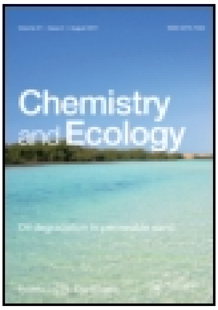

Chemistry and Ecology
Publication details, including instructions for authors and subscription information:
http://www.tandfonline.com/loi/gche20

Effect of air-borne heavy metals on the biochemical signature of tree species in an industrial region, with an emphasis on anticipated performance index

S. Gupta [a], S. Nayek [a] & P. Bhattacharya [a]

[a] Department of Environmental Science, The University of Burdwan, Burdwan, West Bengal, India

To cite this article: S. Gupta, S. Nayek & P. Bhattacharya (2011): Effect of air-borne heavy metals on the biochemical signature of tree species in an industrial region, with an emphasis on anticipated performance index, Chemistry and Ecology, 27:4, 381-392

To link to this article: http://dx.doi.org/10.1080/02757540.2011.561791

Chemistry and Ecology
Vol. 27, No. 4, August 2011, 381–392

Taylor & Francis
Taylor & Francis Group

Effect of air-borne heavy metals on the biochemical signature of tree species in an industrial region, with an emphasis on anticipated performance index

S. Gupta*, S. Nayek and P. Bhattacharya

Department of Environmental Science, The University of Burdwan, Burdwan, West Bengal, India

(*Received 16 September 2010; final version received 26 January 2011*)

The present study demonstrates elevated concentrations of air-borne heavy metals (Fe, 4.791; Cr, 3.142; Pb, 1.718; Cd, 0.069 $\mu g \cdot m^{-3}$) in an industrial region and their subsequent accumulation in tree species grown in that area. *Lagerstomia speciosa* showed the highest leaf metal concentrations, whereas the lowest metal concentration was observed in *Acacia moniliformis*. Air accumulation factors (AAF) for heavy metals were in the sequence Cd > Cr > Pb > Fe. Plants exposed to air-borne heavy metals showed a significant ($p < 0.01$, $p < 0.05$) decrease in total chlorophyll and soluble sugars content, with higher synthesis of cellular antioxidants compared with ascorbic acids, proline and thiols (NP-SH). Plants with higher air-borne metal accumulation factors (AAF) generally have a high air pollution tolerance index (APTI) value. Assessment of the anticipated performance index (API) gave *Alstonia scholaris* as the 'best variety' and *A. moniliformis* and *Shorea robusta* as 'very good' for plantation and greenbelt development in an industrial region.

Keywords: air-borne heavy metals; air accumulation factor; antioxidants; tolerant species; anticipated performance index (API)

1. Introduction

Air pollution, including that from vehicular exhausts, has been a major environmental concern since the beginning of industrialisation, resulting in a greater release of gaseous and particulate pollutants into the atmosphere [1,2]. Industrial emissions contain appreciable amounts of gaseous and particulate heavy metals (Fe, Pb, Cr, Cd). In addition, atmospheric deposition has also been recognised as one of the major source of air-borne heavy metals. Atmospheric heavy metals are deposited on plant foliar surfaces via industrial emissions and also by rain and dust. Leafy vegetation is known to accumulate a sizable quantity of air-borne heavy metals [3]. Several authors have reported a positive relationship between atmospheric deposition and elevated heavy metal concentrations in exposed plants [4–7].

Plants are very sensitive to both gaseous and particulate pollutants, and can be used as a bioindicator for monitoring atmospheric pollution. Sensitive species are useful as early warning indicators of pollution, and tolerant species help in reducing the overall pollution load, leaving

---

*Corresponding author. Email: srimantagupta@yahoo.co.in

ISSN 0275-7540 print/ISSN 1029-0370 online

DOI: 10.1080/02757540.2011.561791
http://www.informaworld.com

the air relatively free of pollutants [8]. Plants take up trace elements available in the air and also in the root environment. Significant yield losses in crop plants exposed to air pollutants in industrial areas have been reported [9]. Air pollutants in urban and industrial areas may be adsorbed, absorbed, accumulated or integrated into the plant body, and if toxic may injure the plant to some degree [10]. Free radical generation is one of the initial responses of plants to abiotic stress (including heavy metals), and can disrupt normal metabolism through oxidative damage to cellular components [11]. Several investigations have been performed on the physiological and biochemical response of plants growing in an industrial region [9,12,13].

