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RESEARCH ARTICLE

Phytoremediation for urban landscaping and air pollution control—a case study in Trivandrum city, Kerala, India

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Abstract
Air pollutant concentration of Trivandrum, the capital of Kerala, exceeded the limits of National Ambient Air Quality (NAAQ) standards, according to a study conducted in 2015 by NATPAC. These polluted corridors harbour vegetation on roadsides and traffic islands, planted solely for aesthetic appeal. Analysis of air pollution tolerance levels of existing plants can act as a scientific basis for efficient planning of the urban landscape. Sixty-seven species, including flowering, fruit-bearing, ornamental, shade-providing and timber-yielding species, were screened for their relative resistance to air pollution. Based on leaf pH, relative water content, chlorophyll and ascorbic acid levels, the Air Pollution Tolerance Indices (APTI) of each species were formulated and they were grouped into the following: tolerant, moderately tolerant, intermediate and sensitive groups. *Agave americana* (18.40), *Cassia roxburghii* (17.63), *Anacardium occidentale* (11.97), *Cassia fistula* (11.60), *Mangifera indica* (11.59) and *Saraca asoca* (10.88) may be considered for planting near green spaces like roundabouts and near pollution prone industrial areas, as they belong to tolerant category. Comparison of APTI during summer and monsoon also revealed the stability of *Agave americana*, *Saraca asoca*, *Ficus benghalensis*, *Peltophorum pterocarpum*, *Ficus elastic*a, *Ixora finlaysoniana*, *Mangifera indica*, *Canna indica* and *Delonix regia* in maintaining pollution tolerance even during water disparity. *Agave americana*, *Anacardium occidentale*, *Ficus elastica*, *Mangifera indica*, *Syzygium cumini*, *Ficus benghalensis*, *Nerium oleander* and *Ficus benjamina* were found to be suited for mass planting, as was evident from their Anticipated Performance Indices (API).

Keywords Air pollution · Air Pollution Tolerance Index · Anticipated Performance Index · Urban landscaping · Plant tolerance · Trivandrum

Introduction

India accommodates 15 cities belonging to the top 20 most polluted cities across the globe (Koshy 2019). The techniques to counter such a huge wave of air pollutants are limited due to economic and spatial limitations in our country. An in-depth study in Trivandrum Corporation by the National Transportation, Planning and Research Centre (NATPAC) in 2015–2016 elucidated the surge in air pollutants like carbon dioxide, carbon monoxide and particulate matter above the permissible National Ambient Air Quality (NAAQ) limits. The study was focused on road corridors with high traffic density. These corridors are endowed with small patches of vegetation at traffic islands, dividers and roundabouts. Every year on the 5th of June, numerous seedlings which are either flowering, fruit bearing, shade giving or timber yielding are distributed by the Kerala Forest Department since 2006 in schools and other institutions to hike up the forest cover in the state. Schemes like 'Vazhiyora Thanal Padhathi' (Shade on roadsides) and 'Haritha Keralam' (Greening Kerala) supplement the ecological health of heavy traffic areas. However, the species selection for such afforestation programmes is currently done only for maintaining the aesthesis of the city. The utilization of existing green space with plants capable of tolerating and thriving well under pollutant stress would add a practical value to the services of such green zones by buffering the concentration of pollutants in air. This process of phylloremediation makes use of leaves as the machinery for detoxifying air. Leaves fix CO_2 and replenish the pool of

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breathable air taken up by the fauna as plants are capable of converting many toxic substances into harmless metabolites by processes inherent in them (Hill 1971, Lin 1976). Trees are proven to remove air pollutants by intercepting airborne particles (Nowak et al. 2006). Since every plant may not necessarily be an air pollution attenuator due to their disparity in stress-response (Gupta 2008), planting species which are resistant aids in saving the time, money and labour put forward in urban landscaping and their overall efficacy. The equable climate of Trivandrum throughout the year may be attributed to its location towards the equator (Balasubramanian 2017). The only significant climatic variable here is rainfall, which is due to its geographical positioning between the Arabian Sea and the Western Ghats (Nair et al. 2014).

The present study aims at identifying air pollution tolerant plant species for efficient landscaping in heavy traffic areas of Trivandrum city using two distinct indices—namely Air Pollution Tolerance Index (APTI) and Anticipated Performance Index (API). Based on this classification, the different locations suited for divergent species are also inferred to yield a concise landscape layout.

Materials and methods

Species commonly distributed for plantation under social forestry scheme by Kerala Forest Department (KFD) and Kerala Road Fund Board and planted at heavy traffic junctions and corridors of Trivandrum city were sampled. Leaves were sampled from the same plant in both summer and monsoons months in the morning between 8.00 and 9.00 am, with the ambient atmospheric temperature being 28 ± 2 °C in the summer and 23 ± 2 °C in the monsoon. The 3rd and 4th leaves from the apex of the branch were collected. In order to avoid experimental error due to pathology and pollution stress other than vehicular emission, healthy plants found near traffic signals and National Highways were selected. The sampling sites were also selected at locations devoid of industrial establishments nearby. Then the Air Pollution Tolerance Index (APTI) formula was applied on each sample collected. This equation was devised after careful consideration of several biochemical and physiological parameters of plants which makes them resilient to withstand air pollution (Singh et al. 1991). Four variables including relative water content (RWC), total chlorophyll, pH and ascorbic acid levels were analysed freshly. The measure of whose culminated empirical relation provides a measure of a plant's relative tolerance to air pollution called the Air Pollution Tolerance Index (APTI). All the experiments were carried out in triplicates and results were tabulated as mean ± standard deviation.

Site selection

The top ten corridors (Table 1) exhibiting heavy pollutant emission in Trivandrum city were selected for the study. Selection was based on the secondary information obtained from Kerala State Pollution Control Board (KSPCB) (NATPAC 2016) (Fig. 1).

