International Journal of Environmental Science and Technology (2019) 16:5857–5870
https://doi.org/10.1007/s13762-018-1963-9

ORIGINAL PAPER

Assessment of vegetation under air pollution stress in urban industrial area for greenbelt development

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Received: 6 November 2017 / Revised: 13 July 2018 / Accepted: 12 August 2018 / Published online: 27 August 2018

Abstract
A plant is a living machine which reduces air pollution by absorbing particulate matter, gases, and metals through leaves. The main polluting substances, i.e., sulfur oxides, nitrogen oxides, and heavy metals, cause damage to the surrounding ecosystem. In the present study, the air pollution tolerance index values of 36 plant species have been evaluated by analyzing three important biochemical parameters and one physiological parameter. The other biological and socioeconomic parameters of these plant species were also considered along with air pollution tolerance index values for calculating anticipated performance index under the influence of overall pollution stress. Based on these two indices, the most pollution-tolerant and economically valuable plant species have been identified for green belt development in and around an urban industrial area, Durgapur, West Bengal, India. It was revealed that *Lagerstroemia speciosa* (Jarul), *Schleichera oleosa* (Kusum), *and Thespesia populnea* (Pipal) would be the outstanding performers. There are many types of assessment categories which were estimated with respect to air pollution tolerance index and anticipated performance index.

Keywords Air pollution tolerance index · Anticipated performance index · Durgapur · Ecosystem · India · Tolerance

Introduction

In recent era worldwide, the air pollution posed a serious threat to human beings. Air pollutants continuously have been loaded into the atmosphere from different sources but their removal occurs very slowly. On earth there are different entities like water, soil, vegetation which can absorb or sequestered air pollutants in a significant manner, yet its concentration increasing day by day. In India, the major concerns about air pollutants are particulate matter and gaseous pollutants. Cement dust, road dust, coal dust, smoke, fly ash, soot, fumes, stone dust, aerosols, heavy metal particles belong to the category of particulate matter, and gaseous pollutants include sulfur dioxide (SO_2), oxides of nitrogen (NO_2, NO), carbon monoxide (CO), photochemical oxidants, hydrogen fluoride (HF), hydrogen sulfide (H_2S), chlorine, ammonia, etc. Pollutants are classified as primary and secondary pollutants (Rai et al. 2011). Primary pollutants directly pollute the air and are produced either from natural or from anthropogenic causes; on the other hand most hazardous secondary air pollutants have been produced when various primary air pollutants and components of air interact with each other (Cunningham et al. 2001). Industrialization, high traffic load, urban and road construction regurgitate million tons of poisonous gases, particulate matters, toxic heavy metals to air which severely affect the health of plants and animals. Heavy air pollution causes acid rain which reduces the pH of soil and water resulting in toxic heavy metals being more bioavailable to vegetation (Singh and Agrawal 2008). Other than this, the aqueous SO_2 can also hamper the plant metabolism by blocking the electron transport system (ETS) and this was due to the competition between CO_2 and sulfite (SO_3^{2-}) for active sites of ribulose 1,5-bisphosphate carboxylase (RUBP) (Agrawal and Deepak 2003). In plant body, the reactive oxygen species (ROS), such as H_2O_2, singlet O_2, O^-, O_3, hydroxyl radicals, superoxide, were produced during different environmental stress conditions and scavenged effectively by tolerant plant species with their cellular antioxidants like ascorbate, glutathione, tocopherol, proline,

Editorial responsibility: M. Abbaspour.

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and ROS-interacting enzymes such as superoxide dismutase (SOD), catalase, peroxidase (Blokhina et al. 2003). The present issue to combat against more complex air pollution is the development of effective greenbelt which soaks the dust particles, poisonous gases and finally attenuates the pollutant levels (Gupta et al. 2008). An effective greenbelt development minimizes air pollution by absorbing, sequestering, and translocating the different gaseous and particulate air pollutants without maximum foliar damage and provides available respirable O_2 to the environment (Sharma et al. 1994; Rawat and Banerjee 1996; Beckett et al. 1998; Brack 2002; Shannigrahi et al. 2003; Prajapati and Tripathi 2008).

In urban industrial area, the greenbelt development by different assessment categories of pollution-tolerant plant species may protect the entire city precisely without hampering the industrial and economic growth. Air pollution produces biochemical and morphological abnormality in sensitive plant species rather than tolerant ones. In the polluted sites, the sensitive species act as early warning indicators of pollution (Ninave et al. 2001; Bakiyaraj and Ayyappan 2014). Biochemical, physiological, and morphological adaptation of tolerant plant species could encounter pollution stress efficiently for their survival. Air pollution tolerance index (APTI) is based on four biochemical properties of leaves: ascorbic acid, leaf extract pH, total chlorophyll, and relative water content (Singh and Rao 1983). The sensitivity and tolerance of plant species were judged depending on this index (Prajapati and Tripathi 2008). Further, anticipated performance index (API) is calculated by evaluating various biochemical, physiological, socioeconomic, and biological characteristics of the plant such as APTI, canopy structure, plant habit, and economic value, and then API score is given to each species according to the criteria (Gupta et al. 2011; Pandey et al. 2015). These indices have been used to rank the plant species in order of tolerance to air pollution and their socioeconomic status. The objectives of the present investigation were aimed to assess the effective pollution-tolerant plant species through analyzing some biochemical parameters and monitoring biological and socioeconomic characteristics of 36 plant species for an effective greenbelt development. Finally, a model map was prepared by those superior varieties of plant species for easy observation and understanding of a functional wall of greenbelt.

Date and location of research The research work was carried out during 2013–2014 session at Durgapur industrial region.

Materials and methods

Study sites

Durgapur is a major industrial hub located at 23.48°N 87.32°E and has an average elevation of 213 ft., near Raniganj, a renowned mining area of Paschim Burdwan District, West Bengal, India. The abundance of raw materials such as coal, iron ore in proximity of Durgapur, adequate availability of river Damodar water, and other infrastructural facilities have encouraged the establishment of several big and other small ferro-alloy steel factories in south of the city. Durgapur is known as the Ruhr of Bengal and lithologically the area belongs to Supra-Panchet Formation of Gondwana Basin. It is highly polluted in respect to having high traffic load and industrial pollution hazard. Durgapur Steel Plant (DSP), Alloy Steel Plant (ASP), Durgapur Project Limited (DPL), Philips Carbon (PC), Mining and Allied Machinery Corporation (MAMC), and a number of different ancillary medium- and small-scale Ferro Alloy (FA) steel factories are the major pollution sources in and around Durgapur. The steel, power, and sponge iron production generates a lot of waste materials which damage the physical, chemical, and biological characteristics of the natural environment.

Sampling methodology

In order to ameliorate the degraded air quality condition through plantation of tolerant variety of higher plants, as a principal way, the understanding about the existing vegetation characteristics is essential. On the basis of these propositions, the present study was aimed by the evaluation of biochemical, physiological, and a biological characteristic of randomly chosen 36 plant species (five plants per species) from all over the industrial region of Durgapur which is located in West Bengal, India, during 2013–2014. The trial uses multiple species that had increased the chance of selecting the appropriate pollution-tolerant plants with higher probability than trials using single or few species. The plant leaf samples were collected at the lowermost part of the canopy at a height of 5–15 ft. from the ground level. The biochemical parameters were total chlorophyll (Arnon 1949), ascorbic acid (Mukherjee and Chaudhuri 1983), pH of leaf extract (Chaudhary and Rao 1977), and the physiological parameter was relative water content (Sen and Bhandari 1978), and all values were mentioned as average. Determination of anticipated performance index (API) of plants under study is gone through by different gradation characteristics like plant habit, canopy structure, type of plants, laminar texture and socioeconomic values and the grades were adopted from Prajapati and Tripathi (2008), Gupta et al. (2011) and Pandey et al. (2015). The results of the study are expected to highlight the screening of some pollution-tolerant plant species from randomly chosen plant variety and enable formulation of the prospective greenbelt around the concerned industrial region.

