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Assessment of Air Pollution Tolerance Indices (APTI) and Anticipated Performance Index (API) of roadside tree species of Bilaspur, Chhattisgarh, India

Prasen Jeet and Anupama Mahato

Department of Forestry, Wildlife and Environmental Sciences, Guru Ghasidas Vishwavidyalaya, Chhattisgarh, India

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Corresponding Author: Anupama Mahato

Abstract

The rapid increase in the number of cars in and around urban centers has led to an increase in vehicular pollution. Vehicular pollutants cause significant changes in the biochemical and physiological processes of roadside trees as they are constantly exposed to air pollutants. The aim of this study is to comparatively assess the effects of road side pollution on tree species in urban, sub urban and control sites of the Bilaspur district of Chhattisgarh. Seven tree species (*Alstonia scholaris*, *Butea monosperma*, *Cassia siamea*, *Dalbergia sissoo*, *Ficus religiosa*, *Mangifera indica*, *Peltophorum ferrugineum*) have been selected for this study which were common to all sampling sites. APTI and API of tree species were estimated. The ascorbic acid content, leaf pH, total chlorophyll content and relative water content were used to calculate APTI, which is used to identify tolerant and sensitive plant species in various locations. On the basis of APTI and some biological and socioeconomic parameters of trees, the Anticipated Performance Index (API) of these trees was calculated. Among all the trees *Mangifera indica* taken under first rank and consider 'best' species. *Ficus religiosa* is categorised as an 'excellent' tree species. *Dalbergia sissoo*, *Cassia siamea* and *Peltophorum ferrugineum* were classified into the 'good' category in the urban area and recommended for the green belt development and road side plantation.

Keywords: Vehicular pollutants, APTI, Relative water content, total chlorophyll, road side plantation

Introduction

Automobiles are the main source of air pollution and automobile exhausts are responsible for more than 75% of all urban air pollution. Primary gaseous pollutants emitted directly from the auto-exhaust system (CO, HC and NO_x), the most toxic being CO. However, hydrocarbons and oxides of nitrogen are also a cause of concern. Secondary pollutants such as ozone, smog etc. are also harmful and a cause of concern.

Trees growing in polluted area exhibit differences in leaf micro-morphological characteristics of leaves, stomatal index, epidermal cell size, trichome density, stomatal aperture size, cuticular variations etc. (Banerjee *et al.*, 2022) [6]. Micro-morphological traits or leaf surface properties are very sensitive to air pollution and their response can be used as indicators of air pollution (Uka *et al.*, 2017) [74]. Air pollutants primarily target the leaf surface's epicuticular wax layer (Bassin *et al.*, 2013) [7].

Plants also serve as sinks of air pollutants and this helps to reduce air pollution through scavenging (Weyens *et al.*, 2015) [80]. The response of tree species towards air pollutants varies from one species to another and from one season to a different season, depending on the nature of pollutant. Leaf surfaces are directly exposed to pollutants and are susceptible to damage (Roy *et al.*, 2024) [62]. The leaf surface comprises the cuticle, which consists of cutin, wax and appendage such as trichomes. The function of surface structures of tree is protection against desiccation, frost and pathogen infestation (Hirano *et al.*, 2000) [22]. The cells,

which are mainly exposed to air pollutants are epidermal cells, but the waxy cuticle is a potential barrier for most air pollutants (Agarwal *et al.*, 2019) [2]. However acidic gases can dissociate and react with cuticular waxes and enter into leaves by penetrating the damaged cuticle (Gupta, 2016) [20]. The pH variation in trees is important for the detoxification process and tolerance (Thawale *et al.*, 2011) [73]. A high pH may indicate a plant species tolerance to pollutants, while low pH indicates tolerance to air pollutants (Govindaraju *et al.*, 2012, Saxena *et al.*, 2012) [19, 66]. Plants exposed to air pollutants, particularly SO₂ produce significant amounts of H⁺ to react with SO₂, which enters through the stomata, resulting in formation of sulphuric acid (H₂SO₄) thus causing reduction in leaf pH (Jenkins, 2001) [24]. It has been reported that leaf extracts with higher pH values result in higher absorption of SO₂ and NO_x (Muneer *et al.*, 2014) [45]. Plant pigments chlorophyll and carotenoids play an important role in photosynthesis as well as in protecting plants from excessive radiation. They convert light energy into chemical energy (Britton & Young, 1993, Sims & Gamon, 2002) [11, 69]. Chlorophyll plays a unique role in the physiology and productivity of green plants and its concentration per unit area is an indicator of a plant's photosynthetic capacity and productivity (Palta, 2019) [50]. APTI is the ideal tool for identifying tree responses to the pollution load at different locations in the study area. Tree species were divided into sensitive and tolerant categories based on their response to air pollution. Air pollution tolerance is also influenced by climatic conditions such as

humidity, temperature, precipitation and photoperiod. These parameters can be used to create bioindicator groups and are crucial for comprehending interactions between plants and their surroundings. The plant species that falls in the intermediate to tolerant category based on APTI values can be used for greenbelt development in high pollution areas. The air pollution tolerance index indicates the capability of a plant to combat air pollution. Plants with a low index value can be used to indicate levels of air pollution, those with a higher index value are more tolerant of air pollution and can be used as a sink to reduce it (Bharti *et al.*, 2018, Kaler *et al.*, 2017)^[10, 26].

Several studies (Singh *et al.* 2024, Vlachokostas *et al.*, 2014)^[71, 77] reported in their research that all tree species are not equally suitable for urban environment due to varying tolerance to air pollution. The indices used to assess the tolerance of tree species to air pollution depend on various physiological and biochemical parameters such as chlorophyll content, relative water content of leaves, pH of leaf extract and ascorbic acid. Trees have a dual effect: on the one hand, they are the most affected by pollutants, and on the other, plants can remove pollutants from their surroundings and improve air quality (Vlachokostas *et al.*,

2014)^[77].

Study area

Bilaspur is located in the state of Chhattisgarh, 110 kilometres from the state capital Raipur. It is the second largest city, in the state after Raipur and is located at 22° 4' 43.11" North latitude and 82° 9' 8.38" East longitude, at an altitude of 207 meters above sea level. Bilaspur city has a total area of 145.76 km², a population of 3,31,030 (Census, 2011) and a population density of 322/km². The city of Bilaspur is located on the bank of the Arpa River which is known to be its lifeline (Koshale and Mahato, 2022)^[29]. It flows from the hills of the Maikal range in Central India. The winter temperature in the region ranges from 10°C to 28°C, while the summer temperature ranges from 20°C to 45°C. In the district of Bilaspur, Ratanpur is a nagarpanchayat and suburban town. It is located at 22°16'52.38' North latitude and 82°9'18.16' East longitude, at an altitude of 306 meters and 25 kilometres from Bilaspur city.

The aim is to determine the effects of vehicular pollutants on the physiology of tree species in urban, suburban, and control sites.