Table 1 Corridors based on vehicular emission (NATPAC 2016)

Rank	Corridor
1	Kazhakootam – Sreekariyam
2	Medical College – Pettah
3	Sreekariyam – Ulloor
4	Ambalamukku – Vellayambalam
5	Pattom – Kowdiar
6	Medical College – Pattom
7	Palayam – Overbridge
8	Karamana – Poojapura
9	Kesavadasapuram – Pattom
9	Vellayambalam – Vazhuthacad
10	Palayam – General Hospital
10	LMS – Vellayambalam
10	Killipalam – Attakulangara

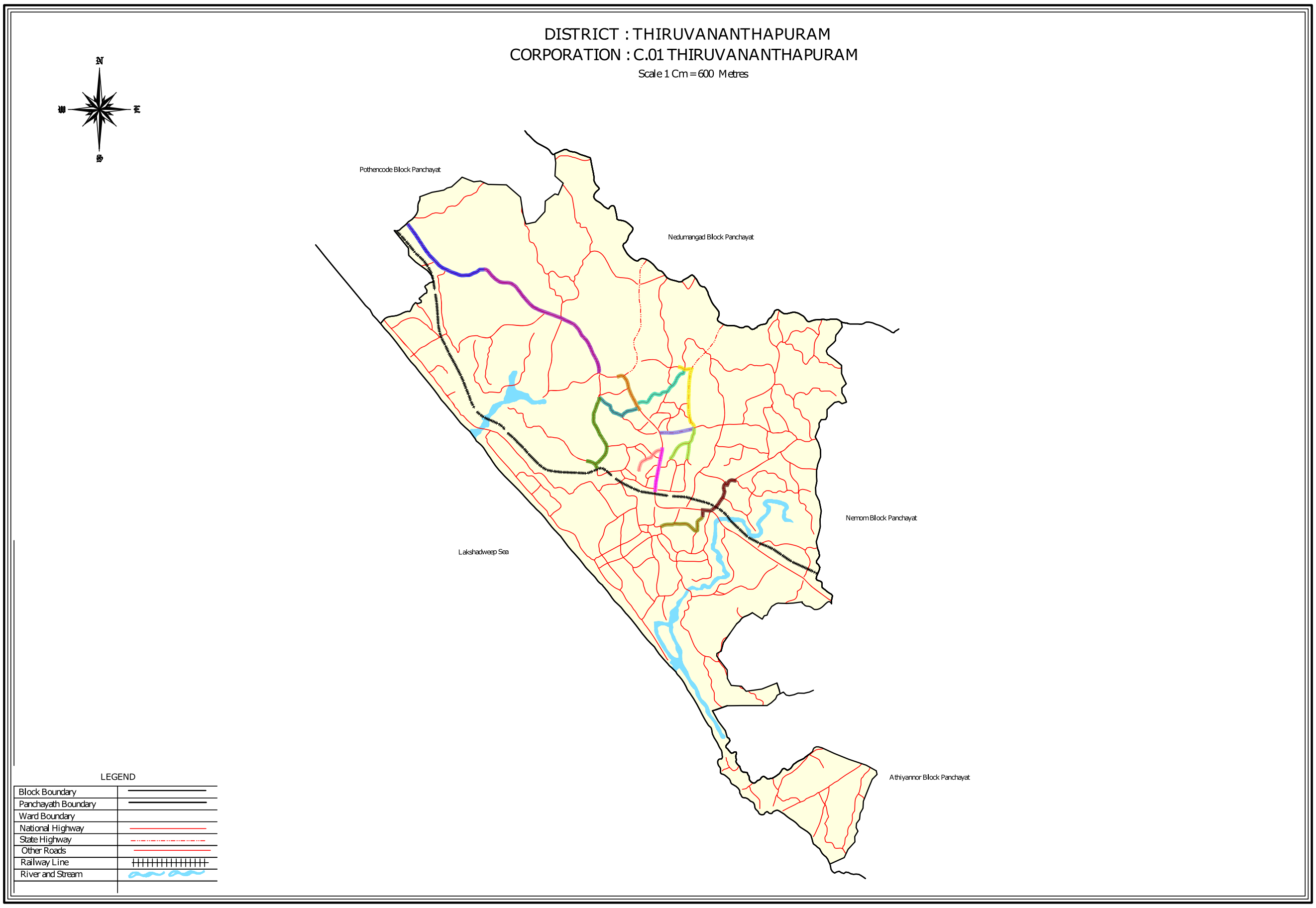

Fig. 1 Trivandrum Corporation (Delimitation Commission 2014). Refer to Table 1 for the color codes

Species selection

The plant species whose leaf biochemistry was to be analysed were decided based primarily on the list of plants distributed by The Kerala Forest Department (KFD) every year, for planting in institutions, traffic islands, parks, roadsides and other public places under ‘social forestry scheme’ of the state government.

Some of the common ornamentals distributed by the Kerala Road Fund Board for planting in traffic islands and strips of land between four or six lane highways were also chosen for sampling.

Altogether, 67 different plant species consisting of both trees and shrubs including 16 flowering/avenue trees, 22 species of ornamental shrubs, 16 fruit bearing species, 9 shade providing trees and 4 timber-yielding species were analysed.

Analysis of Air Pollution Tolerance Index

Relative water content (Singh 1977)

Leaves were cut into pieces after removing the prominent veins and the fresh weight (Fw) was taken. Then they were immersed in distilled water overnight after covering with a lid to prevent water loss by evaporation. The excess water was blotted off the surface and the turgid weight (Tw) was recorded. The weighed sample was kept in an oven at 50 °C overnight and the dry weight (Dw) was noted.

$$\mathrm{RWC} = \frac{(\mathrm{Fw}-\mathrm{Dw})}{(\mathrm{Tw}-\mathrm{Dw})} * 100$$

$\mathrm{Fw} = $ fresh weight, $\mathrm{Tw} = $ turgid weight, $\mathrm{Dw} = $ dry weight.

pH (Singh and Rao 1983)

0.5 g of leaf tissue was ground in 50 ml distilled water using a mortar and pestle. The leaf extract was filtered out into a 25-ml beaker. After proper calibration of the digital pH meter using buffers with ph 7 and 4 respectively, the pH of the solution was measured using Eutech pH tutor.