Air pollution tolerance index (APTI)

The APTI was calculated by the following formula suggested by Singh and Rao (1983). The most tolerant plant species were selected considering their APTI values. In the APTI formula, total chlorophyll has been added with leaf extract pH and multiplied with ascorbic acid. The multiplication of ascorbic acid represented the plant's detoxification ability. The resultant was again added with relative water content, and the outcome is divided by 10 to get the APTI formula.

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

where A = ascorbic acid content in mg/g of fresh weight, T = total chlorophyll in mg/g of fresh weight, P = pH of leaf extract, and R = relative water content (%).

After getting the APTI values for each plant species, the values should be compared with the scale of APTI, which was recommended by Mashita and Paise (2001). If the APTI values are less than 1, then the plant species are marked as highly sensitive; within 1–16 are registered as sensitive; between the range 17–30 have been considered intermittently tolerable, and finally the APTI values in between 30 and 100 are branded as the species which are air pollution tolerant.

Smirnoff (2000) studied ascorbic acid is more powerful, low molecular weight antioxidant (90% is in reduced ascorbate form) detected in chloroplast. A plant becomes adapted to increase intracellular concentration of ascorbate level under different environmental stress conditions (Blokhina et al. 2003). Foyer and Lelandais (1996) described "its intracellular concentration can build up to millimolar range (e.g., 20 mM in the cytosol and 20–300 mM in the chloroplast stroma)." Ascorbic acid estimation was performed by the following method described by Mukherjee and Chaudhury in 1983. According to this method, 10 mg of fresh leaf material was macerated with 10 ml of 6% (w/v) trichloroacetic acid. After centrifugation, 4 ml supernatant of the macerated leaf component was separated and 2 ml of 2% dinitrophenyl hydrazine and one drop of 10% thiourea were mixed properly. The absorbance of unknown solution was measured at 530 nm wavelength in a spectrophotometer.

The leaf pH is responsible for controlling photosynthetic efficiency. Photosynthesis is reduced in plants when leaf pH is low (Thakar and Mishra 2010; Enete et al. 2013). Thus, in APTI formula, the total chlorophyll was added to the leaf pH and then multiplied by ascorbic acid content (Agbaire and Akporhonor 2014). The method of pH estimation of plant leaves was followed by Chaudhary and Rao (1977). About 0.5 g of leaf sample was macerated with 50 ml of deionized water and centrifuged at 7000*g*. The extract pH was measured by a digital pH meter.

Chlorophyll is the essential part of plant for energy production, and depletion of chlorophyll molecule causes decrease in productivity and finally decreases environmental O_2. In plants, the total chlorophyll level becomes decreased under stress conditions (Tripathi and Gautam 2007; Rahmawati et al. 2014). For estimation of total chlorophyll, the method described by Arnon in 1949 was followed. About 100 mg of fresh leaf materials was weighted and mixed with 80% acetone. The absorbance of chlorophyll extract was measured on a spectrophotometer at 652 nm wavelength.

$$\begin{aligned}&\text{Total Chlorophyll (mg/g. fresh weight)}\\&\quad = D_{652} \times 1000/34.5 \times v/1000 \times 1/w,\end{aligned}$$

where D_{652} = optical density taken at 652 nm, v = final volume of 80% acetone, w = leaf fresh weight (100 mg).

Relative water content (RWC) plays an important role in plants to maintain physiological water balance under stress condition (Chaves et al. 2003; Geravandia et al. 2011). Sen and Bhandary (1963) depicted the method for calculating RWC which is as follows:

$$\text{RWC} = \left(W_{\text{f}} - W_{\text{d}}\right) \times 100/(W_{\text{t}} - W_{\text{d}})$$

W_{f} represents the fresh weight of plant leaf pieces on a four-digit balance. These leaf pieces were then immersed in water in a jar overnight and again weighted on next day to get W_{t} (t for turgid weight). To get the W_{d} or dry weight of leaf, the sample was placed in a hot air oven (70 °C) for 2 h.

The correlation between the APTI and biochemical parameters and hierarchical cluster analysis (between said variables and between the plant species) were performed by Statistica for Windows, Version 5.1a, Statsoft, Inc, 1996 and SPSS Inc., 1999.

A list of higher plants was made according to their degree of tolerance against air pollution in and around an industrial steel city, Durgapur. A map was prepared by Q-GIS software (2.18 Las Palmas de G..C.) for future greenbelt development to achieve a clean and fresh environment.

Anticipated performance index

The anticipated performance index (API) was calculated by adding the biological and socioeconomic quality (like plant habit, canopy structure, type of plant, laminar structure, and economic value) of plant species with its APTI value (Shannigrahi et al. 2004; Prajapati and Tripathi 2008) for assessing suitable pollution-tolerant plant species (Table 1). The different grades (+ or −) were subjected based on these biological and socioeconomic quality of plants (Table 2). This grade point is different in different plant species. The grade point of a particular plant species has been compared with the maximum possible grade point (16 which is fixed) of other plant by simple unitary formula. Different plants were numbered according to their grade percentage. Plant categories were graded as best, excellent, good, moderate,

Table 1 Air pollution tolerance index (APTI) was calculated on the basis of ascorbic acid, leaf extract pH, total chlorophyll, and relative water content