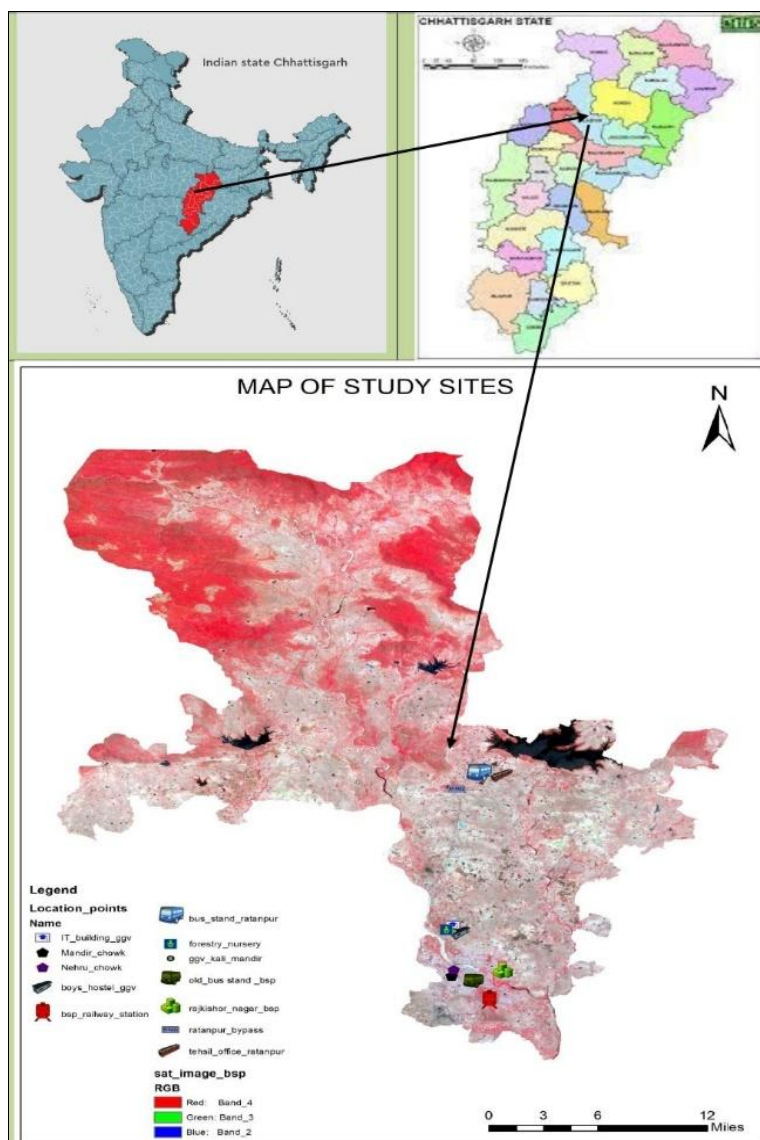


Fig 1: Location map of the study area with sampling sites

For the current study, six locations were selected to examine vehicular pollution and its effects on tree physiology and biochemistry. Maximum three locations were selected from the Bilaspur city area (U-1, U-2 and U-3). The urban site (U-1) has a high vehicular load and is close to Nehru Chowk. Site U-3 has a lot of traffic and is near the railway station, while Site U-2 is near the old bus stop.

Ratanpur which is approximately 25 kilometres from Bilaspur city, was chosen as the suburban site (Koshale and Mahato, 2020)^[30]. Site (suburban) SU-1 at Ratanpur bypass and SU-2 at the Ratanpur bus stop were chosen for the suburban area.

Guru Ghasidas Vishwavidyalaya (GGV) campus was selected as the control site (C). The university is spread over an area of 262 hectares with lush green vegetation (Chandra *et al.*, 2022)^[12]. Due to access restriction, the control site has a lower vehicle load compared to the urban and suburban sites.

Methodology

Leaf sample collection

For this study, seven urban road-side tree species (*Alstonia scholaris*, *Butea monosperma*, *Cassia siamea*, *Dalbergia sissoo*, *Ficus religiosa*, *Mangifera indica*, *Peltophorum ferrugineum*) that are common in study sites were collected. Seasonally, leaf samples were collected in the afternoon. To assess the biochemical parameters, healthy plant leaves were randomly picked from a height of 5 m above the ground and transferred to the laboratory. Samples were analyzed in the laboratory within 24 hours of collection.

Biochemical analysis of leaf samples

- 1. Ascorbic acid analysis:** Ascorbic acid is a powerful reducing agent found in the leaf. This activates many physiological and resistance mechanisms in trees. The reducing power is directly proportional to the concentration of ascorbic acid. In the process of photosynthesis, ascorbic acid plays a role in carbon fixation, where it acts as a reducing agent (Yu *et al.*, 2020)^[82]
- 2. Leaf pH extraction:** The photosynthetic efficiency of plant species is highly dependent on leaf pH (Koyro, 2006).^[31] Increased pH in plant leaves plays a role in the conversion of hexose sugars to ascorbic acid (Escobedo *et al.*, 2008)^[18] while decreased pH is thought to be associated with sensitivity to air pollution (Beckwith *et al.*, 2020)^[8].
- 3. Leaf Relative Water Content (LRWC) analysis:** High relative water content in leaves helps plants maintain of the physiological balance under stressful conditions (Maghsoudi *et al.*, 2016)^[37]. The high RWC value indicates a higher stress resistance of the trees (Roy *et al.*, 2020)^[61]. The pH of cytosol is maintained by the relative water content in the leaves and also

helps to dissolve the air pollutants in the cytosol.

- 4. Total Chlorophyll:** Total chlorophyll content of leaves is often used to evaluate of the effect of air pollutants on the rate of photosynthesis in plant leaves (Sharma *et al.*, 2018)^[68]. Total chlorophyll is responsible for tree activities such as photosynthesis, growth and biomass production through the process of carbon assimilation. Air pollutants such as sulphur dioxide (SO₂) reduce chlorophyll levels in trees and are responsible for sensitivity to air pollution.

$$\text{Chlorophyll a } \left(\frac{\text{mg}}{\text{g}} \right) = \frac{12.7D663 - 2.69D645 * V}{1000 * W}$$

$$\text{Chlorophyll b } \left(\frac{\text{mg}}{\text{g}} \right) = \frac{22.9D645 - 4.68D663 * V}{1000 * W}$$

Total Chlorophyll = Chlorophyll a + b

Where, D = distance travelled by light path (cm), W = Fresh weight of leaf material (mg), V = Volume of extract (ml) and OD = Optical density (nm)

- 5. Air Pollution Tolerance Indices (APTI):** The APTI values were estimated from the four biochemical parameters in tree leaves, namely RWC, total chlorophyll content, pH value and ascorbic acid value.

The Air Pollution Tolerance Indices (APTI) of seven tree species were determined using the following formula:

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

Where, A=Ascorbic acid content (mg/g), T=total chlorophyll (mg/g), P=pH of leaf extract and R=Relative water content of leaf (%).

Table 1: Categories of tree species based on APTI (Kalyani & Singaracharya, 1995)^[27]

APTI value	Response
≤1	very sensitive
1 to 16	sensitive
17 to 29	intermediate
30 to 100	tolerant species

- 6. Anticipated Performance Index (API):** The API was calculated for different tree species by combining the resulting APTI values with some relevant biological and socioeconomic characteristics (tree habits, canopy structure and economic value). Based on these characteristics, the trees are assigned different grades (+/-). Each tree was assessed differently based on the criteria used to compute the API.

Table 2: Gradation of plant species based on APTI and other phenotypic and socioeconomic characteristics (Panda & Rai, 2014) ^[51].

S. No.	Grading character		Pattern assessment	Grade allotted
1	Tolerance	Air Pollution Tolerance Indices (APTI)	5.1-6.0	+
			6.1-7.0	++
			7.1-8.0	+++
			8.1-9.0	++++
			9.1-10	+++++
2	Biological and Socio-Economic	Tree size	Small	-
			Medium	+
			Large	++
		Canopy structure	Sparse/ Irregular/ Globular	-
			Spreading crown/ open/ semi dense	+
			Spreading dense	++
		Type of plant	Deciduous	-
			Evergreen	+
		Laminar structure	Size	
			Small	-
			Medium	+
			Large	++
		Texture	Smooth	-
			Coriaceous	+
		Hardiness	Delineate	-
			Hardy	+
		Economic value	Less than three uses	-
			Three or four uses	+
			Five or more uses	++

Table 3: Anticipated Performance Index (API) of plant species (Prajapati & Tripathi, 2008) ^[57]

Grade	API 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

7. Statistical analysis: Statistical analysis of the data was done using Microsoft excel software.

Results and Discussion

Street trees are an important tool in urban planning and also help mitigate a number of climate-related urban problems (Mahato *et al.*, 2024, Salmond *et al.*, 2016) ^[41, 65]. Sadat (2020) ^[63] explained that selection should be done carefully and care should also be taken to maximize the potential of the trees. Urban trees act as important sinks for particulate matter and the use of plants to improve particulate matter pollution has been widely identified as an environmentally friendly and sustainable approach (Nowak *et al.*, 2013, Prajapati & Tripathi, 2008) ^[47, 58].