Chlorophyll (Arnon 1949)

0.1 g of leaf tissue was extracted in 10 ml of 80% acetone and centrifuged at 3500 rpm for 10 min. Optical density (OD) readings of the extract at 645 nm and 663 nm were obtained using a visible spectrophotometer, Labtronics model LT-39.

$$Chlorophyll\ (mg/g) = \frac{(20.2*\text{OD645}) + (8,02*\text{OD663})}{10} *\text{Dilution Factor}$$

Ascorbic acid (Sadasivam and Balasubramanian 1987)

Titrimetric analysis using DCPIP (dichloro phenyl indophenol) was conducted using leaf extract, ground in 4% oxalic acid and the endpoint noted as V2 when the solution turns light permanent pink colour which persists 15 s of shaking. The same process was done using pure ascorbic acid solution with known concentration and the endpoint was noted as V1.

$$\text{Amount of Ascorbic acid}(mg/100g) = \frac{0.5mg}{\text{V1}\ ml} * \frac{\text{V2}}{5ml} * \frac{100ml}{Sample\ wgt.} *100$$

Calculation of APTI (Singh et al. 1991)

Air Pollution Tolerance Index (APTI) is an essential variable which gives us an idea about the resilience of a plant towards air pollution using four critically important biochemical parameters of the plant leaf, namely, pH, relative water content (RWC), total chlorophyll (TC) and ascorbic acid (AA) content. The plant which can maintain all the four parameters at relatively high levels even under pollution stress is considered to be extremely tolerant to pollution.

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

A = ascorbic acid (mg/g), T = chlorophyll (mg/g), P = pH, R = RWC.

Limits for determining the extent of tolerance towards air pollution were set separately for shrubs and trees, according to the demonstration by Liu et al. 1983. These range limits of APTI values demarcating tolerant, moderately tolerant, intermediate and sensitive species were set after finding out the mean APTI and its standard deviation (SD) (of the entire 67 species analysed). This is because of the tendency of different types of plants, thriving in different environments to exhibit discrete response to pollution stress (Singh and Rao 1983). Tolerant plant species are represented by an APTI value greater than mean APTI+SD, whereas moderately tolerant plants come just below this, i.e. between mean APTI+SD and mean APTI. Within mean APTI and mean APTI-SD comes the intermediate category and finally those below this lowest range are occupied by the sensitive plants (Liu and Ding 2008). Accordingly, the presently set spectra are as follows:

Trees:

Tolerant—greater than 10.83 APTI; Moderately tolerant—10.83 to 8.77 APTI; Intermediate—8.77 to 6.72 APTI; Sensitive—less than 6.72.

Shrubs and herbs:

Tolerant—greater than 10.82 APTI; Moderately tolerant—10.82 to 8.50; Intermediate—8.50 to 6.19; Sensitive—less than 6.19.

Seasonal analysis—premonsoon vs monsoon

For those species showing APTI value greater than 9, (i.e. those which exhibit a significant degree of air pollution tolerance), readings were also taken during the monsoon to find out possible influence of rainfall on the four parameters.

Analysis of Anticipated Performance Index

Anticipated Performance Index (API) is a measure which takes into account both the APTI as well as other socioeconomic attributes of the plant for effective planning of large-scale plantations like greenbelts.

API analysis was done based on the parameters set by Panda et al. 2018.

As shown in Table 2, each plant species was graded according to their respective APTI values and morphological features, in terms of '+' and '−'. By adding up the number of '+' and '−' separately and subtracting the total number of '−' from the total number of '+', a value will be derived. This value corresponds to the plant's Anticipated Performance Index (API). Convert this in terms of 100, taking the maximum value as 16. Once the API score of a plant is derived, it can be compared with the standards for classification in Table 3, which aids in determining how far the plant is suited for mass propagation. The APTI range limits and API grade allocation method were adopted from the work done by Panda et al. (2018) and Pathak et al. (2011) respectively.

For instance, *Delonix regia* has an APTI score of 9.22, which according to Table 2, gives it '++' value for APTI. Being a large (++), spreading dense (++) and deciduous (−) tree having small sized (−), smooth (−) and delineate (−) lamina with more than 5 uses (++), the API score totals to 4, which on conversion in terms of hundred will give 25. This value places *D. regia* in 'Not suggested for mass plantations' category, according to the API assessment grading standards in Table 3.

Table 2 Assessment criteria for determining the Anticipated Performance Index (API)

Grading character	Pattern of assessment	Grade allotted
Air Pollution Tolerance Index	8.5 to 9.0	+
	9.1 to 9.5	++
	9.6 to 10.0	+++
	10.1 to 10.5	++++
	10.6 to 11.0	+++++
Tree habit	Small	–
	Medium	+
	Large	++
Canopy structure	Sparse/irregular/globular	–
	Spreading crown/open/semi dense	+
	Spreading dense	++
Type of tree	Deciduous	–
	Evergreen	+
Laminar characters	Small	–
Size	Medium	+
	Large	++
Texture	Smooth	–
	Coriaceous	+
Hardiness	Delineate	–
	Hardy	+
Economic value	Less than three uses	–
	Three of four used	+
	Five or more used	++

Results and discussion

Six out of the entire 67 species under study were found to have APTI value between 10.88 and 18.40 which included *Agave americana* > *Cassia roxburghii* > *Anacardium occidentale* > *Cassia fistula* > *Mangifera indica* > *Saraca asoca*, and were accommodated in the tolerant category (Table 4.). However, species with APTI between 5.31 and 6.71, exhibiting extreme sensitivity to air pollution, consisted of *Tecoma stans* > *Jacaranda mimosifolia*> *Guazuma ulmifolia* > *Terminalia catappa* > *Pongamia pinnata* = *Tectona grandis*.

Ascorbic acid is a strong reductant capable of reducing water during light reaction in photosynthesis (Singh and Verma 2007). The role of ascorbic acid in tolerance towards air pollution is visibly evident in cellular proliferation and stress response as the concentration of ascorbic acid present was notably proportional to its reducing power (Joshi and Swami 2007). The significance of ascorbic acid in determining APTI can be visualized from the degree of ascorbic acid quantified from leaves of *Agave americana* and *Cassia roxburghii* (Table 4) and their subsequent ranking based on their APTI scores.

Table 3 Grading pattern for API assessment

Grade	Score	Assessment category
0	Up to 30	Not suggested for plantation
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

The influence of pH on tolerance to pollution is loosely tied to the metabolism of ascorbic acid. pH apparently has a direct positive relationship in the breakdown of hexose sugar to ascorbic acid as high pH favours this process and promotes more ascorbic acid accumulation (Bora and Joshi 2014). As the concentration of ascorbic acid increases, so does its reducing power and APTI value. *Ficus benjamina* and *Morus alba* were found to have exceptionally high pH values in this investigation.