Sl. No.	Name of the plant species	A	P	T	R	APTI
1.	*Accacia auriculiformis* A. Cunn ex Benth.	70.92 ± 8.17	5.13 ± 1.26	1.78 ± 0.63	94.44 ± 9.82	65.30 ± 15.77
2.	*Aegel marmelous* (L.) Correa	13.10 ± 2.10	7.41 ± 2.37	2.13 ± 0.75	97.18 ± 7.19	22.80 ± 5.56
3.	*Albizia labbeck* (L.) Willd.	77.91 ± 15.01	8.46 ± 2.36	3.02 ± 1.07	83.33 ± 7.72	101.60 ± 35.53
4.	*Alstonia scholaris* (L.) R.Br.	188.85 ± 5.64	5.21 ± 1.68	1.58 ± 0.22	81.76 ± 17.63	136.78 ± 37.33
5.	*Anthocephalus cadamba* (Roxb.) Miq.	194.96 ± 16.42	3.99 ± 1.30	1.80 ± 0.53	86.96 ± 6.89	120.44 ± 8.41
6.	*Artocarpus heterophyllus* Lam.	54.85 ± 6.24	6.99 ± 1.28	3.60 ± 0.74	79.77 ± 6.37	67.15 ± 16.62
7.	*Azadirachta indica* A. Juss.	42.10 ± 4.42	7.99 ± 1.77	2.63 ± 1.49	92.85 ± 17.89	53.34 ± 10.58
8.	*Bauhinia purpurea* L.	1.39 ± 0.41	6.28 ± 1.11	2.50 ± 0.58	89.52 ± 11.01	10.17 ± 1.33
9.	*Butea monosperma* (L.) Taub	54.15 ± 7.38	4.96 ± 2.89	1.48 ± 0.51	58.78 ± 10.48	42.54 ± 17.84
10.	*Cassia fistula* L.	15.72 ± 2.73	5.68 ± 0.90	2.66 ± 0.65	83.71 ± 4.20	21.86 ± 5.03
11.	*Cassia siamea* Lamk.	8.38 ± 2.77	3.43 ± 0.54	1.19 ± 0.24	80.00 ± 14.33	11.93 ± 1.76
12.	*Dalbergia sissoo* Roxb.	37.56 ± 2.98	5.92 ± 2.01	2.20 ± 0.60	66.66 ± 10.55	37.16 ± 9.19
13.	*Eucalyptus territicornis* Sm.	91.36 ± 5.24	4.44 ± 0.69	2.53 ± 0.36	97.64 ± 4.28	73.67 ± 7.92
14.	*Ficus benghalensis* L.	19.04 ± 2.66	7.30 ± 2.00	1.40 ± 0.48	87.35 ± 38.63	24.65 ± 5.68
15.	*Ficus hispida* L. f.	5.06 ± 0.64	6.91 ± 0.62	1.06 ± 0.22	83.69 ± 2.91	12.39 ± 0.06
16.	*Ficus religiosa* L.	82.80 ± 7.01	7.01 ± 1.47	2.05 ± 1.41	92.88 ± 10.56	86.30 ± 29.97
17.	*Glirichidia pinnata*	75.47 ± 12.22	7.89 ± 1.59	2.50 ± 0.97	84.61 ± 12.70	86.49 ± 20.29
18.	*Glochidion lanceolarium* Roxb.	3.84 ± 0.67	7.76 ± 2.83	3.18 ± 0.22	97.84 ± 7.41	14.11 ± 1.66
19.	*Gmelina arborea* Roxb.	160.54 ± 5.76	5.19 ± 0.79	3.44 ± 0.19	7.31 ± 1.08	138.73 ± 10.99
20.	*Holoptelea integrifolia* Planch	17.64 ± 4.75	5.34 ± 2.06	0.93 ± .034	95.65 ± 5.72	21.51 ± 6.55
21.	*Inga dulcis* (Roxb.) Willd.	19.21 ± 3.60	8.21 ± 2.27	3.65 ± 1.40	93.03 ± 9.50	33.34 ± 11.05
22.	*Lagerstroemia speciosa* (L.) Pers.	230 ± 6.31	6.85 ± 1.36	3.05 ± 0.17	64.97 ± 9.88	233.78 ± 25.44
23.	*Mangifera indica* L.	45.24 ± 2.40	4.33 ± 1.37	2.72 ± 1.12	86.91 ± 4.58	40.41 ± 2.52
24.	*Mimusops elengi* L.	23.58 ± 1.58	5.99 ± 1.05	3.31 ± 0.74	86.77 ± 2.79	30.85 ± 5.77
25.	*Peltophorum ferregineum* (Decne.) Benth.	89.97 ± 11.46	6.03 ± 1.36	2.26 ± 0.53	26.66 ± 5.41	78.90 ± 22.97
26.	*Pongamia pinnata* (L.) Pierre	65.68 ± 13.31	5.75 ± 3.62	1.33 ± 0.49	83.10 ± 6.69	49.86 ± 16.00
27.	*Psidium guajava* L.	81.75 ± 9.38	5.20 ± 2.10	1.72 ± 0.62	86.91 ± 9.52	62.82 ± 12.24
28.	*Pterospermum acerifolium* (L.)Willd.	113.20 ± 10.55	6.18 ± 1.56	2.30 ± 1.05	28.96 ± 4.54	98.72 ± 28.82
29.	*Scleichera oleosa*	99.22 ± 7.25	5.61 ± 1.44	2.84 ± 0.36	28.03 ± 5.07	87.76 ± 23.63
30.	*Shorea robusta* Gaertn.	92.24 ± 17.00	5.23 ± 0.37	2.15 ± 0.55	86.88 ± 5.35	78.06 ± 19.64
31.	*Syzizium cumini* (L.) Skeels.	10.30 ± 2.99	3.69 ± 2.37	0.95 ± 0.38	56.59 ± 3.78	11.12 ± 4.27
32.	*Tamarindus indica* L.	3.31 ± 0.48	4.42 ± 0.28	1.56 ± 0.24	86.46 ± 5.69	10.63 ± 0.97
33.	*Tectona grandis* L.	0.5 ± 0.05	3.82 ± 1.27	2.05 ± 1.49	87.86 ± 2.24	9.08 ± 0.18
34.	*Thespesia populnea* (L.) Sol. ex Correa.	162.99 ± 21.3	5.91 ± 1.91	1.62 ± 0.75	67.79 ± 5.77	126.23 ± 33.17
35.	*Terminalia arjuna* Bedd.	39.30 ± 3.05	5.06 ± 0.63	1.64 ± 0.35	93.86 ± 3.86	35.56 ± 3.78
36.	*Zizyphus jujube* Mill.	5.93 ± 2.41	6.26 ± 1.53	2.40 ± 1.09	85.71 ± 10.48	14.32 ± 4.65

A = ascorbic acid content in mg/g of fresh weight, *T* = total chlorophyll in mg/g of fresh weight, *P* = pH of leaf extract, *R* = relative water content (%)

and poor (Tiwari et al. 1993). Here, in this study, the categorization of plants was increased due to higher APTI value.

$$\text{API}(\%) = \frac{\text{Plant get their own grade}}{\text{Recommended maximum grade of any plant species}} \times 100$$

Assessment of ambient air quality

In Durgapur, the main air pollutants are SO_2, NO_2, SPM (Suspended Particulate Matter) and RSPM (Respirable Suspended Particulate Matter). The normal ranges of SO_2, NO_2, SPM, and RSPM prescribed by Central Pollution Control

Table 2 Gradation of plant species by combining the APTI values with some relevant biological and socioeconomic characteristics

Grading characters	Pattern of assessment	Grade allotted
(a) Tolerance		
APTI	9–18.0	1(+)
	18.1–27.0	2(+)
	27.1–36.0	3(+)
	36.1–45.0	4(+)
	45.1–54.0	5(+)
	54.1-onwards	6(+)
(b) Biological and socioeconomic		
(i) Plant habit	Small	1(−)
	Medium	1(+)
	Large	2(+)
(ii) Canopy structure	Sparse/irregular/globular	1(−)
	Spreading crown/open/semidense	1(+)
	Spreading dense	2(+)
(iii) Type of plant	Deciduous	1(−)
	Evergreen	1(+)
(iv) Laminar structure		
Size	Small	1(−)
	Medium	1(+)
	Large	2(+)
Texture	Smooth	1(−)
	Coriaceous	1(+)
Hardiness	Delineate	1(−)
	Hardy	1(+)
(v) Economic value	Less than three uses	1(−)
	Three or four uses	1(+)
	Five or more uses	2(+)

Board (CPCB) in industrial, residential, rural, and other areas are 80.0 μg/m^3, 80.0 μg/m^3, 200 μg/m^3, and 100 μg/m^3, respectively. In Durgapur, all of these pollutants exceed their normal value except SO_2 (36.36 μg/m^3), and the recorded concentrations of the remaining were NO_2—95.36 μg/m^3, SPM—245 μg/m^3, and RSPM—366 μg/m^3. Air pollution parameters like SO_2, NO_2, and SPM (Suspended Particulate Matter) were measured by a Handy Air Sampler (Envirotech Model APM 821). On the other hand, the Respirable Suspended Particular Matter (RSPM) was measured by Respirable Dust Sampler (Envirotech Model APM 460 BL) (insert Tables 3, 4).