In the present research, the seven most common tree species found (*Alstonia scholaris*, *Butea monosperma*, *Cassia siamea*, *Dalbergia sissoo*, *Ficus religiosa*, *Mangifera indica* and *Peltophorum ferrugineum*) at all sites have been selected.

1. Ascorbic acid analysis: The ascorbic acid content in the leaf chloroplast determines the amount of chlorophyll present. Several research (Lohe *et al.*, 2015, Iqbal *et al.*, 2015) ^[36, 23] reported that chlorophyll content in the leaves carries the variable number of

pollutants present in the cells of that plant. Such content helps the plant develop the plant's resistance mechanism to air pollutants.

At the control site, *Mangifera indica* (1.64 mg/g) had the highest ascorbic acid content, while *Ficus religiosa* (0.67 mg/g) had the lowest ascorbic acid content. At the Urban site, *Mangifera indica* (1.54 mg/g) had the highest ascorbic acid content, while *Peltophorum ferrugineum* (0.96 mg/g) and *Dalbergia sissoo* (0.87 mg/g) had the lowest ascorbic acid content. Table 4 displays the ascorbic acid content at the control site, suburban and urban sites. In the urban and suburban sites, all tree species showed increased ascorbic acid content, except *Mangifera indica*, which had reduced ascorbic acid content compared to the control site. Increased ascorbic acid content in trees despite exposure to environmental pollution, therefore, indicates a high tolerance of the plant to the pollution. Ascorbic acid is said to be able to reduce the amount of ozone that penetrates the cell wall to reach the plasma membrane (Bellini & De, 2019, Alayafi, 2020) ^[9, 4]. A common antioxidant in plant parts, ascorbic acid contributes to resistance to air pollution (Pathak *et al.*, 2011) ^[56]. Ascorbic acid is known as a vital reducing agent and is therefore very important for cell wall synthesis, defence and cell division (Conklin, 2001) ^[14].

In the present study *Alstonia scholaris*, *Butea monosperma*, *Cassia siamea*, *Ficus religiosa* and *Peltophorum ferrugineum* showed that the concentration of ascorbic acid in the urban and suburban site were higher than control site. In *Mangifera indica*, ascorbic acid content at the urban site was 6.1% lower at the urban site and 12.2% lower at the suburban site than at the control site. Pollution stress caused an increase in the ascorbic acid content of all plant species, with the exception of *Mangifera indica*. This is because the production rate of Reactive Oxygen Species (ROS) remains higher during photo-oxidation (Nwadinigwe, 2014, Rai *et al.*, 2013) ^[48, 60].

Varshney & Varshney (1985) ^[75] reported that the higher ascorbic acid content of the plant indicates its immunity to pollution caused by sulphur dioxide. Researchers have reported higher ascorbic acid content at the control site and reduced ascorbic acid content at the experimental sites (Rai & Panda, 2014, Jyothi & Jaya, 2010) ^[59, 25].

2. Leaf pH extraction: Plants having low pH value are susceptible to air pollution (Bharti *et al.*, 2018) ^[10]. The elevated pH causes hexose sugar to be converted to ascorbic acid (Ogagaoghene, 2017) ^[49]. Plants absorb NO_x and SO₂ due to the high pH of the leaves. At the control site *Dalbergia sissoo* (7.5) showed the highest pH, while *Cassia siamea* (4.3) showed the lowest pH, and at the suburban site, *Ficus religiosa* (7.8) showed the highest pH, while *Cassia siamea* (4.4) showed the lowest pH value. In the urban and suburban sites, all tree species exhibited lower pH compared to the control site. Leaf exposure to acidic pollutant such as SO_x and NO_x results in a decrease in leaf pH, and this decrease is more pronounced in sensitive trees than in tolerant trees (Bharti *et al.*, 2018) ^[10]. The cellular system functions well at optimal pH, but when exposed to acidic pollutants for a long period of time, the pH decreases in less tolerant species, thus disrupting the plants biological activities (Verkleij *et al.*, 2009) ^[76].

The results of the present study indicate that the pH of leaf extracts at the urban and suburban sites was lower than that at the control site. A similar observation was reported in (Bharti *et al.*, 2018) ^[10]. Lower pH was observed in leaf extract where road side SO₂ value was higher. These properties suggest that the pH of the leaf extract could be used as an indicator of vehicular air pollution. While high pH may improve the efficiency of the conversion from hexose sugar to ascorbic acid, low pH demonstrated a strong correlation with sensitivity to air pollution (Escobedo *et al.*, 2008) ^[18].

3. Leaf Relative Water Content (LRWC) analysis: Relative Water Content (RWC) is the amount of water contained in the leaf compared to its fully turgid state. In highly polluted area, plants limit the transpiration process to maintain the balance of plants physiological activities. Pollutants reduce the level of relative water content in plants and influence the rate and process of tree transpiration rate (Wang *et al.*, 2011, Ashenden, 1979) ^[78, 51]. In this study, *Alstonia scholaris*, *Butea monosperma*, *Cassia siamea*, *Dalbergia sissoo*, *Ficus religiosa* and *Mangifera indica*, had higher relative water content at the urban and suburban sites than at the control site. Thus, the higher relative water content in the urban and suburban sites might be responsible for combating pollution stress for the normal functioning of biological processes. Under stressful conditions, high relative water content inside a plant ensures the maintenance of its physiological equilibrium. The relative water content is related to the permeability of protoplasm in the cells, resulting in loss of water along with dissolved nutrients, resulting in drying of leaves (Agrawal & Tiwari, 1997) ^[3]. A high relative water content indicates drought resistance in plants (Dedio

1975) ^[16]. It also helps maintain physiological balance under stressful conditions. Plants with high relative water content are more tolerant to pollutants.

4. Total Chlorophyll: The degradation of photosynthetic pigments is often used as an indicator of air pollution (Ninave *et al.*, 2001) ^[46]. Trees with higher chlorophyll content were resistant to increased pollution rates (Talebzadeh & Valeo, 2022) ^[72]. At the control, suburban and urban sites, *Peltophorum ferrugineum* (3.99, 3.72 and 3.48mg/g) had the highest chlorophyll content, while *Alstonia scholaris* (1.54, 1.11 and 1.17mg/g) had the lowest chlorophyll content. The present study found that the chlorophyll content of all tree species decreased in urban and suburban sites compared to the control site. The present study showed that the total chlorophyll content in all tree species varies with the pollutant load of the area. It is worth noting that a rise in the level of pollution, primarily from automobile exhaust, is correlated with a decrease in chlorophyll content. This observation is noteworthy in the study of plant physiology and ecology.

The present study found that total leaf chlorophyll content decreased significantly in urban and suburban areas compared to the control area. *Alstonia scholaris*, *Butea monosperma*, *Cassia siamea*, *Dalbergia sissoo*, *Ficus religiosa*, *Mangifera indica* and *Peltophorum ferrugineum* showed a reduction in the total amount of chlorophyll in urban and suburban area. The maximum reduction percentage was found in *Alstonia scholaris* (28.57%), followed by *Ficus religiosa* (16.84%), *Dalbergia sissoo* (10.88%), *Mangifera indica* (8.16%), *Peltophorum ferrugineum* (6.77%), *Cassia siamea* (5.20%) and *Butea monosperma* (3.83%) at the urban site compared to the control site. In contrast, the percentage reduction in total chlorophyll at the suburban site was highest in *Ficus religiosa* (34.69%), followed by *Alstonia scholaris* (24.18%), *Mangifera indica* (22.70%), *Dalbergia sissoo* (13.47%), *Peltophorum ferrugineum* (12.78%), *Cassia siamea* (9.83%) and *Butea monosperma* (7.18%) respectively. The decline in leaf chlorophyll content may be attributable to the alkaline condition generated by the dissolution of chemicals within in dust particles, such as metals and polycyclic hydrocarbons, which impede the diffusion of air through stomatal pores. This impediment places a stress on the plant metabolism, leading to chlorophyll degradation (Wang, 2019) ^[79].