Vegetation behaves as a sponge or sink of air pollutants including gases and particulate matter detrimental to the fauna (Dash and Sahoo 2017). However, contact and eventual coating of plants with such particulates can lead to clogging of stomatal pores, which would tremendously affect the photosynthetic efficiency of the plant (Trivedi and Singh 1995).

Studies by Bora and Joshi (2014) highlight the negative impact of air pollution on the amount of total chlorophyll content. The photosynthetic productivity of the plant was

Table 4 Results of APTI analysis during premonsoon season

List of plants	RWC (relative water content) (%)	pH	TC (total chlorophyll) (mg/g)	AA (ascorbic acid) (mg/g)	APTI	Status
Flowering or avenue trees						
Cassia roxburghii DC.	69.57 ± 1.94	6.28 ± 0.05	3.04 ± 0.09	11.45 ± 0.3	17.63	**Tolerant**
Cassia fistula L.	36.61 ± 1.83	6.31 ± 0.1	5.91 ± 0.52	6.5 ± 2.07	11.60	**Tolerant**
Saraca asoca (Roxb.) Willd.	85.73 ± 1.11	6.47 ± 0.13	2.12 ± 0.06	2.74 ± 0.3	10.88	**Tolerant**
*Peltophorum pterocarpum (*DC.) K.Heyne	86.91 ± 3.76	5.69 ± 0.22	7.18 ± 0.43	1.45 ± 0.15	10.56	Moderately
Ficus benjamina L.	74.17 ± 0.76	8.76 ± 0.12	3.28 ± 0.21	1.88 ± 0.15	9.68	Moderately
Ixora finlaysoniana Wall. Ex G.Don	83.07 ± 2.88	5.97 ± 0.04	1.65 ± 0.09	1.71 ± 0.3	9.61	Moderately
Delonix regia (Hook.) Raf.	68.28 ± 3.27	6.00 ± 0.18	3.98 ± 0.18	2.39 ± 0.3	9.22	Moderately
Callistemon lanceolatus (Sm.) Sweet	77.7 ± 1.05	6.29 ± 0.09	2.18 ± 0.2	1.03 ± 0.00	8.64	Intermediate
Wodyetia bifurcata A.K.Irvine	74.53 ± 0.15	6.27 ± 0.1	1.63 ± 0.04	1.45 ± 0.15	8.60	Intermediate
Lagerstroemia speciosa (L.) Pers.	80.54 ± 3.93	5.79 ± 0.12	4.19 ± 0.3	0.51 ± 0.00	8.57	Intermediate
Dypsis lutescens (H.Wendl.) Beentje & J.Dransf.	75.71 ± 3.12	6.06 ± 0.02	2.19 ± 0.09	0.77 ± 0.26	8.21	Intermediate
Senna siamea (Lam.) H.S.Irwin & Barneby	66.12 ± 0.20	5.37 ± 0.2	4.13 ± 0.03	1.37 ± 0.3	7.91	Intermediate
Polyalthia longifolia (Sonn.) Thwaites	66.13 ± 3.08	6.15 ± 0.05	3.7 ± 0.17	0.68 ± 0.3	7.29	Intermediate
Alstonia scholaris (L.) R. Br.	64.45 ± 3.4	6.26 ± 0.04	2.52 ± 0.17	0.94 ± 0.15	7.27	Intermediate
Spathodea campanulata P.Beauv.	65.77 ± 0.73	6.64 ± 0.11	4.29 ± 0.4	0.51 ± 0.00	7.14	Intermediate
Jacaranda mimosifolia D.Don	51.61 ± 2.23	6.31 ± 0.03	5.35 ± 0.53	0.68 ± 0.15	5.96	Sensitive
Ornamentals						
Agave americana L.	93.25 ± 0.22	4.75 ± 0.05	0.29 ± 0.03	18.03 ± 0.39	18.40	**Tolerant**
Caesalpinia pulcherrima (L.) Sw.	61.50 ± 2.10	6.28 ± 0.05	5.22 ± 0.10	3.59 ± 0.3	10.28	Moderately
Canna indica L.	84.48 ± 1.2	6.49 ± 0.1	2.40 ± 0.2	1.03 ± 0.00	9.54	Moderately
Calotropis gigantea (L.) Dryand.	70.17 ± 2.34	6.32 ± 0.04	2.01 ± 0.24	2.22 ± 0.3	8.87	Moderately
Bougainvillea spectabilis Willd.	65.92 ± 5.44	6.47 ± 0.46	4.21 ± 0.35	2.05 ± 0.00	8.78	Moderately
Hamelia patens Jacq.	78.49 ± 0.11	4.55 ± 0.20	1.95 ± 0.14	1.37 ± 0.00	8.74	Moderately
Nerium oleander L.	70.78 ± 1.82	6.11 ± 0.08	1.71 ± 0.15	2.05 ± 0.00	8.68	Moderately
Heliconia psittacorum L.f.	76.68 ± 5.02	6.30 ± 0.13	1.18 ± 0.32	1.03 ± 0.00	8.44	Intermediate
Tabernaemontana divaricata (L.) R.Br.ex Roem. & Schult.	65.05 ± 3.50	5.98 ± 0.10	3.01 ± 0.09	2.05 ± 0.51	8.35	Intermediate
Duranta erecta L.	69.28 ± 3.19	6.16 ± 0.04	1.40 ± 0.17	1.54 ± 0.00	8.09	Intermediate
Jatropha integerrima Jacq.	73.07 ± 2.97	5.30 ± 0.01	2.78 ± 0.05	2.22 ± 0.3	8.08	Intermediate
Allamanda cathartica L.	70.28 ± 2.74	5.77 ± 0.19	1.34 ± 0.17	1.37 ± 0.30	8.00	Intermediate
Bambusa ventricosa McClure	60.45 ± 0.55	6.03 ± 0.1	4.62 ± 0.12	1.71 ± 0.29	7.87	Intermediate
Plumeria rubra L.	68.32 ± 4.49	6.26 ± 0.10	1.90 ± 0.12	1.20 ± 0.30	7.81	Intermediate
Pisonia grandis R. Br.	71.80 ± 3.46	6.5 ± 0.06	0.75 ± 0.12	0.68 ± 0.3	7.68	Intermediate
Lantana camara L.	58.05 ± 1.78	6.64 ± 0.04	3.24 ± 0.45	1.88 ± 0.30	7.66	Intermediate
Ixora coccinea L.	69.41 ± 3.78	5.36 ± 0.10	2.31 ± 0.16	0.85 ± 0.30	7.60	Intermediate
Bambusa multiplex (Lour.) Raeusch. Ex Schult.	61.57 ± 2.65	6.26 ± 0.17	2.79 ± 0.04	1.54 ± 0.26	7.55	Intermediate
Phyllanthus myrtifolius (Wight) Müll.Arg.	65.20 ± 1.80	4.82 ± 0.08	1.93 ± 0.16	1.20 ± 0.30	7.33	Intermediate
Clerodendrum thomsoniae Balf.f.	57.97 ± 1.55	6.17 ± 0.16	1.32 ± 0.19	1.28 ± 0.26	6.76	Intermediate
Bauhinia purpurea L.	52.00 ± 3.28	6.40 ± 0.05	3.39 ± 0.20	1.37 ± 0.30	6.54	Intermediate
Tecoma stans (L.) Juss. ex Kunth	41.51 ± 3.76	6.16 ± 0.13	3.52 ± 0.14	1.20 ± 0.30	5.31	Sensitive
Fruit-bearing species						
Anacardium occidentale L.	89.37 ± 2.66	5.49 ± 0.03	3.25 ± 0.24	3.86 ± 0.14	11.97	**Tolerant**
Mangifera indica L.	82.72 ± 3.61	6.50 ± 0.09	3.42 ± 0.24	3.23 ± 0.41	11.59	**Tolerant**
Psidium guajava L.	65.02 ± 1.20	5.81 ± 0.01	3.76 ± 0.48	3.60 ± 0.08	10.04	Moderately
Phyllanthus emblica L.	76.06 ± 7.80	4.15 ± 0.02	2.74 ± 0.48	4.10 ± 0.55	9.86	Moderately
Syzygium jambos (L.) Alston	67.73 ± 3.05	5.99 ± 0.07	3.25 ± 0.24	2.24 ± 0.37	9.44	Moderately
Averrhoa bilimbi L.	49.90 ± 2.11	6.44 ± 0.03	4.96 ± 0.24	2.33 ± 0.21	9.33	Moderately
Artocarpus heterophyllus Lam.	63.75 ± 1.46	6.39 ± 0.08	2.39 ± 0.24	4.40 ± 0.36	8.95	Moderately
Annona squamosa L.	82.94 ± 3.92	5.21 ± 0.06	3.75 ± 0.40	0.68 ± 0.15	8.91	Moderately
Annona muricata L.	81.71 ± 0.93	5.81 ± 0.06	4.81 ± 0.11	0.68 ± 0.3	8.90	Moderately
Achras sapota L.	64.24 ± 0.99	6.41 ± 0.06	2.91 ± 0.24	1.97 ± 0.01	8.86	Moderately
Morus alba L.	64.58 ± 0.51	7.25 ± 0.14	1.88 ± 0.48	4.63 ± 0.18	8.69	Intermediate
Tamarindus indica L.	75.59 ± 1.00	4.01 ± 0.02	0.85 ± 0.24	2.16 ± 0.05	8.08	Intermediate