Results and discussion

Table 5 showed that *Lagerstroemia speciosa* has the highest ascorbic acid content (230 mg/g fresh weight) followed by *Anthocephalus cadamba* (194.96), *Alstonia scholaris* (188.85), *Thespesia populnea* (162.99), *Gmelina arborea* (160.54), *Pterospermum acerifolium* (113.20), respectively, while the lowest value was calculated in *Tectona grandis* (0.5 mg/g fresh weight). Ascorbic acid is a low molecular weight powerful antioxidant and is responsible for directly scavenging the stress-dependent reactive oxygen species (ROS) like superoxide, hydroxyl radicals, singlet oxygen, and reduced H_2O_2 (Jyothi and Jaya 2010; Sanghi et al. 2015). Organic macromolecules like carbohydrate, protein, fat, and nucleic acid are prone to damage by ROS (Blokhina et al. 2003). Increased level of ascorbic acid in leaves provides greater protection to plant cells against all types of adverse environmental situations (Garg et al. 2015), and it was strongly proved that its concentration is positively correlated with intensities of air pollution (Enete et al. 2013).

In Fig. 1, the hierarchical cluster analysis reflects clustering of plant species on the basis of biochemical and physiological parameters and APTI values. It is the statistical application which could segregate the measured variables into homogeneous groups possessing similar characteristics and differ from the other heterogeneous groups or clusters. In this figure, a total of six clusters were observed. *Ficus hispida* (Fh) to *Syzizium cumini* (Sc) form the first cluster in which 14 plant species were included. The second cluster

Table 3 Anticipated performance index (API) of plant species

Grade	Scores (%)	Assessment category
1	Up to 40	Not recommended
2	41–50	(i) Very poor
3		(ii) Poor
4	51–60	Moderate
5	61–70	(i) Satisfactory
6		(ii) Good
7	71–80	Very good
8	81–90	(i) Very very good
9		(ii) Excellent
10	91–100	(i) Best
11		(ii) Outstanding

Table 4 The average values of SOx, NOx, SPM and RSPM comparing with standard values of the same pollutants recommended by Central Pollution Control Board (CPCB)

Pollutants (μg/m^3)	SO_x	NO_x	SPM	RSPM
Central Pollution Control Board (CPCB)	80	80	200	100
Durgapur (Overall Industrial area)	36.36	95.36	245	366

formed with five plant species, i.e., *Mangifera indica* (Mi) to *Dalbergia sishoo* (Ds). Third and fourth clusters recruited three and nine plant species with *Peltophorum ferregineum* (Pf) to *Pterospermum acerifolium* (Pa) in third and *Albizzia labek* (Al) to *Artocarpus heterophyllus* (Ah) in fourth, respectively. Three plant species, i.e., *Alstonia scholaris* (As) to *Thespesia populnea* (Tp), showed the fifth cluster which forms another and final cluster with two plant species, i.e., *Gmelina arborea* (Ga) and *Lagerstroemia speciosa* (Ls). The fifth and sixth clusters were much more nearer with each other regarding their high pollution tolerance capabilities while fourth, third, second, and first clusters were farthest subsequently from the sixth cluster with possessing lower pollution tolerance index accordingly. The cluster analysis of various plant species has done to create many similar groups by which proper screening out of pollution-tolerant plant species has been possible. In addition to cluster analysis which is substantiated through statistical analysis in SPSS, another qualitative assessment has also been programmed for categorical classification of plant species by providing biological and socioeconomic values.

In Fig. 2, another dendrogram was made by air pollution tolerance index (APTI) and biochemical parameters based on different selective plant species in Durgapur steel city. This figure showed that there are some distinct clusters depending upon the similar pattern of biochemical changes. Ascorbic acid (AA) and APTI form a cluster; pH and total chlorophyll (TCh) form another cluster. This second cluster forms another cluster with relative water content (RWC) which is distantly located from the first cluster. This distribution therefore indicates the lesser influence of RWC among other biochemical parameters in relation to APTI. Our findings were also supported by negative correlation between APTI and RWC (Table 6, 7).

From the correlation analysis in Tables 6 and 7 of different biochemical parameters and APTI it was found that APTI is positively correlated with ascorbic acid and total chlorophyll content and are significant both at 5% level of significance. For statistical computation and presentation SPSS Inc. 1999 were used.

Majority of the plant showed a leaf extract pH in the range of 5–7, while additional acidic pH represents sensitivity toward air pollution. Acidic pollutants decrease the leaf extract pH, and the decline is greater in sensitive plant species (Das and Prasad 2010). On the other hand, higher leaf extract pH will combat more against air pollution (Bora and Joshi 2014). The highest leaf extract pH was recorded in *Albizzia labek* (8.46) and the lowest recorded in *Cassia siamea* (3.43). Ascorbic acid is produced from hexose sugar in a level of alkaline pH but the efficiency of conversion will decrease when pH becomes acidic during heavy acid pollution (Escobedo 2008). In this study, it was observed that some plant species showed major variation or non-genetic biochemical and physiological spatial plasticity in effect of local atmospheric and meteorological conditions. The actual biochemical footprint of ascorbic acid was not disclosed properly inside the cells till now though the concentration of it might be regulated by the internal pH level. As biochemical data was taken in an average i.e., five plants per species which were chosen randomly from the vast area of Durgapur, therefore sometimes the higher pH level has been favored the higher concentration of ascorbic acid in comparatively non-polluted area. In contrast, in higher air pollution zone, the leaf extract pH becomes low which ultimately downregulated the level of ascorbic acid for the same plant species. This type of variation of measured variables impacts on the final outcome of the biochemical analysis, for example *Alstonia scholaris* and *Anthocephalus cadamba*, though they have low pH level, i.e., 5.21 and 3.99, respectively, yet both have possessed higher level of ascorbic acid.

The highest total chlorophyll content (mg/g fresh weight) of 36 plant species tested was recorded in *Inga dulcis* (3.65) followed by *Artocarpus heterophyllus* (3.60), *Gmelina arborea* (3.44), *Mimusops elengi* (3.31), *Glochidion lanceolarium* (3.18), *Lagerstroemia speciosa* (3.05), and *Albizia lebbeck* (3.02), respectively. Katiyar and Dubey (2001) have studied the chlorophyll content of plant leaves that becomes changed

Table 5 Evaluation of plant species by combining APTI values and some relevant biological and socioeconomic characteristics