5. Air Pollution Tolerance Indices (APTI): APTI is a composite measure of tree health (Panda *et al.*, 2018) ^[52]. APTI is calculated from the ascorbic acid, total chlorophyll, pH and relative water content of the leaf extract. APTI is an effective tool for assessing air pollution because these parameters are influenced by air pollutants (Molnar *et al.*, 2020) ^[43]. APTI can also provide information about the cities pollution levels based on trees. According to Yadav and Pandey (2020) ^[81], plants that fall into the excellent, very good and good performers APTI categories are recommended for the development of green belts. As a bio-indicator, APTI sensitive trees can be employed (Latwal *et al.*, 2023) ^[33].

Table 4: APTI value of different tree species at different sites

Sites Tree species	pH			TCh (mg/g)			RWC (%)			AA (mg/g)			APTI		
	U	SU	C	U	SU	C	U	SU	C	U	SU	C	U	SU	C
<i>Alstonia scholaris</i>	5.7	5.8	6.1	1.17	1.11	1.54	79.9	72.1	51.8	1.31	1.12	0.99	8.89	8.00	5.9
<i>Butea monosperma</i>	6.2	6.3	6.5	1.94	2.01	2.09	66.7	59.5	55.7	1.28	1.25	1	7.72	7.00	6.4
<i>Cassia siamea</i>	4.3	4.4	4.3	1.56	1.63	1.73	65.4	58.5	54	1.22	1.05	0.85	7.26	6.50	5.9
<i>Dalbergia sissoo</i>	7.4	7.5	7.5	1.67	1.71	1.93	76.5	69.8	61.4	0.87	0.73	0.73	8.44	7.70	6.8
<i>Ficus religiosa</i>	7.3	7.8	8	1.28	1.62	1.96	87.5	83.7	79.8	1.07	1.07	0.67	9.67	9.40	8.6
<i>Mangifera indica</i>	5.7	6	6.1	2.18	2.59	2.82	80.7	78.3	52.2	1.54	1.44	1.64	9.28	9.10	6.7
<i>Peltophorum ferrugineum</i>	6.7	6.9	7	3.48	3.72	3.99	59.9	41.2	43.4	0.96	1.1	0.82	6.97	5.30	5.2

Note: pH=Leaf pH, TCh=Total Chlorophyll, RWC= Relative Water Content, AA= Ascorbic Acid, U=Urban, SU=Sub-Urban, C= Control sites

In the control, suburban and urban sites, *Ficus religiosa* (79.8, 83.7 and 87.5%) showed the highest leaf relative water content, while *Peltophorum ferrugineum* (43.4, 41.2 and 59.9%) showed the lowest leaf relative water content.

In the present study, in urban sites, *Ficus religiosa* (9.67) showed the highest APTI value while *Peltophorum ferrugineum* (5.20) had the lowest APTI value at control site.

Across all seasons and for seven tree species, the Air Pollution Tolerance Index (APTI) varied from 5.20 to 9.67. At the suburban site (Table 4), the highest APTI value was observed in *Ficus religiosa* (9.40), followed by *Madhuca indica* (9.10). While *Alstonia scholaris*, *Butea monosperma*, *Cassia siamea*, *Dalbergia sissoo* and *Peltophorum ferrugineum* had APTI value of 8.0, 7.0, 6.5, 7.7 and 5.3 respectively.

Since APTI values were below 16 for all seven tree species examined, they all fall into the 'sensitive' category. All of these tree species could be conveniently used as bioindicators given their relative advantages compared to traditional physicochemical monitors. Air pollution affects all tree species. Not only tolerant tree species help reduce air pollution, but sensitive trees also maintain ecological balance, by controlling soil erosion and improving the aesthetic aspects of polluted areas (Zhang *et al.*, 2013) [84]. The sensitive species can serve as biological indicators of air pollution, while the tolerant species are considered as sinks and are intended to be used to control pollutant levels in that specific environment (Shannigrahi *et al.*, 2004) [67]. Similar studies on air pollution tolerance index were also conducted by Karthiyayini *et al.*, (2005) [28], Agbaire & Esiefarienrhe (2009) [1], Pandey *et al.* (2015a) [53]. The reason for the high susceptibility of the sensitive tree species to the vehicle pollutants, which inhibit or enhance the

various biochemical and physiological factors, is their high dust absorption capacity (Singh *et al.*, 2020) [70]. Molnar *et al.* (2020) [43] reported that more particulate matter was deposited on tree leaves in the urban study area compared to industrial and rural locations.

6. Anticipated Performance Index (API): Tree species for roadside green belt development were assessed based on their APTI and relevant socio-economic and biological parameters. These parameters were subjected to a grading scale to determine the anticipated performance of the tree. The grading pattern of tree species evaluated is presented in Table 3.

Based on Anticipated Performance Index (API) at the control site (Table 5), *Mangifera indica* was rated very good, *Ficus religiosa* was rated good, followed by *Cassia siamea*, *Dalbergia sissoo* and *Peltophorum ferrugineum* each for moderate. While the other tree species *Butea monosperma* was rated as poor and *Alstonia scholaris* as very poor.

At the suburban site (Table 5), *Mangifera indica* was rated best, *Ficus religiosa* was rated excellent, followed by *Cassia siamea* and *Dalbergia sissoo* each with 'good'. While the other tree species *Peltophorum ferrugineum* were rated as moderate, *Alstonia scholaris* and *Butea monosperma* each performed poorly.

At the urban site (Table 5), *Mangifera indica* performed best, *Ficus religiosa* excellent, followed by *Cassia siamea*, *Dalbergia sissoo* and *Peltophorum ferrugineum* each with good. On the other hand, *Alstonia scholaris* and *Butea monosperma* were classified as moderate tree species. The tree species selected above have a dense canopy and most of them are evergreen.

Table 5: API of tree species at different sites control (a), sub-urban (b) and urban sites (c)

Tree species	APTI Value	Tree habit	Canopy Structure	Type of tree	Laminar structure			Economic Importance	Grade allotted Total plus	% of score	API gradation	Assessment
					Size	Texture	Hardness					
A	+	+	+	+	-	-	+	+	6	37.5	1	VP
B	++	+	+	-	+	+	+	+	8	50	2	P
C	+	++	+	+	+	+	+	+	9	56.25	3	M
D	++	++	+	-	+	+	+	+	9	56.25	3	M
F	+++	++	+	-	++	+	+	+	11	68.75	4	G
M	++	++	++	+	++	+	+	+	12	75	5	V
P	+	++	+	-	++	+	+	+	9	56.25	3	M

Tree species	APTI Value	Tree habit	Canopy Structure	Type of tree	Laminar structure			Economic Importance	Grade allotted Total plus	% of score	API gradation	Assessment
					Size	Texture	Hardness					
A	+++	+	+	+	-	-	+	+	8	50	2	P
B	++	+	+	-	+	+	+	+	8	50	2	P
C	++	++	+	+	+	+	+	+	10	62.5	4	G
D	+++	++	+	-	+	+	+	+	10	62.5	4	G
F	+++++	++	+	-	++	+	+	+	13	81.25	6	E
M	+++++	++	++	+	++	+	+	+	15	93.75	7	B
P	+	++	+	-	++	+	+	+	9	56.25	3	M

