catappa, Eucalyptus citriodora* showed excellent in the both areas Table 3 and 4. The present study results compared with the API results of earlier workers reported from different cities Table 5.

The study results revealed that, the API score is more accurate in identifying air pollution-resistant species. Biological, biochemical, and physiological, socioeconomic factors, soil type, climatic conditions of plant species have a role in determining plant sensitivity and tolerance to air pollution[43].

Table 3. Evaluation and comparison of trees species based on APTI and other Biological and socioeconomic characteristics in control andindustrial areas

Name of the tree species	Study area	APTI	TH	CS	T. T	L		EV	H	GA		API grade
						S	T			Total (+)	% Scoring	
Acacia auriculiformis	Industrial	+++++	+	-	+	-	-	+	+	9	56.25	3
	Control	+++++	+	++	+	-	-	+	+	11	68.75	4
Albizia lebbeck	Industrial	+++++	++	++	+	-	-	-	+	11	68.75	4
	Control	+++++	+	++	+	-	-	-	+	10	62.5	4
Artocarpus heterophyllus	Industrial	+++++	+	+	+	+	+	++	+	13	81.25	6
	Control	+++++	++	+	+	+	+	++	+	14	87.5	6
Azadirachta indica	Industrial	+++++	++	+	+	-	-	++	+	12	75	5
	Control	+++++	++	++	+	-	-	++	+	13	81.25	6
Bauhinia purpurea	Industrial	+++++	+	+	+	++	+	++	+	14	87.5	6
	Control	+++++	+	+	+	++	+	++	+	14	87.5	6
Cassia fistula	Industrial	+++++	+	+	+	+	-	-	-	9	56.25	3
	Control	+++++	+	+	+	-	-	-	-	8	50	3
Delonix regia	Industrial	+++++	+	+	+	-	-	-	+	9	56.25	3
	Control	+++++	++	++	+	-	-	-	+	12	75	5
Eucalyptus citriodora	Industrial	+++++	+	+	+	+	+	++	+	13	81.25	6
	Control	+++++	++	+	+	+	+	++	+	14	87.5	6
Ficus benghalensis	Industrial	+++++	++	++	+	++	+	++	+	15	93.75	7
	Control	+++++	+	++	+	++	+	+	+	14	87.5	6
Mangifera indica	Industrial	+++++	++	+	+	+	+	++	-	12	75	5
	Control	+++++	++	++	+	++	+	++	-	14	87.5	6
Mimusops elengi	Industrial	+++++	-	+	+	+	-	-	-	8	50	3
	Control	+++++	-	++	+	-	-	-	-	9	56.25	3
Nerium oleander	Industrial	+++++	-	+	+	+	+	-	-	9	56.25	4
	Control	+++++	-	++	+	-	+	-	-	10	62.5	4
Pongamia pinnata	Industrial	+++++	-	+	+	+	-	+	+	10	62.5	4
	Control	+++++	+	++	+	+	-	+	+	12	75	5
Polyalthia longifolia	Industrial	+++++	+	+	+	+	-	+	+	11	68.75	6
	Control	+++++	++	+	+	+	-	+	+	12	75	5
Syzygium cumini	Industrial	+++++	+	++	+	+	+	++	+	14	87.5	5
	Control	+++++	++	++	+	++	+	++	+	15	93.75	7
Tamarindus indica	Industrial	+++++	+	++	+	-	-	++	+	12	75	5
	Control	+++++	++	++	+	++	-	++	+	13	81.25	6
Terminalia catappa	Industrial	+++++	+	++	+	+	+	+	+	13	81.25	6
	Control	+++++	+	+	+	+	+	+	+	13	81.25	6

1.*APTI=Air Pollution Tolerance Index, TH tree height, CScanopy structure, TT type of tree, L laminar structure, S leaf size, T texture, EE economic value, H hardness, GA grade allotted, Total(+) score, API Anticipated Performance Index

Table 4. Anticipated performance index (API) of trees species in two different environmental backdrops

Name of the tree species		Grade allotted	API value %	API grade	Assessment
Ficus benghalensis	I	15	93.75	7	
	C	14	87.25	6	E
Bauhinia purpurea	I	14	81.25	6	E
	C	14	87.25	6	E
Syzygium cumini	I	14	87.5	6	E
	C	15	93.75	7	
Artocarpus heterophyllus	I	13	81.25	6	E
	C	14	87.25	6	E
Terminalia catappa	I	13	87.25	6	E
	C	13	81.25	6	E
Eucalyptus citriodora	I	13	81.25	6	E
	C	14	87.25	6	E
Mangifera indica	I	12	75	6	VG
	C	14	87.25	6	E
Tamarindus indica	I	12	75	5	VG
	C	13	81.25	6	E
Azadirachta indica	I	12	75	5	VG
	C	13	81.25	6	E
Albizia lebbeck	I	11	68.75	3	G
	C	10	56.25	3	M
Polyalthia longifolia	I	11	68.75	4	G
	C	12	75	5	VG
Pongamia pinnata	I	10	62.25	4	G
	C	12	75	5	VG
Acacia auriculiformis	I	9	56.25	3	M
	C	11	56.25	3	M
Cassia fistula	I	9	56.25	3	M
	C	8	50	2	
Delonix regia	I	9	56.25	3	M
	C	12	75	5	VG
Nerium oleander	I	9	56.25	3	M
	C	10	56.25	3	M
Mimusops elengi	I	8	50	2	
	C	9	56.25	3	M