SI. no.	Name of the plant	Assessment parameters										
		APTI	Tree habit	Canopy structure	Type of tree	Laminar		Economic importance	Hardiness	Grade allotted		API grade
						Size	Texture			Total plus (+)	% scoring	
1.	*Acacia auriculiformis*	6(+)	2(+)	1(–)	1(+)	1(+)	1(+)	1(–)	1(+)	12	75	7
2.	*Aegle marmelos*	2(+)	1(+)	1(+)	1(–)	1(+)	1(+)	1(+)	1(+)	8	50	3
3.	*Albizzialebbek*	6(+)	2(+)	2(+)	1(–)	1(–)	1(–)	2(+)	1(+)	13	81	8
4.	*Alstonia scholaris*	6(+)	1(+)	2(+)	1(+)	1(+)	1(+)	1(+)	1(–)	13	81	8
5.	*Anthocephalus cadamba*	6(+)	2(+)	1(+)	1(–)	2(+)	1(+)	1(+)	1(+)	14	87	9
6.	*Artocarpus heterophyllus*	6(+)	1(+)	1(+)	1(+)	2(+)	1(–)	2(+)	1(+)	14	87	9
7.	*Azadirachta indica*	5(+)	2(+)	2(+)	1(–)	1(–)	1(–)	2(+)	1(+)	12	75	7
8.	*Bauhinia purpurea*	1(+)	1(+)	1(–)	1(–)	1(+)	1(+)	2(+)	1(+)	7	44	2
9.	*Butea monosperma*	4(+)	1(+)	1(–)	1(–)	2(+)	1(+)	2(+)	1(+)	11	68	6
10.	*Cassia fistula*	2(+)	1(+)	1(+)	1(–)	1(+)	1(–)	1(+)	1(+)	7	44	2
11.	*Cassia siamea*	1(+)	1(+)	1(+)	1(+)	1(+)	1(+)	1(+)	1(+)	8	50	3
12.	*Dalbergia sissoo*	4(+)	2(+)	2(+)	1(+)	1(+)	1(+)	1(+)	1(+)	13	81	8
13.	*Eucalyptus tereticornis*	6(+)	2(+)	1(–)	1(+)	1(+)	1(–)	2(+)	1(+)	13	81	8
14.	*Ficus benghalensis*	2(+)	2(+)	2(+)	1(+)	2(+)	1(+)	2(+)	1(+)	13	81	8
15.	*Ficus hispida*	1(+)	1(+)	1(–)	1(–)	1(+)	1(+)	2(+)	1(+)	7	44	2
16.	*Ficus religiosa*	6(+)	2(+)	1(+)	1(–)	2(+)	1(+)	1(+)	1(+)	14	87	9
17.	*Glirichidia pinnata*	6(+)	1(+)	1(–)	1(–)	1(+)	1(+)	1(+)	1(+)	11	68	6
18.	*Glochidion lanceolarium*	1(+)	1(+)	1(+)	1(+)	2(+)	1(+)	1(+)	1(+)	9	56	4
19.	*Gmelina arborea*	6(+)	1(+)	2(+)	1(–)	1(+)	1(+)	2(+)	1(+)	14	87	9
20.	*Holoptelea integrifolia*	2(+)	2(+)	1(+)	1(–)	1(+)	1(+)	2(+)	1(+)	10	62	5
21.	*Inga dulcis*	3(+)	2(+)	1(+)	1(+)	1(+)	1(+)	2(+)	1(+)	12	75	7
22.	*Lagerstroemia speciosa*	6(+)	2(+)	2(+)	1(–)	2(+)	1(+)	2(+)	1(+)	16	100	11
23.	*Mangifera indica*	4(+)	2(+)	1(+)	1(+)	2(+)	1(+)	2(+)	1(+)	14	87	9
24.	*Mimusops lengi*	3(+)	2(+)	2(+)	1(+)	2(+)	1(+)	1(+)	1(+)	13	81	8
25.	*Peltophorum ferregineum*	6(+)	2(+)	1(–)	1(–)	1(–)	1(–)	1(+)	1(–)	9	56	4
26.	*Pongamia pinnata*	6(+)	1(+)	1(+)	1(+)	1(+)	1(–)	2(+)	1(–)	12	75	7
27.	*Psidium guajava*	6(+)	1(+)	1(+)	1(+)	1(+)	1(+)	1(+)	1(+)	13	81	8
28.	*Pterospermum acerifo-lium*	6(+)	1(+)	2(+)	1(+)	2(+)	1(+)	1(+)	1(+)	15	94	10
29.	*Scleichera oleosa*	6(+)	2(+)	2(+)	1(–)	2(+)	1(+)	2(+)	1(+)	16	100	11
30.	*Shorea robusta*	6(+)	2(+)	1(+)	1(–)	2(+)	1(+)	2(+)	1(+)	15	94	10
31.	*Syzygium cumini*	1(+)	2(+)	2(+)	1(+)	1(+)	1(–)	1(+)	1(+)	9	56	4

Table 5 (continued)

Sl. no.	Name of the plant	Assessment parameters								Grade allotted		API grade
		APTI	Tree habit	Canopy structure	Type of tree	Laminar		Economic importance	Hardiness	Total plus (+)	% scoring	
						Size	Texture					
32.	*Tamarindus indica*	1(+)	2(+)	2(+)	1(+)	1(−)	1(−)	1(+)	1(−)	7	44	2
33.	*Tectona grandis*	1(+)	2(+)	1(+)	1(−)	2(+)	1(+)	1(−)	1(+)	8	50	3
34.	*Thespesia populnea*	6(+)	2(+)	1(+)	1(+)	2(+)	1(+)	2(+)	1(+)	16	100	11
35.	*Terminalia arjuna*	3(+)	2(+)	1(+)	1(−)	2(+)	1(+)	1(+)	1(+)	11	68	6
36.	*Zizyphus jujube*	1(+)	1(+)	1(−)	1(+)	1(+)	1(−)	1(+)	1(+)	6	35	1

according to leaf age, species variation, and their degree of tolerance to pollution level. Higher pollution decreases the chlorophyll production (Rai and Panda, 2014) and finally reduces the plant biomass and productivity. In this study, the plants containing higher chlorophyll level had higher APTI values (> 30) which suggested that all were capable to cope up the adverse air quality conditions except *Glochidion lanceolarium* (APTI 14.11) which was sensitive to air pollution. In contrast, the study also reflected high pollution-tolerant plant species hosted comparatively low level of total chlorophyll such as *Thespesia populnea* (1.62 mg/g), *Alstonia scholaris* (1.58 mg/g), *Anthocephalus cadamba* (1.80 mg/g), and many others. Generally, the tolerance capability might be due to the superior activity of ascorbic acid which acts as an antioxidant for removal of free radicals from plant body. In the APTI formula, the ascorbic acid has been multiplied with addition of total chlorophyll and pH and played an influential role in determining a plant as sensitive or tolerant to air pollution. The higher the chlorophyll content, there will be better adaptation against air pollution; this statement is not always true for all the plant species.

The relative water content (RWC) was high in *Glochidion lanceolarium* (97.84%) followed by *Eucalyptus territicornis* (97.64%), *Aegel marmelous* (97.18%), *Holoptelea integrifolia* (95.65%), *Accacia auriculiformis* (94.44%), *Terminalia arjuna* (93.86), *Inga dulcis* (93.03%), respectively. Higher the RWC, higher will be the tolerance against drought, pollution, or any adverse environmental condition (Dedio 1975; Kuddus et al. 2011).

APTI of 36 plant species was calculated, and different plant species showed considerable variation in their susceptibility to air pollution. As shown in Table 5, plant species with higher APTI values were *Lagerstroemia speciosa* (233.78), *Gmelina arborea* (138.73), *Alstonia scholaris* (136.78), *Thespesia populnea* (126.23), *Anthocephalus cadamba* (120.44), *Albizzia lebbeck* (101.60), *Pterospermum acerifolium* (98.72). Plants with high APTI value (i.e., > 30) can serve as tolerant species to air pollution; on the other hand, sensitive species has lower APTI values (i.e., 1–16) (Jyothi and Jaya 2010). In response to air pollution tolerance capability, all plants showed major to minor variability in their APTI values depending on spatial (Banerjee et al. 2016) and temporal basis (Liu and Ding 2007; Das and Prasad 2010; Bhattacharya et al. 2013). Ascorbic acid mainly plays a significant role for determination of APTI values of a plant species. Its very high value has elevated the APTI result to a peak to make a plant more tolerant to air pollution, though the associated parameters were kept low or very low. The formation of ascorbic acid varied widely depending on the local air pollution status. In Table 1, the evaluation was carried out for 36 plant species and individual plants were graded by combining their APTI values and relevant socioeconomic and biological characteristics.