The major objectives of this study include: (1) assessment of the atmospheric heavy metal (Fe, Pb, Cr, Cd) concentration in an industrial zone, (2) the biophysiological response of a plant community exposed to industrial emissions, and (3) screening of tolerant species by measuring the anticipated performance index (API) for future plantation and greenbelt development in an industrial area to mitigate atmospheric pollution.

2. Materials and methods

2.1. *Study area*

The research work was conducted at Mangalpur (latitude 23°37′N and longitude 87°08′E), a well-known industrial complex in the Raniganj coalfield, situated in the western part of West Bengal, India. This region under the current status of a developing industrial zone consists of mainly small-scale industries such as sponge iron and ferro alloy, along with their captive power plants; and has been run for more than 10 years. These industries are thought to be prime contributors of air-borne heavy metals and responsible for the deterioration in air quality in the surrounding areas.

The field study component of this research was performed in two different zones from which air and plant samples were collected.

(1) *Industrial sites*. The industrial sites were located within a 1–2 km radius of the core industrial area. This zone is enriched with a number of small-scale industries with a higher density of heavy vehicles.
(2) *Control site*. To compare data from industrial site, an unpolluted site was selected and treated as the control. This zone is a residential area, located 10–12 km from industrial area. This zone has abundant green vegetation and a lower traffic density.

2.2. *Sampling strategy and analytical procedures*

Bulk air particulate matters were monitored using a high volume sampler (NPM-HVS). Monitoring was carried out at regular intervals for 12 h periods in different selected sites. The sampling sites were free of any high, overhead obstacles that might collect atmospheric particulate matter. The apparatus was kept at 2 m from the ground, to avoid soil-borne particles. Immediately after collection, air particulate matter was acidified with 70% HNO_3 and stored in the dark at ambient temperature.

Only abundant plant species, growing in the vicinity of the industrial region were considered for assessment. The same plant species from the control area were also considered to assess the impact of air-bone heavy metals on plants and also for comparative evaluation. Fresh leaf samples were collected from different examined species and cleaned thoroughly with distilled water to remove dust/particulate matter on the leaf surface.

To analyse heavy metal concentrations, cleaned plant leaves were oven-died (80 °C), ground and passed through a 2-mm sieve. A tri-acid mixture (70% HNO_3, 65% $HClO_4$ and 70% H_2SO_4; 5:1:1) was used to digest air particulate matter and dried plant samples [14]. Digested samples were filtered (Whatman 42 filter paper), diluted to 50 mL and analysed for Fe, Pb, Cr and Cd in an atomic absorption spectrophotometer (GBC Avanta).

2.3. *Air accumulation factor*

The efficiency of heavy metal accumulation in vegetation due to atmospheric deposition is measured by the air accumulation factor (AAF) [15,16].

The AAF is calculated using the equation:

$$\frac{\text{Metal content in plants/Metal concentrations in air deposition in industrial area}}{\text{Metal content in plants/Metal concentrations in air deposition in control area}}.$$

2.4. *Estimation of physiological and biochemical parameters*

Freshly collected leaf samples were cleaned carefully with distilled water, refrigerated and examined to estimate some basic biochemical parameters. The pH of the leaf extract and the relative water content in the leaf was measured as per Sing and Rao [17]. Total chlorophyll content was estimated using 80% acetone [18] and soluble sugars were estimated using the anthrone method [19]. Ascorbic acid was measured according to Mukherjee and Choudhuri [20], and proline content according to Bates et al. [21]. Non-protein thiol (NP-SH) in plant leaves was estimated using Ellman's reagents [22].

2.4.1. *Air pollution tolerance index*

The air pollution tolerence index (APTI) is unique and incorporates four different biochemical parameters: total chlorophyll, ascorbic acids, pH of leaf extracts and relative water content [16]. The APTI was calculated using the formula:

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

where $A =$ ascorbic acid ($\text{mg}\cdot\text{g}^{-1}$), $T =$ total chlorophyll ($\text{mg}\cdot\text{g}^{-1}$), $P =$ pH of the leaf extract and $R =$ relative water content of leaf (%).

2.4.2. *Anticipated performance index*

On the basis of APTI and some relevant biological and socio-economic characteristics, the anticipated performance index (API) values were calculated for the examined species, and plants were categorised as excellent, good, moderate and poor [9].

The collected plants species were *Delbergia sissoo* (Family: Fabaceae), *Acacia moniliformis* (Family: Fabaceae), *Alstonia scholaris* (Apocynaceae), *Cassia semia* (Family: Fabaceae), *Cassia fistula* (Family: Fabaceae), *Lagerstomia speciosa* (Family: Lythraceae), *Tectona grandis* (Family: Verbenaceae), *Peltophorum pterocarpum* (Family: Fabaceae) and *Shorea robusta* (Dipterocarpeceae).