Table 4 (continued)

List of plants	RWC (relative water content) (%)	pH	TC (total chlorophyll) (mg/g)	AA (ascorbic acid) (mg/g)	APTI	Status
Flacourtia jangomas (Lour.) Raeusch.	61.60 ± 1.83	6.18 ± 0.12	1.88 ± 0.24	2.57 ± 0.55	7.80	Intermediate
Syzygium cumini (L.) Skeels	55.57 ± 0.56	4.45 ± 0.06	2.39 ± 0.29	3.63 ± 0.24	7.49	Intermediate
Punica granatum L.	63.45 ± 1.03	5.50 ± 0.06	1.71 ± 0.48	2.57 ± 0.16	7.28	Intermediate
Terminalia catappa L.	61.80 ± 5.65	5.12 ± 0.29	0.51 ± 0.00	4.75 ± 0.51	6.68	Sensitive
Shade-providing species						
Ficus elastica Roxb. ex Horneum.	92.58 ± 1.52	6.17 ± 0.38	1.13 ± 0.06	0.68 ± 0.15	9.76	Moderately
Ficus religiosa L.	83.37 ± 1.35	6.59 ± 0.08	3.60 ± 0.02	1.11 ± 0.65	9.47	Moderately
Azadirachta indica A. Juss.	63.58 ± 3.58	6.16 ± 0.05	3.27 ± 0.04	3.25 ± 0.15	9.42	Moderately
Ficus benghalensis L.	85.28 ± 2.9	6.03 ± 0.07	3.28 ± 0.21	0.77 ± 0.26	9.31	Moderately
Samanea saman (Jacq.) Merr.	62.31 ± 2.85	6.43 ± 0.06	3.6 ± 0.08	1.8 ± 0.26	8.03	Intermediate
Muntingia calabura L.	42.12 ± 3.19	6.1 ± 0.07	4.59 ± 0.24	2.82 ± 0.26	7.22	Intermediate
Thespesia populnea (L.) Sol. ex Corrêa	64.11 ± 3.57	5.88 ± 0.15	3.09 ± 0.23	0.51 ± 0.00	6.87	Intermediate
Pongamia pinnata (L.) Pierre	59.87 ± 2.74	6.05 ± 0.14	2.39 ± 0.12	0.86 ± 0.3	6.71	Sensitive
Guazuma ulmifolia Lam.	52.03 ± 2.15	6.7 ± 0.09	2.69 ± 0.18	0.86 ± 0.3	6.01	Sensitive
Timber-yielding species						
Mimusops elengi L.	66.74 ± 3.59	4.90 ± 0.22	2.33 ± 0.04	2.65 ± 0.15	8.59	Intermediate
Swietenia mahogani L.	64.65 ± 2.13	6.45 ± 0.04	2.78 ± 0.05	0.51 ± 0.00	6.94	Intermediate
Artocarpus hirsutus Lam.	53.65 ± 3.04	6.25 ± 0.07	2.916 ± 0.34	1.54 ± 0.00	6.78	Intermediate
Tectona grandis L.f.	52.11 ± 1.82	5.97 ± 0.08	3.75 ± 0.32	1.54 ± 0.00	6.71	Sensitive