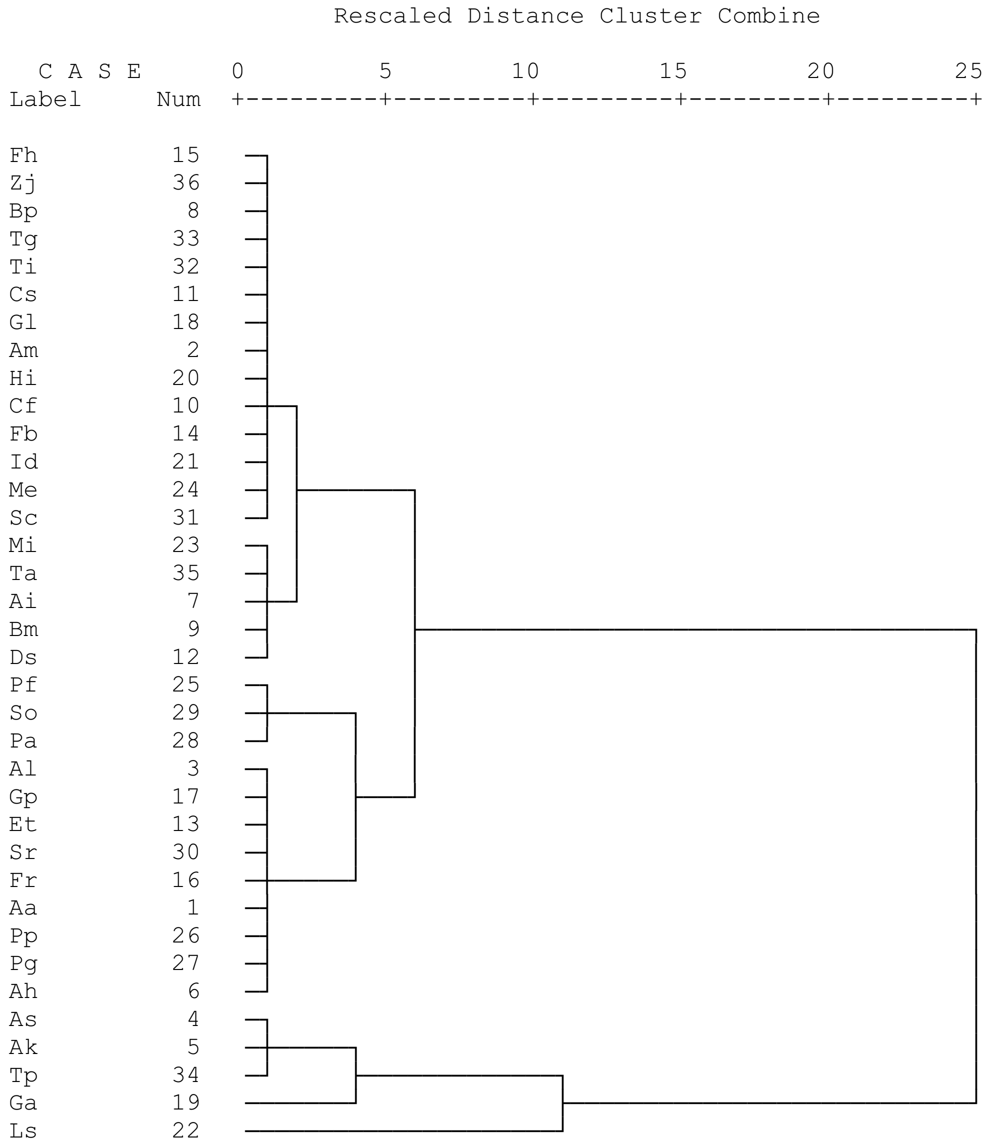
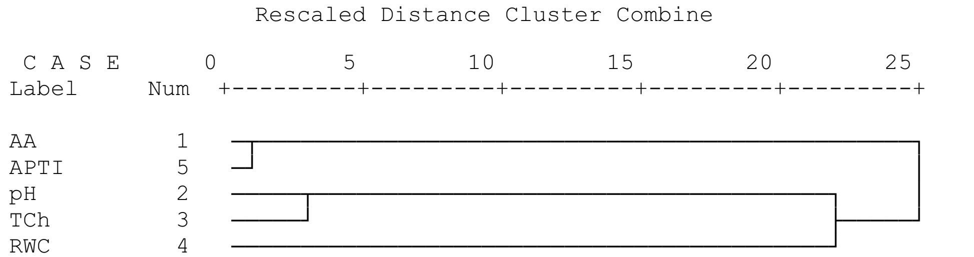


Fig. 1 Hierarchical cluster analysis of different selected plant species of Durgapur Industrial Township depending on the APTI values and biochemical parameters (i.e., ascorbic acid, pH, total chlorophyll, and relative water content). Plant code 1 = *Accacia auriculiformis* (Aa) (Sonajhuri), 2 = *Aegel marmelous* (Am) (Bel), 3 = *Albizzia labek* (Al) (Sirish), 4 = *Alstonia scholaris* (As) (Chatim), 5 = *Anthocephalus kadamba* (Ak) (Kadom), 6 = *Artocarpus heterophyllus* (Ah) (Kanthal), 7 = *Azadirachta indica* (Ai) (Neem), 8 = *Bauhinia purpurea* (Bp) (Kanchan), 9 = *Butea monosperma* (Bm) (Palas), 10 = *Cassia fistula* (Cf) (Bandarlathi), 11 = *Cassia siamea* (Cs) (Cassia), 12 = *Dalbergia sishoo* (Ds) (Sishu), 13 = *Eucalyptus territicornis* (Et) (Eucalyptus), 14 = *Ficus benghalensis* (Fb) (Banyan), 15 = *Ficus hispida* (Fh) (Dumur), 16 = *Ficus religiosa* (Fr) (Asvattha), 17 = *Gliricidia pinnata* (Gp) (Saranga), 18 = *Glochidion lanceolarium* (Gl) (Cheese tree), 19 = *Gmelina arborea* (Ga) (Gamar), 20 = *Holoptelea integrifolia* (Hi) (Nata karanja), 21 = *Inga dulcis* (Id) (Madras thorn), 22 = *Lagerstroemia speciosa* (Ls) (Jarul), 23 = *Mangifera indica* (Mi) (Mango), 24 = *Mimusops elengi* (Me) (Bakul), 25 = *Peltophorum ferregineum* (Pf) (Flametree), 26 = *Pongamia pinnata* (Pp) (Karancha), 27 = *Psidium guajava* (Pg) (Peyara), 28 = *Pterospermum acerifolium* (Pa) (Kanak Champa), 29 = *Scleichera oleosa* (So) (Kusum), 30 = *Shorea robusta* (Sr) (Sal), 31 = *Syzizium cumini* (Sc) (Jamun), 32 = *Tamarindus indica* (Ti) (Tentul), 33 = *Tectona grandis* (Tg) (Segun), 34 = *Thespesia populnea* (Tp) (Pipal), 35 = *Terminalia arjuna* (Ta) (Arjun), 36 = *Zizyphus jujube* (Zj) (Kool)

Air is a complex mixture of many kinds of hazardous chemicals, poisonous gases, and particulate matter distorting the stability of the ecosystem. In most ecosystems, plants are the significant interceptors of air pollution. There is considerable variability among different plant species in their response to air pollution stress. Table 8 depicts that out of 36 plant species, *Lagerstroemia speciosa*, *Schleichera oleosa, Thespesia populnea* would be the outstanding



1=Ascorbic acid (AA), 2=pH, 3=Total chlorophyll (TCh), 4=Relative water content (RWC), 5=Air Pollution Tolerance Index (APTI).