2.4.3. *Quality control assurances*

Care was taken to collect fresh, uninfected, healthy plant samples from both the control and polluted sites for investigation. E-mark standard solutions (AR grade, Germany) were used for atomic absorption spectrophotometer calibration to detect heavy metal concentrations in digested samples. To maintain accuracy, control standard solutions (blanks) were used at the beginning and after every five samples. Each analytical method was performed in triplicate to ensure the accuracy and reliability of the obtained results (reproducibility was within ±5%), and only mean values with standard deviation (SD) were represented.

2.4.4. *Statistical calculations*

A correlation study (Pearson's) was perfomed between air-borne heavy metal concentrations and the foliar heavy metal content of the examined plants. Linear regression analysis was performed between AAF values of metals and the APTI value of individual tree species. Two-way, two-factor analysis of variance (ANOVA) tests were introduced to determine the significance ($p < 0.05$, 0.01) of biochemical alterations in plant species grown in an industrial area in comparison wuth control sites. All statistical calculations were performed using XL Stat, Version 10.

3. Results and discussion

3.1. *Atmospheric particulate heavy metal concentrations and their accumulation in surrounding plants*

Atmospheric deposition in an industrial–urban environment is often found to be highly enriched with heavy metals [4,6,7]. This study revealed high concentrations of total particulate matter ($1458 \pm 23.64\,\mu\text{g} \cdot \text{m}^{-3}$) in the industrial region in comparison with the control site ($227 \pm 16.65\,\mu\text{g} \cdot \text{m}^{-3}$), which exceeded prescribed annual average National Ambient Air Quality Standards (1993) for industrial areas ($360\,\mu\text{g}{\cdot}\text{m}^{-3}$). Air-borne Fe concentrations in the industrial site ($4.791 \pm 0.128\,\mu\text{g} \cdot \text{m}^{-3}$) were higher than in control areas ($0.367 \pm 0.032\,\mu\text{g} \cdot \text{m}^{-3}$). A higher atmospheric Pb concentration in industrial areas has been reported earlier [7,11]. The elevated Pb concentration ($1.718 \pm 0.105\,\mu\text{g} \cdot \text{m}^{-3}$) in our studied area can be attributed to industrial emissions and a greater density of heavy vehicles in comparison with control sites ($0.632 \pm 0.035\,\mu\text{g} \cdot \text{m}^{-3}$). Cr and Cd concentrations in the atmosphere of industrial regions (3.142 ± 0.656 and $0.683 \pm 0.061\,\mu\text{g} \cdot \text{m}^{-3}$) were noticeably higher than in control sites (0.124 ± 0.011 and $0.069 \pm 0.005\,\mu\text{g} \cdot \text{m}^{-3}$).

Our study revealed (Table 1) that in all the studied species, the Fe concentration was noticeably higher than the concentration of other heavy metals (Pb, Cr and Cd). However, heavy metal accumulation in plants did not follow any particular pattern, which might be due to their inherent metal accumulation capacity, variations in growth rate and stage of maturity [5,6]. Heavy metals like Fe are required structural and catalytic components of proteins and enzymes, essential for the normal growth and development of plants. However, an excess of these micronutrients and other heavy metals in plants operates as a stress factor [23]. Elevated levels of heavy metals may cause oxidative stress either by inducing the generation of reactive oxygen species (ROS) within subcellular compartments or by decreasing enzymatic and non-enzymatic antioxidants due to an affinity with sulphur-containing groups (-SH) [24]. Among the examined plant species, *L. speciosa* showed the highest foliar heavy metal concentrations, while the lowest heavy metal content was observed in *A. moniliformis*. AAF values for Fe, Pb and Cr in the examined plants are presented in Table 2. In all examined plant species, the AAF value

Table 1. Heavy metal concentrations ($\mu g{\cdot}g^{-1}$) in foliage parts of tree species in industrial sites and control areas ($n = 8$).