Scientific names authenticated from *The Plant List* Version 1.1. (2013) (accessed on 24 June 2020)

High APTI values showing significant tolerance are in bold

found to have a direct influence on the amount of chlorophyll content present in the leaves (Agrawal and Tiwari 1997). Apparently, the entry of air pollutants via the stomata causes the clogging up of the stomata leading to a drastic decrease in the photosynthetic rate which intern reduces the sugar, protein and chlorophyll quantities of the leaf (Joshi and Swami 2007; Prajapati and Tripathi 2008; Narwaria and Kush 2012). Here (Table 4), we can see that *Peltophorum pterocarpum* (7.18 mg/g), *Cassia fistula* (5.91 mg/g), *Jacaranda mimosifolia* (5.35 mg/g) and *Caesalpinia pulcherrima* (5.22 mg/g) lead while taking chlorophyll content into consideration. The positioning of *Jacaranda mimosifolia* in the sensitive category even in the presence of high concentration of chlorophyll itself reveals the synergistic effect of all the four parameters in determining the degree of tolerance to air pollution. Similarly, extremely tolerant plants like *Agave americana* displayed very low chlorophyll content and *Cassia fistula* indicated very low RWC, but the culminated result keeps both in the resilient category which corroborates the above said concept of synergy.

Relative water content (RWC) is however associated with the protoplasmic permeability in plants which leads to loss of water and nutrients under stressful conditions (Geravandi et al. 2011). RWC is a measure which determines the water retention capacity of the plant under stress (Krishnaveni et al. 2013). If the plant is able to maintain its turgor and water holding capacity under pollution prone conditions, it will have very high RWC and hence a considerably high APTI score. Few examples from our study include *Agave americana*, *Ficus elastica* and *Canna indica*, all of which exhibits a very high percentage of RWC.

Agave americana and *Cassia roxburghii* were found to be the best among the entire 67 species analysed, considering their APTI scores and this is the first report of their extreme defense against air pollutants. Previous reports on *Agave americana* from Perummal Malay Hills, Salem, position it only in the moderate to intermediate range of pollution tolerance (Krishnaveni et al. 2013).

Results in agreement with the present study were observed by Lakshmi et al. (2009) in the industrial sites of Visakhapatanam regarding the tolerance of *Cassia fistula* against air pollution. But conflicting findings were observed at Erhoike- Kokori oil exploration station of Delta state by Agbaire as the trend of air pollution tolerance was mostly different from the present results observed with *Psidium guajava* and *Anacardium occidentale* pronounced as being sensitive and *Terminalia catappa* as being tolerant. *Mangifera indica* was found to be the most stable assuming very high air pollution tolerance in majority of the studies especially of those in Delta state, Udaipur, Asansol, Trivandrum and Shivamogga (Agbaire and Esiefarienrhe 2009; Rathore et al. 2018; Choudhary and Banerjee 2009; Jyothi and Jaya 2010; Adamsab et al. 2011).

Studies by Tripathi and Tiwari (2009) also coincide with the present results regarding the robustness of *Saraca asoca* in resisting air pollution stress; however, *Pongamia pinnata* was found to be extremely sensitive to air pollution in the city of Trivandrum which differs considerably from what was observed in Brass city by Tripathi. The present APTI results of *Ficus* species were observed to come in the moderate to tolerant range which is invariably supported by the views of Choudhary and Banerjee (2009).

Studies in Bengaluru mimic the presently observed trend of the high APTI score of *Bougainvillea spectabilis* among ornamentals in withstanding pollutant stress (Manjunath and Reddy 2019). The current investigation along with other studies in Kathmandu green belt areas, Nauni Solan State Highway in Himachal Pradesh and industrial areas of Bhopal highlights the extreme sensitivity of *Jacaranda mimosifolia* towards air pollution as is clearly visible from their respective APTI values (Shrestha and Malla 1996; Haseena 2016; Tiwari and Bansal 1994). However, the influence of other uncontrollable environmental factors affecting the stability of APTI value of a plant species is evident from the studies conducted in Ambo town, Ethiopia, as *Jacaranda mimosifolia* tops the charts in being highly tolerant to air pollution (Sekhar and Sekhar 2019).

Among the 4 parameters, RWC and ascorbic acid content plays a significant role in nullifying the detrimental effects of air pollution in plants as is evident from the results obtained (Table 4).

Seasonal analysis was conducted to elucidate any possible trends of variability existing in the plant biochemistry in accordance with air pollution. The RWC was found to be the only significant trait showing a general disparity during monsoon and summer months as during monsoon, the RWC increased in all the plants analysed compared to summer (Table 5). This may be attributed to the replenishment of the ground water table due to rain. The increase in APTI value during monsoon in all the plants analysed may be due to the washing effect of rain which unclogs the stomatal pores off dust particles and other minute particulate matter. This would facilitate easier gaseous and water vapour exchange between the plant and the atmosphere which in fact removes a potential source of plant stress.

Anticipated Performance Index (API) takes into account the APTI value, the socio-economic and biological aspects and provides a basis for sieving out species suited for large scale plantations like greenbelts (Table 6).