Fig. 2 Hierarchical cluster analysis of air pollution tolerance index (APTI) and biochemical parameters based on different selective plant species in Durgapur steel city. 1 = Ascorbic acid (AA), 2 = pH, 3 = total chlorophyll (TCh), 4 = relative water content (RWC), 5 = air pollution tolerance index (APTI)

Table 6 Correlation matrix between APTI and biochemical parameters of plant leaves in Durgapur steel city

	AA						
pH	− 0.07	pH					
TCh	0.52	0.16	TCh				
RWC	− 0.4	0.14	− 0.44	RWC			
APTI	0.95*	0.11	0.62*	− 0.39			

Parameters are abbreviated as follows: *AA* ascorbic acid, *TCh* total chlorophyll, *RWC* relative water content

*Marked correlations are significant at $p < 0.05$

performers against air pollution. These plants have dense canopy structure; they are hardy, coriaceous, and their large leaves minimize the dissemination of particulate matter reaching a specified distance. *Pterospermum acerifolium* and *Shorea robusta* were selected to be best performer, while *Anthocephalus cadamba*, *Artocarpus heterophyllus*, *Ficus religiosa*, *Gmelina arborea,* and *Mangifera indica* were evaluated as excellent category. These plant species may act as a first line of defense against air pollution and must be planted around the first periphery of industrial sites. In Fig. 3, the GIS map showed that toward south of Durgapur

Table 7 Graphical representation of correlation matrix with above variables which include ascorbic acid (VAR1), pH (VAR2), total chlorophyll (VAR3), relative water content (VAR4), and APTI (VAR5)

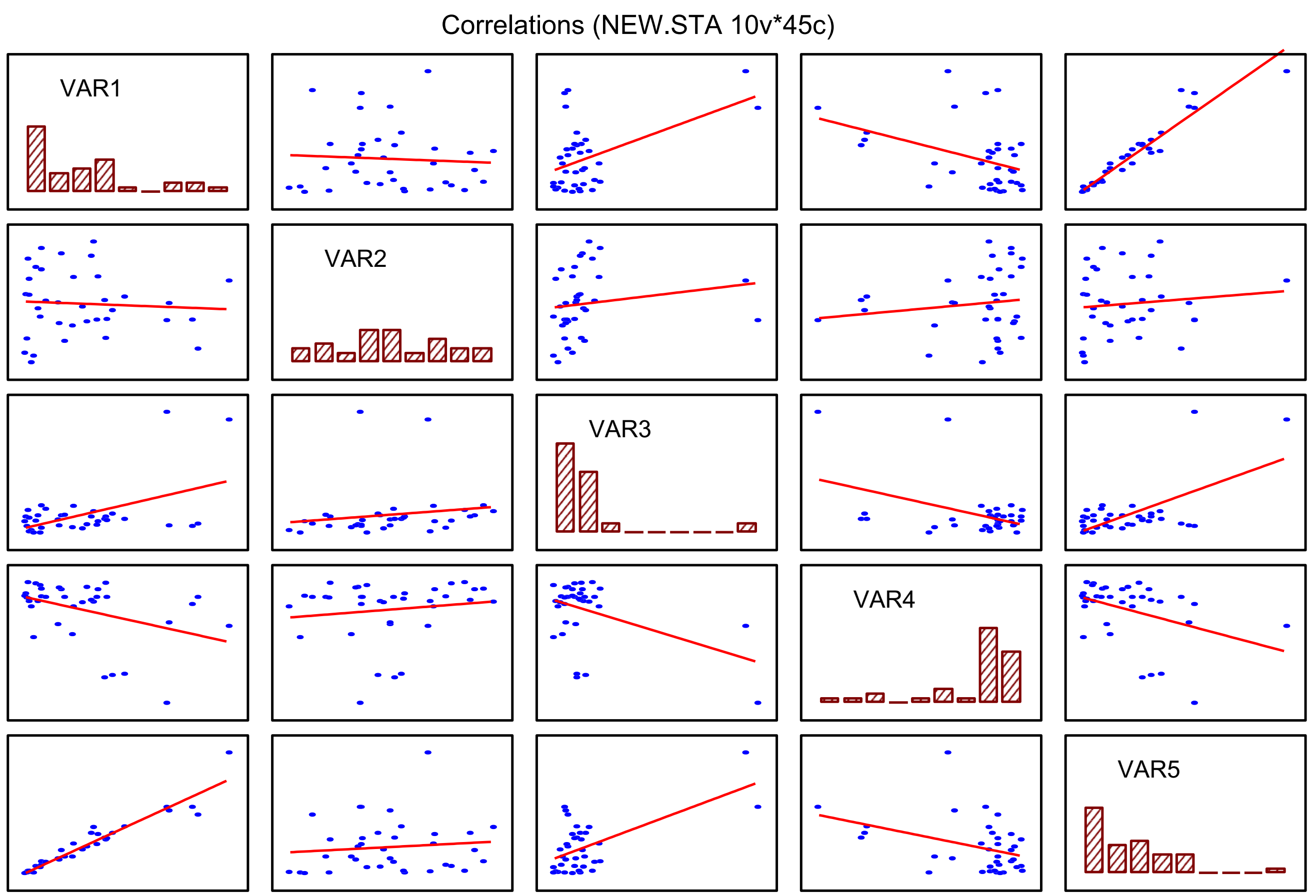


Table 8 Anticipated performance index (API) of different plant species in Durgapur Industrial Township

SI. No.	Name of the Plant	Grade allotted		API value	Assessment
		Total	%		
1.	*Lagerstroemia speciosa*	16	100	11	Outstanding
2.	*Scleichera oleosa*	16	100	11	
3.	*Thespesia populnea*	16	100	11	
4.	*Pterospermum acerifolium*	15	94	10	Best
5.	*Shorea robusta*	15	94	10	
6.	*Anthocephalus cadamba*	14	87	9	Excellent
7.	*Artocarpus heterophyllus*	14	87	9	
8.	*Ficus religiosa*	14	87	9	
9.	*Gmelina arborea*	14	87	9	
10.	*Mangifera indica*	14	87	9	
11.	*Albizia lebbeck*	13	81	8	Very very Good
12.	*Alstonia scholaris*	13	81	8	
13.	*Dalbergia sissoo*	13	81	8	
14.	*Eucalyptus tereticornis*	13	81	8	
15.	*Ficus benghalensis*	13	81	8	
16.	*Mimusops elengi*	13	81	8	
17.	*Psidium guajava*	13	81	8	
18.	*Acacia auriculiformis*	12	75	7	Very good
19.	*Azadirachta indica*	12	75	7	
20.	*Inga dulcis*	12	75	7	
21.	*Pongamia pinnata*	12	75	7	
22.	*Butea monosperma*	11	68	6	Good
23.	*Glirichidia pinnata*	11	68	6	
24.	*Terminalia arjuna*	11	68	6	
25.	*Holoptelea integrifolia*	10	62	5	Satisfactory
26.	*Glochidion lanceolarium*	9	56	4	Moderate
27.	*Peltophorum ferregineum*	9	56	4	
28.	*Syzygium cumini*	9	56	4	
29.	*Aegle marmelos*	8	50	3	Poor
30.	*Cassia siamea*	8	50	3	
31.	*Tectona grandis*	8	50	3	
32.	*Bauhinia purpurea*	7	44∀	2	Very poor
33.	*Cassia fistula*	7	44	2	
34.	*Ficus hispida*	7	44	2	
35.	*Tamarindus indica*	7	44	2	
36.	*Zizyphus jujube*	6	35	1	Not recommended