*C Control; I Industrial, B Best, E Excellent, M Moderate, P Poor, VG Very Good

Table 5. Comparison of API grades of the present study with earlier studies conducted at different cities

Name of the tree species	API grade	Study area	Author
Ficus benghalensis and *Mangifera indica*	Excellent	Burdwan Town, Bengal	Gupta et al., [44]

Continued on next page

Table 5 continued

Ficus benghalensis	Excellent	Varanasi City, Utter Pradesh	Pathak et al., [45]
Syzygium cumini	Excellent		
Artocarpus heterophyllus	Good		
Terminalia catappa	Moderate		
Tamarindus indica	Good		
Ficus benghalensis	Excellent	Aurangabad city	Chavan et al., [46]
Terminalia catappa	Good	University of Ilorin	Ogunkunle et al., [47]
Ficus benghalensis	Best		
Bauhinia purpurea	Excellent		
Syzygium cumini	Excellent		
Artocarpus heterophyllus	Excellent	Industrial area of Visakhapatnam	Present Study
Terminalia catappa	Excellent		
Eucalyptus citriodora	Excellent		
Mangifera indica	Very Good		
Tamarindus indica	Very Good		

3.3 Correlation results

The correlation coefficient analysis were performed between various biochemical parameters such as cell sap pH, relative water content, total chlorophyll, and ascorbic acid in both control and industrial area to assess the impact of air pollution on plant tolerance. The results revealed that in the control area, a significant correlation (<0.01 level) has existed among all biochemical parameters, whereas in the industrial area, the relation among the parameters is non-significant. This clearly indicates that the tree species in the industrial area were having stress and facing a reduction in resource capture ability. The higher value of ascorbic acid in industrial tree species is an indication of reduction in resource capture[48]. The changes in biochemical parameters manifest changes in the tolerance level of species Table 6.

Table 6. Corelation coefficient among various biochemical parameters

		Cell sap pH	RWC	TCC
RWC	Control	0.689^{**}		
	Industrial	0.275^{ns}		
TCC	Control	0.840^{**}	0.624^{**}	
	Industrial	0.088^{ns}	0.017^{ns}	
AA	Control	0.669^{**}	0.596^{**}	0.873^{**}
	Industrial	0.200^{ns}	0.433^{ns}	0.032^{ns}

** significant at 0.01 level; ns- nonsignificant; n=17

The detrimental effects of various pollutants or contaminants on plants' morphological, anatomical, and physiological parameters are well documented. Still, a specific parameter effect is not sufficient to comprehend the multiple changes induced by pollutants[25,35].The APTI is recognized as a crucial parameter in biomonitoring studies of plants, and Zhang et al.[49] have used this index for air monitoring in industrial areas due to its effectiveness in assessing the influence of pollutants on their biochemical parameters. *Ficus benghalensis* showed the highest API value among all species compared with other species.

In addition to APTI, the Anticipated Performance Index (API) is used for green belt expansion[49]. The API is enrichment over the APTI, used to identify the suitability of tree species for green belt development by examining the potentiality of prevailing species to reduce air pollutants. A greenbelt is the mass plantation of pollution-tolerant tree species (deciduous and evergreen) for air pollution mitigation in an effective system by intercepting, filtering, and absorbing pollutants[49]. A greenbelt is the mass plantation of pollution-tolerant tree species (deciduous and evergreen) for air pollution mitigation in an effective system by intercepting, filtering, and absorbing pollutants[49]. *Ficus benghalensis* showed the highest API value among all species compared with other species. Similarly, *Bauhinia purpurea*; *Syzygium cumini; Artocarpus heterophyllus; Terminalia catappa; Eucalyptus citriodora; Mangifera indica; Tamarindus indica; Azadirachta indica; Acacia auriculiformis*, and *Polyalthia longifolia* are reported under excellent API grade Tables 3 and 4.

4 Conclusions

The present study provides information for 17 dominant tree species of both urban and industrial vegetation of Visakhapatnam city. Further, the study found that the eleven tree species (*Ficus benghalensis; Bauhinia purpurea; Syzygium cumini; Artocarpus heterophyllus; Terminalia catappa; Eucalyptus citriodora; Mangifera indica; Tamarindus indica; Azadirachta indica; Acacia auriculiformis*, and *Polyalthia longifolia*) are relatively more tolerant at study area and can be used for the development of green belt. These species may help scavenge more significant amounts of ambient air pollutants than other existing species at Visakhapatnam. The studies suggest that the ratio of the ascorbic acid/chlorophyll of these species at different sites can be used as an indicator for pollution monitoring. However, more studies from other geographical regions and more species are needed to validate this ratio's importance in biomonitoring.

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