Plants with high API scores like *Agave americana*, *Anacardium occidentale*, *Ficus elastica, Mangifera indica*, *Syzygium cumini*, *Ficus benghalensis*, *Nerium oleander* and *Ficus benjamina* give heavy weightage to both APTI as well as its exploitable uses. Gupta et al. (2016) identified *Ficus benghalensis*, *Mangifera indica*, *Swietenia mahogani*, *Saraca asoca* and *Psidium guajava* as trees with excellent API scores. A critical review of about 89 research articles by Sahu and Sahu

Table 5 Results of APTI analysis during monsoon season

Name of the plant	RWC (relative water content) (%)	pH	TC (total chlorophyll) (mg/g)	AA (ascorbic acid) (mg/g)	APTI
Cassia roxburghii	87.13 ± 5.00	6.48 ± 0.12	3.28 ± 0.22	16.58 ± 1.80	24.89
Agave americana	92.91 ± 1.35	4.67 ± 0.10	0.60 ± 0.02	17.78 ± 0.39	18.66
Cassia fistula	58.43 ± 2.45	6.72 ± 0.01	5.91 ± 0.52	7.16 ± 0.92	14.88
Anacardium occidentale	96.79 ± 0.51	6.03 ± 0.01	3.98 ± 0.10	2.56 ± 0	12.24
Mangifera indica	84.68 ± 1.15	5.42 ± 0.19	3.72 ± 0.21	3.93 ± 0.24	12.06
Azadirachta indica	91.27 ± 5.01	5.90 ± 0.18	3.54 ± 0.21	3.08 ± 0.00	12.03
Ficus benjamina	86.82 ± 0.70	8.82 ± 0.24	3.79 ± 0.42	2.56 ± 0.00	11.91
Caesalpinia pulcherrima	93.27 ± 3.89	6.00 ± 0.05	3.13 ± 0.10	2.82 ± 0.30	11.90
Peltophorum pterocarpum	87.23 ± 3.49	6.10 ± 0.10	4.23 ± 0.35	2.56 ± 0.00	11.37
Phyllanthus emblica	95.28 ± 0.54	4.72 ± 0.08	2.76 ± 0.24	2.22 ± 0.24	11.18
Averrhoa bilimbi	77.51 ± 0.45	5.53 ± 0.26	2.36 ± 0.41	3.93 ± 0.24	10.85
Saraca asoca	86.96 ± 3.72	6.16 ± 0.10	3.03 ± 0.06	2.74 ± 0.3	11.21
Ficus religiosa	96.01 ± 2.56	6.59 ± 0.22	4.87 ± 0.37	0.85 ± 0.30	10.58
Psidium guajava	77.50 ± 1.61	6.17 ± 0.1	1.07 ± 0.16	3.76 ± 0.24	10.47
Canna indica	86.72 ± 3.15	6.76 ± 0.12	2.38 ± 4.53	1.53 ± 0.00	10.08
Syzygium jambos	77.09 ± 0.32	4.95 ± 0.07	1.64 ± 0.21	3.59 ± 0.00	10.07
Ficus elastica	92.87 ± 2.48	5.71 ± 0.13	0.87 ± 0.09	0.86 ± 0.3	9.85
Ixora finlaysoniana	87.48 ± 2.24	5.37 ± 0.03	2.77 ± 0.16	0.77 ± 0.00	9.37
Ficus benghalensis	86.51 ± 1.44	5.45 ± 0.22	3.28 ± 0.21	0.77 ± 0.26	9.32
Delonix regia	73.81 ± 0.85	5.92 ± 0.24	2.05 ± 0.29	2.39 ± 0.3	9.29

(2015) also points out the significantly high Anticipated Performance Indices of *Mangifera indica*, *Ficus religiosa* and *Azadirachta indica* and their potential in greenbelt development.