city, maximum industrial sectors were established and there gaseous pollutants, particulate matter, and heavy metal load in air were high naturally. The first three categorized plant varieties were strongly recommended on these particular regions for future greenbelt development programme to protect the entire city. *Albizzia lebbeck*, *Alstonia scholars*, *Dalbergia sissoo*, *Eucalyptus tereticornis*, *Ficus benghalensis*, *Mimusops elengi*, and *Psidium guajava* are anticipated to be very very good performers, and *Acacia auriculiformis*, *Azadirachta indica*, *Inga dulcis*, and *Pongamia pinnata* were regarded as very good performers. *Butea monosperma*, *Gliricidia pinnata*, *Terminalia arjuna* were judged to be good performers against air pollution. These three assessment categories of tree species act as second line of defense and were suggested to plant between the industry and habitation zone. The satisfactory and moderate category of plant species (i.e., *Holoptelea integrifolia* and *Glochidion lanceolarium*, *Peltophorum ferregineum*, *Syzygium cumini*) acts as a third line of defense against air pollution and could be planted inside and outskirts of the habitation area. The remaining seven plants under the poor and very poor category (i.e., *Aegle marmelos*, *Cassia siamea*, *Tectona grandis* and *Bauhinia purpurea*, *Cassia fistula*, *Ficus hispida*, *Tamarindus indica*) and last one *Ziziphus jujuba* were unsuitable for pollution sink and

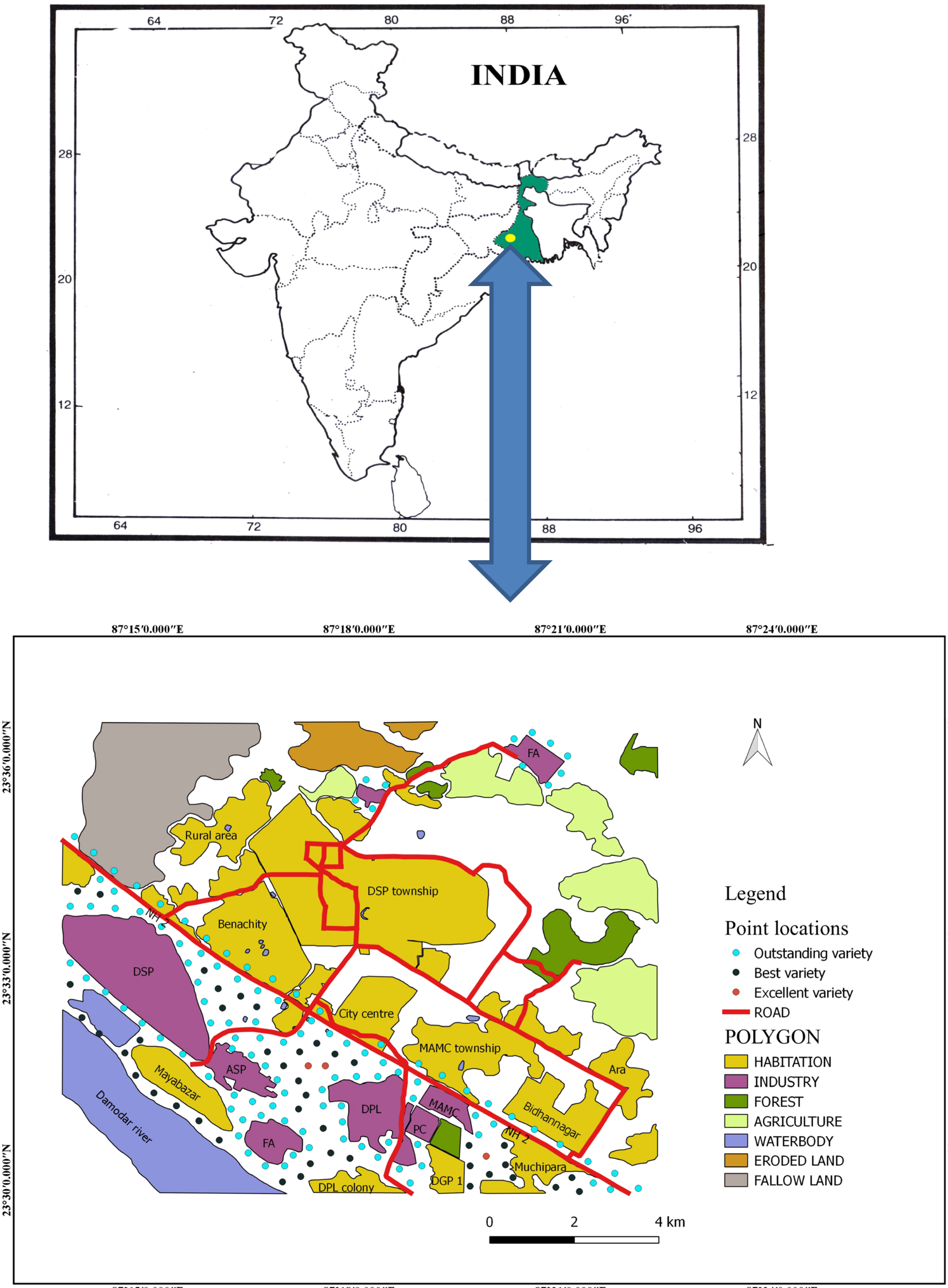


Fig. 3 Map showing proposed greenbelt around the industries by different varieties of plant species in Durgapur steel city, West Bengal, India

not recommended for plantation and greenbelt development programme.

A pictorial model of structural greenbelt was prepared by using the Q-GIS software (Fig. 3). The map on which the legends like point locations, lines, and polygons were superimposed is Google earth images that were taken from all over Durgapur of concerned area, and finally prepared master photocopy was considered as base map. The software-generated pictorial model of greenbelt reflected the green buffer zone with different-categorized tolerant varieties of plant species in and around the industrial zones. This greenbelt not only acts as a natural buffer against air pollution, but this would also increase the biodiversity of a region with polycultural practice. This imagery provides an overall concept of possible spatial deterioration of ambient air quality and future application of structural greenbelt.

Conclusion

Air pollution tolerance index (APTI) becomes a powerful tool in the selection of appropriate tree species when it was pooled with anticipated performance index (API) value. Plants having high APTI and API values are recommended for greenbelt development in and around an industrial urban city. These indices are based on biochemical parameters and biological and socioeconomic characters and can be applied worldwide. This study indicates that *Lagerstroemia speciosa* (Jarul), *Schleichera oleosa* (Kusum), and *Thespesia populnea* (Pipal) are the outstanding category of plant species and can be expected to perform well against air pollution. Similarly, there are other assessment categories in which several species are ranked and within them up to the satisfactory level the afforestation programme could be running for pollution management and aesthetic purpose. The remaining moderate, poor, and very poor categories of plants are sensitive to air pollution and are not recommended for plantation. In conclusion, in recent age researches on biochemical multi-parameter of plant leaves provided more reliable results than analyzing a single biochemical parameter and APTI determination would be the target for future pollution mitigation and the purpose of greenbelt development.

Acknowledgements The authors are grateful to Prof. Ambarish Mukherjee, Dept. of Botany, University of Burdwan for identification of plant species. Authors are also thankful to the Assistant Professor R. Chatterjee, Dept. of English, Sanskrit College University, Kolkata, and professors of Conservation Biology, Durgapur, West Bengal, India, to carry forward the research work. This research did not receive any specific grant from funding agencies in the public, commercial, or not-for-profit sectors.

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