Tree species	APTI Value	Tree habit	Canopy Structure	Type of tree	Laminar structure			Economic Importance	Grade allotted Total plus	% of score	API gradation	Assessment
					Size	Texture	Hardness					
A	++++	+	+	+	-	-	+	+	9	56.25	3	M
B	+++	+	+	-	+	+	+	+	9	56.25	3	M
C	+++	++	+	+	+	+	+	+	11	68.75	4	G
D	++++	++	+	-	+	+	+	+	11	68.75	4	G
F	+++++	++	+	-	++	+	+	+	13	81.25	6	E
M	+++++	++	++	+	++	+	+	+	15	93.75	7	B
P	++	++	+	-	++	+	+	+	10	62.5	4	G

Note: A= *Alstonia scholaris*, B= *Butea monosperma*, C= *Cassia siamea*, D= *Dalbergia sissoo*

F= *Ficus religiosa*, M= *Mangifera indica*, P= *Peltophorum ferrugineum*, VP= Very Poor, P= Poor, M= Moderate, G=Good, E=Excellent, B= Best

of the seven tree species, *Mangifera indica* and *Ficus religiosa* were found to be the best and most outstanding and suitable tree species for green belt development. *Cassia siamea*, *Dalbergia sissoo* and *Peltophorum ferrugineum* were judged to be 'good' performer and considered efficient in controlling air pollution. *Alstonia scholaris* and *Butea monosperma*, on the other hand, qualified for the category of 'moderate' performer, which are also preferred for roadside plantation. Therefore, an assessment of the anticipated performance index of tree species could be very useful in selecting suitable tree species for green belt development and considering them beneficial for heavy traffic areas or planting along roadsides (Pandey *et al.*, 2015b and Mohammadi *et al.*, 2018) ^[54, 42]. Furthermore, such physiological studies should be repeated, to provide more information about the sensitivity and tolerance of different tree species, which can be used to mitigate of air pollution along roadsides and urban areas. The ground truthing of the urban green spaces of Bilaspur city shows that 83 species belonging to 15 families are found here (Mahato *et al.*, 2024) ^[41].

The study reveals that *Alstonia scholaris* and *Butea monosperma* were expected to perform poorly in the control and suburban sites and moderate in the urban sites. Similar results were observed by Dhankhar *et al.* (2015) ^[17], and they reported that *Alstonia scholaris* growing around the university campus of Rohtak, Haryana showed poor performance. Mondal *et al.*, (2011) ^[44] reported moderate performance of *Alstonia scholaris*, in their study. Conversely, Gupta *et al.* (2011) ^[21] found that the best tree for plantation around the industrial area with the pollution of various heavy metals is *Alstonia scholaris*, while Pandey *et al.* (2015a) ^[53] reported that the good performance of *Alstonia scholaris*, *Cassia siamea* and *Dalbergia sissoo* and these species were expected to be moderate in control and good performer at urban and suburban areas. Similar results were reported by Mondal *et al.* (2011) ^[44] who reported that *Dalbergia sissoo* showed moderate performance in Golapbag campus of Burdwan University. Pathak *et al.* (2011) ^[56] evaluated the API of some tree species growing on the roadside in Varanasi city and reported that *Cassia*

siamea performed moderately. *Ficus religiosa* and *Mangifera indica*'s API was assessed, and it was found that *Ficus religiosa* performed well at the urban, suburban and control site, while *Mangifera indica* showed the better performance at the control site and at urban and suburban sites. Pathak *et al.* (2011) ^[56] evaluated the APTI of 35 tree species growing near the city of Varanasi and found that *Ficus infectoria*, *Mangifera indica* and *Ficus religiosa* had higher resistance potential to pollution load. A similar study was conducted by Zahid *et al.* (2023) ^[83] in the Lahore city of Pakistan. According to their research, *Alstonia scholaris* and *Mangifera indica* are susceptible to air pollution near roadsides and residential areas.

Mondal *et al.* (2011) ^[44] determined the APTI and API of ten tree species in Burdwan city, West Bengal. Among the ten tree species Mango (*Mangifera indica*), Banyan (*Ficus benghalensis*), Mahagunii (*Swietenia mahoganii*), Asoke (*Saraca indica*) showed excellent API value. While Guava (*Psidium guajava*) showed very good, Asattha (*Ficus religiosa*) and Debdaru (*Polyanthia longifolia*) showed good. Dumur (*Ficus hispida*) and Chattim (*Alstonia scholaris*) demonstrated very poor API values, while Sissoo (*Dalbergia sissoo*) showed moderate.

Overall, *Mangifera indica* was rated as the best performing plant in the urban location, followed by *Ficus religiosa* (excellent). *Cassia siamea*, *Dalbergia sissoo* and *Peltophorum ferrugineum* were rated as a good performer while *Alstonia scholaris* and *Butea monosperma* evaluated as a moderate performer at the urban site for roadside planting. Singh *et al.*, (2024) ^[71] recommended *Ficus religiosa*, *Ficus infectoria*, *Alstonia scholaris*, and *P. longifolia* as the most effective species for controlling air pollution, and therefore can be used for urban landscaping and green space cover in Delhi and NCR region. Sahu *et al.*, (2020) ^[64] conducted a similar study using 21 tree species from the controlled and polluted sites of Sambhalpur city of Odisha. Their study recommends *Ficus religiosa*, *Mahuca indica*, *Artocarpus heterophyllus*, *Mangifera indica*, *Ficus bengalensis* and *Sygiumcumini* as the most suitable tree species based on their Expected Performance Index (EPI).

The current study's findings point to a significant positive

correlation between relative water content and APTI values. In the present study, an increase in relative water content was observed in the polluted urban and suburban sites. Patel and Kousar (2011)^[55] and Kuddus *et al.* (2011)^[32] recorded a higher RWC value under polluted conditions. Molnar *et al.*, (2020)^[43] also observed that RWC was higher at the polluted sites than at a control site.

A similar study was conducted by Dadkhah-Aghdash *et al.* (2022)^[15] in the arid region of Tehran, India. They reported that *Ailanthus altissima*, and *Salix babylonica* are sensitive to air pollution, while *Moras alba* has moderate resistance and can be recommended for planting in arid regions of the country.

Li *et al.* (2023)^[34] studied the suitability assessment of six tree species through a combined analysis of PM 2.5 trapping ability and APTI. Their study found that *Pinus tabuliformis* is the best species for building an urban green belt. Deepalakshmi *et al.* (2013) revealed that *Peltophorum pterocarpum* and *Portulaca oleraceae* are the tolerant species, because they showed the least percentage reduction in the APTI. Rai and Mishra (2013)^[60] examined the effect of air pollution on roadside tree species i.e. *Pongamia pinnata* (L.). Their study showed the significant change in epidermal traits with an increased number of epidermal cells and stomata per unit area, as well as leaf samples from the polluted sites showed shorter guard and epidermal cell lengths and widths than those from the controlled areas.

A related study was carried out by Molnar *et al.* (2020)^[43]. They assessed the usefulness of the APTI as a composite environmental health index in the Hungarian city of Debrecen. APTI values can be used to select pollution tolerant species for urban greening and also to select species for green belt development. Plant with higher APTI values are tolerant and can be used as a sink to control environmental pollution (Zahid *et al.*, 2023)^[83].

Heavy vehicular traffic led to increased dust deposition on urban sites in the city centre. Our results showed that roadside trees reduced air pollution by retaining dust particles on the leaf surface, and they indicated pollution levels by changing biochemical parameters.

The urban sites were located in the city centre where pollutants easily accumulate due to poor/ unfavourable diffusion conditions and traffic. Chaudhary & Rathore (2018)^[13] also reported a similar finding where dust deposition in tree leaves is higher in urban areas than in commercial and residential areas. In our study, the total chlorophyll content of tree leaves was significantly higher at the rural site than at the urban site (Molnar *et al.*, 2020)^[43]. UGS improves the physical and mental health of children, adults and the elderly (Li *et al.*, 2023a, Kuhn *et al.*, 2021, Mahata and Mahato, 2024, Mahato and Ekka, 2023)^[35, 39, 41, 38]. Several researchers (Mahato and Singh, 2019)^[40] have also illustrated that forestry and urban green spaces serve as a tool for mitigating the recent climate change events.