Table 6 Results of Anticipated Performance Index (API) analysis

List of plants	APTI	Habit	Canopy type	Type of plant	Lamina size	Leaf texture	Leaf hardiness	Uses	API	Status
Agave americana	5	2	1	1	2	1	1	2	94	Best
Anacardium occidentale	5	1	2	1	1	1	1	2	88	Excellent
Ficus elastica	3	2	2	1	2	1	1	2	88	Excellent
Mangifera indica	5	2	2	1	1	− 1	1	2	81	Excellent
Syzygium cumini	1	2	2	1	1	1	1	2	69	Good
Ficus benghalensis	3	2	2	1	1	1	− 1	2	69	Good
Nerium oleander	1	2	1	1	1	1	1	2	63	Good
Ficus benjamina	3	2	1	1	− 1	1	1	1	56	Moderate
Cassia fistula	5	1	2	− 1	1	− 1	− 1	2	50	Poor
Saraca asoca	5	1	1	1	1	− 1	− 1	1	50	Poor
Spathodea campanulata	1	2	1	1	1	1	− 1	2	50	Poor
Bambusa ventricosa	1	2	2	1	1	1	1	− 1	50	Poor
Artocarpus heterophyllus	1	2	1	1	1	1	− 1	2	50	Poor
Ficus religiosa	2	2	2	1	1	− 1	− 1	2	50	Poor
Mimusops elengi	1	1	2	1	1	− 1	1	2	50	Poor
Artocarpus hirsutus	1	2	1	1	1	1	− 1	2	50	Poor
Peltophorum pterocarpum	5	2	2	− 1	− 1	− 1	− 1	2	44	Poor
Calotropis gigantea	1	1	1	1	1	1	− 1	2	44	Poor
Bougainvillea spectabilis	1	1	2	1	1	1	− 1	1	44	Poor
Heliconia psittacorum	1	1	1	1	2	− 1	1	1	44	Poor
Pisonia grandis	1	1	1	1	1	1	− 1	2	44	Poor
Bambusa multiplex	1	1	2	1	1	1	1	− 1	44	Poor
Averrhoa bilimbi	2	1	1	1	1	− 1	1	1	44	Poor
Achras sapota	1	1	1	1	1	− 1	1	2	44	Poor
Terminalia catappa	1	2	1	− 1	2	1	− 1	2	44	Poor
Muntingia calabura	1	1	2	1	1	− 1	1	1	44	Poor
Tectona grandis	1	2	1	− 1	2	1	− 1	2	44	Poor
Lagerstroemia speciosa	1	1	1	1	1	− 1	1	1	38	Very poor
Senna siamea	1	1	2	1	1	− 1	− 1	2	38	Very poor
Alstonia scholaris	1	2	1	− 1	1	1	− 1	2	38	Very poor
Canna indica	2	1	1	1	2	− 1	1	− 1	38	Very poor
Clerodendrum thomsoniae	1	1	1	1	1	1	− 1	1	38	Very poor
Bauhinia purpurea	1	2	1	− 1	1	1	− 1	2	38	Very poor
Tecoma stans	1	2	2	1	1	− 1	− 1	1	38	Very poor
Phyllanthus emblica	3	1	2	− 1	− 1	− 1	1	2	38	Very poor
Tamarindus indica	1	2	1	1	− 1	− 1	1	2	38	Very poor
Punica granatum	1	1	2	− 1	− 1	1	1	2	38	Very poor
Samanea saman	1	2	1	1	− 1	− 1	1	2	38	Very poor
Guazuma ulmifolia	1	1	1	1	1	1	− 1	1	38	Very poor
Swietenia mahogani	1	2	1	1	1	− 1	− 1	2	38	Very poor
Cassia roxburghii	5	1	2	1	− 1	− 1	− 1	− 1	31	Very poor
Polyalthia longifolia	1	2	1	1	1	− 1	− 1	1	31	Very poor
Lantana camara	1	1	1	1	1	− 1	− 1	2	31	Very poor
Psidium guajava	3	− 1	1	1	1	− 1	− 1	2	31	Very poor
Syzygium jambos	2	1	1	1	1	− 1	− 1	1	31	Very poor
Flacourtia jangomas	1	1	2	− 1	1	− 1	1	1	31	Very poor
Azadirachta indica	2	2	1	1	− 1	− 1	− 1	2	31	Very poor
Thespesia populnea	1	1	1	1	1	− 1	− 1	2	31	Very poor
Pongamia pinnata	1	1	2	1	1	− 1	− 1	1	31	Very poor
Delonix regia	2	2	2	− 1	− 1	− 1	− 1	2	25	Not suggested
Callistemon citrinus	1	1	1	1	− 1	− 1	1	1	25	Not suggested
Dypsis lutescens	1	1	1	1	1	− 1	1	− 1	25	Not suggested
Hamelia patens	1	2	2	1	− 1	− 1	− 1	1	25	Not suggested
Jatropha integerrima	1	1	1	1	1	1	− 1	− 1	25	Not suggested
Plumeria rubra	1	2	− 1	− 1	2	− 1	1	1	25	Not suggested
Wodyetia bifurcata	1	2	1	1	1	− 1	− 1	− 1	19	Not suggested
Caesalpinia pulcherrima	4	1	1	1	− 1	− 1	− 1	− 1	19	Not suggested
Duranta erecta	1	1	2	1	− 1	− 1	− 1	1	19	Not suggested
Phyllanthus myrtifolius	1	1	2	1	− 1	− 1	1	− 1	19	Not suggested
Ixora finlaysoniana	3	− 1	1	1	1	− 1	− 1	− 1	13	Not suggested
Tabernaemontana divaricata	1	− 1	2	1	− 1	− 1	− 1	2	13	Not suggested
Allamanda cathartica	1	1	1	1	− 1	1	− 1	− 1	13	Not suggested
Annona squamosa	1	− 1	1	1	1	− 1	− 1	1	13	Not suggested
Annona muricata	1	− 1	1	1	1	− 1	1	− 1	13	Not suggested
Morus indica	1	− 1	1	− 1	1	1	− 1	1	13	Not suggested
Jacaranda mimosifolia	1	1	1	− 1	− 1	− 1	− 1	2	6.3	Not suggested
Ixora coccinea	1	− 1	2	1	− 1	− 1	− 1	1	6.3	Not suggested

Table 7 Possible recommendations on the basis of present study for future landscaping in Trivandrum city

Name of the plant	Location	Reasons
Agave americana	Roundabouts	APTI: tolerant ; API: best Large, spreading and thick serrated foliage, ornamental
Cassia roxburghii *Cassia fistula* *Peltophorum pterocarpum* *Delonix regia*	Roadsides	High APTI Immense canopy Aesthetic value
Saraca asoca *Caesalpinia pulcherrima*	Green spaces between 4 or 6 lane roads	High APTI Moderate size Aesthetic value
Canna indica *Nerium oleander* *Calotropis gigantea Psidium guajava* *Phyllanthus emblica* *Syzygium jambos* *Averrhoa bilimbi* *Annona squamosa* *Annona muricata*	Traffic islands—medium sized	Moderately tolerant Small/medium sized No visibility hindrances in heavy traffic
Canna indica	Narrow dividers	High APTI; does not hinder vision during heavy traffic
Bougainvillea spectabilis *Hamelia patens* *Ficus benjamina*	As hedge plantations	Dense spreading canopy Serve as air pollutant and noise attenuator Requires regular pruning
Anacardium occidentale *Mangifera indica*	Recreational areas and greenbelts (towards periphery)	High APTI High API Socio-economic relevance
Psidium guajava *Phyllanthus emblica* *Syzygium jambos* *Averrhoa bilimbi* *Artocarpus heterophyllus* *Annona squamosa* *Annona muricata* *Achras sapota* *Ficus elastica* *Ficus religiosa* *Azadirachta indica* *Ficus benghalensis*	Recreational areas and greenbelts (towards interior)	Moderately tolerant Fruit bearing or shade providing species

All in all, *Agave americana* was found to rank the first considering all the three aspects under study, i.e. APTI, seasonal stability of RWC and API score.

The aforementioned plants (Table 7) can be used for structuring the landscape layout in regions showing similar ecodynamics and species availability as that of Trivandrum city.

Conclusions

This is the first report on the relative efficacy of *Agave americana*, *Cassia roxburghii* in withstanding air pollution in Trivandrum city. Tolerant species with very high APTI including *Agave americana* (18.40), *Cassia roxburghii* (17.63), *Anacardium occidentale* (11.97), *Cassia fistula* (11.60), *Mangifera indica* (11.59) and *Saraca asoca* (10.88) are detected to be suited for planting near areas prone to heavy vehicular air pollution. Species with high API score *Agave americana*, *Anacardium occidentale*, *Ficus elastica*, *Mangifera indica*, *Syzygium cumini*, *Ficus benghalensis*, *Nerium oleander* and *Ficus benjamina* can be planted in mass plantations like greenbelts. Sensitive species with very low APTI value like *Jacaranda mimosifolia*, *Tecoma stans*, *Terminalia catappa*, *Pongamia pinnata*, *Guazuma ulmifolia* and *Tectona grandis* can be used in crude prediction of pollutant presence exceeding tolerable limits.

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