Abbreviations

(APTI-Air Pollution Tolerance Indices, API- Anticipated Performance Index, CO- Carbon Monoxide, HC- Hydrocarbon, H₂SO₄- Sulphuric acid, LRWC- Leaf Relative Water Content, NO_x- Nitrogen Oxides, SO₂- Sulphur dioxide, UGS- Urban Green Spaces

Conclusion

Urban green spaces, in addition to aesthetic and recreational benefits, also offer enormous potential to recover from the health problem caused by technological advancement, environmental pollution etc. Of the seven tree species, *Mangifera indica* and *Ficus religiosa* were found to be the best and excellent performers and suitable tree species for green belt development. *Cassia siamea*, *Dalbergia sissoo* and *Peltophorum ferrugineum* were judged to be good performer and considered efficient in controlling air pollution. *Alstonia scholaris* and *Butea monosperma*, on the other hand, qualified for the category of 'moderate' performer, which are also preferred for roadside plantation. The study shows that *Alstonia scholaris* and *Butea monosperma* are likely to perform poorly in control and suburban, while they are moderately performer at the urban sites. This study found that rural locations are least disturbed by anthropogenic activities due to high chlorophyll and low element concentration in leaves of trees.

Conflict of Interest: None

References

1. Agbaire PO, Esiefarienrhe E. Air Pollution tolerance indices (APTI) of some plants around Otorogun Gas Plant in Delta State, Nigeria. J Appl Sci Environ Manage. 2009;13(1):11-4.
<https://doi.org/10.4314/JASEM.V13I1.55251>
2. Agarwal P, Sarkar M, Chakraborty B, Banerjee T. Phytoremediation of air pollutants: prospects and challenges. In: Phytomanagement of polluted sites. 2019. p. 221-41.
3. Agrawal S, Tiwari SL. Susceptibility level of few plants on basis of air pollution tolerance index. Indian For. 1997;123(4):319-22.
4. Alayafi AAM. Exogenous ascorbic acid induces systemic heat stress tolerance in tomato seedlings: transcriptional regulation mechanism. Environ Sci Pollut Res. 2020;27(16):19186-99.
<https://doi.org/10.1007/s11356-019-06195-7>
5. Ashenden TW. Effects of SO₂ and NO₂ pollution on transportation in Phaseolus vulgaris L. Environ Pollut. 1979;18(1):45-50.
[https://doi.org/10.1016/0013-9327\(79\)90032-6](https://doi.org/10.1016/0013-9327(79)90032-6)
6. Banerjee S, Banerjee A, Palit D. Morphological and biochemical study of plant species- a quick tool for assessing the impact of air pollution. J Clean Prod. 2022;339:130647.
<https://doi.org/10.1016/J.JCLEPRO.2022.130647>
7. Bassin S, Volk M, F. J. Species composition of subalpine grassland is sensitive to nitrogen deposition, but not to ozone, after seven years of treatment. Ecosystems. 2013;16(6):1105-17.
8. Beckwith T, Cecil K, Altaye M, Severs R, Wolfe C, Percy Z, *et al.* Reduced gray matter volume and cortical thickness associated with traffic-related air pollution in a longitudinally studied pediatric cohort. PLoS ONE. 2020;15(1).
<https://doi.org/10.1371/JOURNAL.PONE.0228092>
9. Bellini E, De Tullio MC. Ascorbic acid and ozone: Novel perspectives to explain an elusive relationship.

- Plants. 2019;8(5).
<https://doi.org/10.3390/plants8050122>
10. Bharti SK, Trivedi A, Kumar N. Air pollution tolerance index of plants growing near an industrial site. *Urban Clim.* 2018;24:820-9.
<https://doi.org/10.1016/J.UCLIM.2017.10.007>
 11. Britton G, Young AJ. Methods for the isolation and analysis of carotenoids. In: *Carotenoids in Photosynthesis*. 1993. p. 409-57.
https://doi.org/10.1007/978-94-011-2124-8_10
 12. Chandra KK, Omesh V, Bhadouria R. Guru Ghasidas University Campus Greenery for offsetting Carbon Dioxide and Improving Students' Academic Performance. *Curr World Environ.* 2022;17(1):213-25.
<https://doi.org/10.12944/CWE.17.1.19>
 13. Chaudhary IJ, Rathore D. Suspended particulate matter deposition and its impact on urban trees. *Atmos Pollut Res.* 2018;9(6):1072-82.
<https://doi.org/10.1016/J.APR.2018.04.006>
 14. Conklin PL. Recent advances in the role and biosynthesis of ascorbic acid in plants. *Plant Cell Environ.* 2001;24(4):383-94.
<https://doi.org/10.1046/j.1365-3040.2001.00686.x>
 15. Dadkhah-Aghdash H, Rasouli M, Rasouli K, Salimi A. Detection of urban trees sensitivity to air pollution using physiological and biochemical leaf traits in Tehran, Iran. *Sci Rep.* 2022;12(1):15398.
 16. Dedio W. Water Relations in Wheat Leaves As Screening Tests for Drought Resistance. *Can J Plant Sci.* 1975;55(2):369-78. <https://doi.org/10.4141/cjps75-059>
 17. Dhankhar R, Mor V, Lilly S, CK, KA. Evaluation Of Anticipated Performance Index Of Some Tree Species Of Rohtak City, Haryana, India. *Int J Recent Sci Res.* 2015;6(3):2890-6.
 18. Escobedo FJ, Wagner JE, Nowak DJ, De la Maza CL, Rodriguez M, Crane DE. Analyzing the cost effectiveness of Santiago, Chile's policy of using urban forests to improve air quality. *J Environ Manage.* 2008;86(1):148-57.
<https://doi.org/10.1016/J.JENVMAN.2006.11.029>
 19. Govindaraju M, Ganeshkumar RS, Muthukumaran VR, Visvanathan P. Identification and evaluation of air-pollution-tolerant plants around lignite-based thermal power station for greenbelt development. *Environ Sci Pollut Res.* 2012;19(4):1210-23.
<https://doi.org/10.1007/s11356-011-0637-7>
 20. Gupta A. Effect of air pollutants on plant gaseous exchange process: effect on stomata and respiration. In: *Plant responses to air pollution*. Singapore: Springer Singapore; 2016. p. 85-92.
 21. Gupta S, Nayek S, Bhattacharya P. Effect of air-borne heavy metals on the biochemical signature of tree species in an industrial region, with an emphasis on anticipated performance index. *Chem Ecol.* 2011;27(4):381-92.
<https://doi.org/10.1080/02757540.2011.561791>
 22. Hirano SS, Upper CD. Bacteria in the leaf ecosystem with emphasis on *Pseudomonas syringae*—a pathogen, ice nucleus, and epiphyte. *Microbiol Mol Biol Rev.* 2000;64(3):624-53.
 23. Iqbal MZ, Shafiq M, Qamar Zaidi S, Athar M. Effect of automobile pollution on chlorophyll content of roadside urban trees. *Glob J Environ Sci Manag.* 2015;1(4):283-96. <https://doi.org/10.7508/GJESM.2015.04.003>
 24. Jenkins M. Physiological effects of sulphur dioxide induces stress on vegetation under natural conditions. *Biological Sciences, Master of;* 2001.
 25. Jyothi SJ, Jaya DS. Evaluation of air pollution tolerance index of selected plant species along roadsides in Thiruvananthapuram, Kerala. *J Environ Biol.* 2010.
 26. Kaler NS, Kashyap P, Prasad H, Singh TJ. Air pollution tolerance index (APTI) of tree species: a review. *Int J Chem Stud.* 2017;5(4):716-20.
 27. Kalyani V, Singaracharya M. Biomonitoring of Air Pollution in Warangal City (A.P.). *Act Botanica Indica.* 1995;23:21-3.
 28. Karthiayini R, Ponnammal NR, R AGINAJ. Air pollution tolerance index of certain plants of Coimbatore-Ooty highways, near ITI area, Coimbatore, Tamilnadu. *Pollut Res.* 2005;24(2):363.
 29. Koshale JP, Mahato A. Quantitative analysis of the morphometric characteristics of Arpa River Basin (ARB), Chhattisgarh, India. *Indian Hydrobiology.* 2022;21(1):81-95.
 30. Koshale JP, Mahato A. Spatio-Temporal Change Detection and Its Impact on the Waterbodies by Monitoring LU/LC Dynamics - A Case Study from Holy City of Ratanpur, Chhattisgarh, India. *Nature Environ Pollut Technol.* 2020;19(5):1801-1810.
<https://doi.org/10.46488/NEPT.2020.v19i05.003>
 31. Koyro HW. Effect of salinity on growth, photosynthesis, water relations and solute composition of the potential cash crop halophyte *Plantago coronopus* (L.). *Environ Exp Bot.* 2006;56(2):136-46.
<https://doi.org/10.1016/J.ENVEXPBOT.2005.02.001>
 32. Kuddus M, Kumari R, Ramteke PW. Studies on air pollution tolerance of selected plants in Allahabad city, India. *E3 J Environ Res Manag.* 2011;2(3):42-46.
 33. Latwal M, Sharma S, Kaur I, Nagpal AK. Global Assessment of Air Pollution Indices of Trees and Shrubs for Biomonitoring and Green Belt Development - A Tabulated Review. *Water Air Soil Pollut.* 2023;234(3):1-22. <https://doi.org/10.1007/S11270-023-06194-Y/METRICS>
 34. Li M, Tan P, Rai P, Li Y, Meng H, Zhang T, *et al.* Suitability Assessment of Six Tree Species through Combined Analysis of PM2.5 Capture Ability and Air Pollution Tolerance Index for Urban Green Belt. *Sustainability.* 2023;15.
<https://doi.org/10.3390/su152014744>
 35. Li Q, Liu Y, Yang L, Ge J, Chang X, Zhang X. The impact of urban green space on the health of middle-aged and older adults. *Front Public Health.* 2023;11:1244477.
<https://doi.org/10.3389/FPUBH.2023.1244477/BIBTEX>
 36. Lohe RN, Tyagi B, Singh V, Tyagi PK, Khanna DR, Bhutiani R. A comparative study for air pollution tolerance index of some terrestrial plant species. *Glob J Environ Sci Manag.* 2015;1(4):315-24.
<https://doi.org/10.7508/gjesm.2015.04.006>
 37. Maghsoudi K, Emam Y, Pessarakli M. Effect of silicon on photosynthetic gas exchange, photosynthetic

- pigments, cell membrane stability and relative water content of different wheat cultivars under drought stress conditions. *J Plant Nutr.* 2016;39(7):1001-15. doi:10.1080/01904167.2015.1109108
38. Mahato A, Ekka M. Nature within us: A sustainable lifestyle approach to connect with nature. *Int J Adv Biochem Res.* 2023;SP-7(2):85-8.
 39. Mahata S, Mahato A. Human health benefits and Urban Greens Spaces (UGS). *Dynamics Urban For.* 2024:111-23. ISBN 979-8-89222-182-5
 40. Mahato A, Singh AK. Climate change and its mitigation strategies through forestry. *Chhattisgarh J Sci Technol.* 2019;16(4):31-4. ISSN 0973-7219
 41. Mahato A, Sahu N, Koshale JP. Perspective of Urban Green Spaces (UGS) in the smart city of Bilaspur, India. *Dynamics Urban For.* 2024:41-55. ISBN 979-8-89222-182-5
 42. Mohammadi A, Mokhtari M, Arani AM, Taghipour H, Hajizadeh Y, Fallahzadeh H. Biomonitoring levels of airborne metals around Urmia Lake using deciduous trees and evaluation of their tolerance for greenbelt development. *Environ Sci Pollut Res.* 2018;25(21):21138-48. doi:10.1007/s11356-018-1899-0
 43. Molnar VE, Simon E, Tothmeresz B, Ninsawat S, Szabo S. Air pollution induced vegetation stress - The Air Pollution Tolerance Index as a quick tool for city health evaluation. *Ecol Indic.* 2020;113:106234. doi:10.1016/j.ecolind.2020.106234
 44. Mondal D, Gupta S, Datta JK. Anticipated performance index of some tree species considered for green belt development in an urban area. *Int Res J Plant Sci.* 2011;2(4):99-106. Available from: <http://www.interestjournals.org/IRJPS>
 45. Muneer S, Kim TH, Choi BC, Lee BS, Lee JH. Effect of CO, NO_x and SO₂ on ROS production, photosynthesis and ascorbate-glutathione pathway to induce *Fragaria×annasa* as a hyperaccumulator. *Redox Biol.* 2014;2(1):91-8. doi:10.1016/j.redox.2013.12.006
 46. Ninave SY, Chaudhari PR, Gajghate DG, Tarar JL. Foliar Biochemical Features of Plants As Indicators of Air Pollution. *Bull Environ Contam Toxicol.* 2001;67(1):133-40. doi:10.1007/s00128-001-0101-3
 47. Nowak DJ, Greenfield EJ, Hoehn RE, Lapoint E. Carbon storage and sequestration by trees in urban and community areas of the United States. *Environ Pollut.* 2013;178:229-36. doi:10.1016/j.envpol.2013.03.019
 48. Nwadinigwe AO. Air pollution tolerance indices of some plants around Ama industrial complex in Enugu State, Nigeria. *Afr J Biotechnol.* 2014;13(11):1231-6. doi:10.5897/ajb2014.13616
 49. Ogagaoghene AJ. pH level, ascorbic acid, proline and soluble sugar as bio - indicators for pollution. *ChemSearch J.* 2017;8(2):41-9. Available from: <https://www.ajol.info/index.php/csj/article/view/166247>
 50. Palta JP. Stress Interactions at the Cellular and Membrane Levels. *HortScience.* 2019;25(11):1377-81. doi:10.21273/hortsci.25.11.1377
 51. Panda LLS, Rai PK. Issues and Trends of Wildlife Conservation in Northeast India Study of Air Pollution Tolerance Index of some common road side plant species in an industrial (Rourkela) and non-industrial (Aizawl) area of India: An ecomanagement. *Issues Trends Wildl Conserv Northeast India.* 2014;4(April):86-95.
 52. Panda LRL, Aggarwal RK, Bhardwaj DR. A review on Air Pollution Tolerance Index (APTI) and Anticipated Performance Index (API). *Curr World Environ.* 2018;13(1):55-65. doi:10.12944/cwe.13.1.06
 53. Pandey AK, Pandey M, Mishra A, Tiwary SM, Tripathi BD. Air pollution tolerance index and anticipated performance index of some plant species for development of urban forest. *Urban For Urban Green.* 2015a;14(4):866-71. doi:10.1016/j.ufug.2015.08.001
 54. Pandey AK, Pandey M, Tripathi BD. Air Pollution Tolerance Index of climber plant species to develop Vertical Greenery Systems in a polluted tropical city. *Landsc Urban Plan.* 2015b;144:119-27. doi:10.1016/j.landurbplan.2015.08.014
 55. Patel AM, Kousar H. Assessment of relative water content, leaf extract pH, ascorbic acid and total chlorophyll of some plant species growing in Shivamogga. *Plant Arch.* 2011;11(2):935-9.
 56. Pathak V, Tripathi BD, Mishra VK. Evaluation of Anticipated Performance Index of some tree species for green belt development to mitigate traffic generated noise. *Urban For Urban Green.* 2011;10(1):61-6. doi:10.1016/j.ufug.2010.06.008
 57. Prajapati SK, Tripathi BD. Anticipated Performance Index of some tree species considered for green belt development in and around an urban area: A case study of Varanasi city, India. *J Environ Manage.* 2008;88(4):1343-9. doi:10.1016/j.jenvman.2007.07.002
 58. Prajapati SK, Tripathi BD. Seasonal Variation of Leaf Dust Accumulation and Pigment Content in Plant Species Exposed to Urban Particulates Pollution. *J Environ Qual.* 2008;37(3):865-70. doi:10.2134/jeq2006.0511
 59. Rai PK, Panda LLS. Dust capturing potential and air pollution tolerance index (APTI) of some road side tree vegetation in Aizawl, Mizoram, India: An Indo-Burma hot spot region. *Air Qual Atmos Health.* 2014;7(1):93-101. doi:10.1007/s11869-013-0217-8
 60. Rai PK, Panda LLS, Chutia BM, Singh MM. Comparative assessment of air pollution tolerance index (APTI) in the industrial (Rourkela) and non industrial area (Aizawl) of India: An eco-management approach. *Afr J Environ Sci Technol.* 2013;7(October):944-8.
 61. Roy A, Bhattacharya T, Kumari M. Air pollution tolerance, metal accumulation and dust capturing capacity of common tropical trees in commercial and industrial sites. *Sci Total Environ.* 2020;722:137622. doi:10.1016/j.scitotenv.2020.137622
 62. Roy A, Mandal M, Przybysz A, Haynes A, Robinson SA, Sarkar A, Popek R. Phytoremediating the air down under: Evaluating airborne particulate matter accumulation by 12 plant species in Australia. *Ecol Res.* 2024.
 63. Sadat N. Tree Species Selection For Street Planting In The Central Business District Of naturally in Rajshahi and provides a basis for selecting suitable (CBD) of Rajshahi. 2020;22-34.
 64. Sahu C, Basti S, Sahu SK. Air pollution tolerance index (APTI) and expected performance index (EPI) of trees

- in sambalpur town of India. SN Appl Sci. 2020;2(8). doi:10.1007/s42452-020-3120-6
65. Salmond JA, Tadaki M, Vardoulakis S, Arbuthnott K, Coutts A, Demuzere M, Dirks KN, Heaviside C, Lim S, MacIntyre H, McInnes RN, Wheeler BW. Health and climate related ecosystem services provided by street trees in the urban environment. Environ Health. 2016;15(1):95. doi:10.1186/s12940-016-0103-6
 66. Saxena P, Bhardwaj R, Ghosh C. Status of Air Pollutants after Implementation of CNG in Delhi. Curr World Environ. 2012;7(1):109-15. doi:10.12944/cwe.7.1.17
 67. Shannigrahi AS, Fukushima T, Sharma RC. Anticipated air pollution tolerance of some plant species considered for green belt development in and around an industrial/urban area in India: An overview. Int J Environ Stud. 2004;61(2):125-37. doi:10.1080/0020723032000163137
 68. Sharma R, Singh H, Kaushik M, Nautiyal R, Singh O. Adaptive physiological response, carbon partitioning, and biomass production of *Withania somnifera* (L.) Dunal grown under elevated CO₂ regimes. 3 Biotech. 2018;8(6). doi:10.1007/s13205-018-1292-1
 69. Sims DA, Gamon JA. Relationships between leaf pigment content and spectral reflectance across a wide range of species, leaf structures and developmental stages. Remote Sens Environ. 2002;81(2-3):337-54. doi:10.1016/S0034-4257(02)00010-X
 70. Singh H, Yadav M, Kumar N, Kumar A, Kumar M. Assessing adaptation and mitigation potential of roadside trees under the influence of vehicular emissions: A case study of *Grevillea robusta* and *Mangifera indica* planted in an urban city of India. PLoS One. 2020;15(1):e0227380. doi:10.1371/journal.pone.0227380
 71. Singh L, Sindhu SS, Singh MC, Jaiswal S, Ankit, Kumar S, Sharma DK, Singh B, Anand. Evaluation of tree species using Air Pollution Tolerance Index for urban landscaping in Delhi. Indian J Agric Sci. 2024;94(1):86-91. doi:10.56093/ijas.v94i1.139605
 72. Talebzadeh F, Valeo C. Evaluating the Effects of Environmental Stress on Leaf Chlorophyll Content as an Index for Tree Health. IOP Conf Ser Earth Environ Sci. 2022;1006(1):012007. doi:10.1088/1755-1315/1006/1/012007
 73. Thawale PR, Satheesh Babu S, Wakode RR, Singh SK, Kumar S, Juwarkar AA. Biochemical changes in plant leaves as a biomarker of pollution due to anthropogenic activity. Environ Monit Assess. 2011;177(1-4):527-35. doi:10.1007/s10661-010-1653-7
 74. Uka UN, Hogarh J, B D. Morpho-anatomical and biochemical responses of plants to air pollution. Int J Mod Bot. 2017;7(1):1-11.
 75. Varshney SRK, Varshney CK. Response of peroxidase to low levels of SO₂. Environ Exp Bot. 1985;25(2):107-14. doi:10.1016/0098-8472(85)90016-4
 76. Verkleij JAC, Golan-Goldhirsh A, Antosiewicz DM, Schwitzguébel JP, Schröder P. Dualities in plant tolerance to pollutants and their uptake and translocation to the upper plant parts. Environ Exp Bot. 2009;67(1):10-22. doi:10.1016/j.envexpbot.2009.05.009
 77. Vlachokostas C, Michailidou AV, Matziris E, Achillas C, Moussiopoulos N. A multiple criteria decision-making approach to put forward tree species in urban environment. Urban Clim. 2014;10(P1):105-18. doi:10.1016/j.uclim.2014.10.003
 78. Wang H, Ouyang Z, Chen W, Wang X, Zheng H, Ren Y. Water, heat, and airborne pollutants effects on transpiration of urban trees. Environ Pollut. 2011;159(8-9):2127-37. doi:10.1016/j.envpol.2011.02.031
 79. Wang M. Novel Strategy for Disease Control of Rice and Examination of the Associated Microbiome. ProQuest Dissertations and Theses. 2019;322. Available from: <https://search.proquest.com/docview/2393755698?accountid=27575>
 80. Weyens N, Thijs S, Popek R, Witters N, Przybysz A, Espenshade J, et al. The role of plant-microbe interactions and their exploitation for phytoremediation of air pollutants. Int J Mol Sci. 2015;16(10):25576-604. doi:10.3390/ijms161025576
 81. Yadav R, Pandey P. Assessment of Air Pollution Tolerance Index (APTI) and Anticipated Performance Index (API) of Roadside Plants for the Development of Greenbelt in Urban Area of Bathinda City, Punjab, India. Bull Environ Contam Toxicol. 2020;105(6):906-14. doi:10.1007/s00128-020-03027-0
 82. Yu L, Zhang Q, Lu L, Gao H, Liu Q, Liu Y, et al. The role of ascorbic acid in rice leaf senescence and photo-carbon imbalance. Funct Plant Biol. 2020;47(3):263-78. doi:10.1071/FP19248
 83. Zahid A, Ali S, Anwar W, Fatima A, Chattha MB, Ayub A, et al. Assessing the air pollution tolerance index (APTI) of trees in residential and roadside sites of Lahore, Pakistan. SN Appl Sci. 2023;5(11):1-11. doi:10.1007/s42452-023-05470-0
 84. Zhang X, Zhou P, Zhang W, Zhang W, Wang Y. Selection of Landscape Tree Species of Tolerant to Sulfur Dioxide Pollution in Subtropical China. Open J For. 2013;3(4):104-8. doi:10.4236/ojfor.2013.34017