	Fe		Pb		Cr		Cd	
Plant species	Industrial	Control	Industrial	Control	Industrial	Control	Industrial	Control
Alstonia scholaris	13.53 ± 2.04	3.59 ± 0.89	5.97 ± 1.27	0.72 ± 0.16	6.84 ± 1.41	0.092 ± 0.01	3.68 ± 0.78	0.046 ± 0.005
Acacia moniliformis	11.34 ± 1.98	2.56 ± 0.74	3.09 ± 0.57	0.67 ± 0.22	6.86 ± 1.09	0.11 ± 0.02	2.58 ± 0.69	0.037 ± 0.002
Lagerstomia speciosa	19.94 ± 2.00	3.66 ± 1.10	11.04 ± 2.24	0.94 ± 0.28	10.56 ± 1.68	0.14 ± 0.03	1.15 ± 1.12	0.048 ± 0.006
Peltophorum pterocarpum	11.97 ± 2.23	1.74 ± 0.52	6.81 ± 1.34	0.83 ± 0.31	9.74 ± 1.94	0.084 ± 0.01	2.06 ± 0.61	0.029 ± 0.002
Cassia semia	8.75 ± 2.10	1.65 ± 0.32	4.29 ± 0.72	0.65 ± 0.11	5.63 ± 0.97	0.087 ± 0.01	1.87 ± 1.04	0.041 ± 0.004
Cassia fistula	18.71 ± 1.90	2.24 ± 0.61	6.90 ± 1.48	0.96 ± 0.34	12.93 ± 2.02	0.12 ± 0.03	3.03 ± 0.62	0.039 ± 0.003
Tectona grandis	21.97 ± 2.40	4.22 ± 1.34	10.53 ± 2.11	1.27 ± 0.41	11.82 ± 2.18	0.16 ± 0.04	7.14 ± 1.07	0.066 ± 0.006
Delbergia sissoo	16.44 ± 2.08	3.14 ± 0.92	8.65 ± 1.66	0.79 ± 0.26	11.89 ± 1.85	0.106 ± 0.02	3.04 ± 0.93	0.042 ± 0.003
Shorea robusta	15.03 ± 2.33	3.36 ± 1.04	8.43 ± 1.97	1.04 ± 0.39	7.26 ± 0.83	0.14 ± 0.03	4.84 ± 1.34	0.051 ± 0.004

Table 2. Air accumulation factor (AAF) of different heavy metals with air pollution tolerance index (APTI) in different plants.

Plant species	AAF				APTI value	Regression equation
	Fe	Pb	Cr	Cd		
Alstonia scholaris	1.77	3.08	2.76	10.96	19.05	$Y = 0.2451X^*$
Acacia moniliformis	1.49	1.42	2.38	3.03	13.86	$Y = 0.15X$
Lagerstomia speciosa	2.05	4.28	2.94	10.84	9.74	$Y = 0.5243X^*$
Peltophorum pterocarpum	1.60	2.96	3.05	4.74	10.72	$Y = 0.29X$
Cassia semia	1.03	1.89	1.93	4.61	13.96	$Y = 0.1702X^*$
Cassia fistula	2.12	2.64	3.81	6.66	10.22	$Y = 0.3707X^*$
Tectona grandis	1.17	3.04	2.93	12.65	11.20	$Y = 0.4384X^*$
Delbergia sissoo	2.32	3.99	4.74	9.82	12.08	$Y = 0.4342X^*$
Shorea robusta	2.61	3.17	2.11	9.98	14.93	$Y = 0.302X^*$

Note: *Significant R^2 value at 0.01 level.

was >1 for each heavy metal, indicating a higher accumulation of air-borne particulate metals. The average air accumulation factors of heavy metals in the examined plant species are in the order Cd > Cr > Pb > Fe. Our investigation is consistent with earlier studeis [6,7], which also reported high AAF values for heavy metals in most of the plants grown in an industrial/urban region.

Correlation analysis between air-borne heavy metal concentrations and foliar heavy metal content in examined plants did not show significant inter-relations, which may correspond with the variable capabilities of plants to absorb and accumulate heavy metals. Besides, heavy metal concentrations in top-soil and prevailing meteorological conditions (wind velocity, direction and annual average precipitation) can also be determining factors [10].

3.2. ***Biochemical response of vegetation exposed to industrial emissions***

Plants differ markedly in their responses to pollutants, some being highly sensitive and others hardy and tolerant [25,26]. Continuous exposures to air pollution, even at low concentrations, can result in injury to plants without exhibiting any distinct visible symptoms.

3.2.1. *Total chlorophyll*

Chlorophyll content is often measured to assess the impact of environmental stress in plants, because changes in pigment content are associated with visual symptoms in plants as well as the photosynthetic rate. Several investigations have shown a reduction in photosynthetic pigments due to atmospheric pollution [11,12,27]. Our investigation showed a significant ($p < 0.05$) loss of chlorophyll in *L. speciosa*, *C. fistula*, *D. sisoo*, *T. grandis* and *A. moniliformis* in the industrial region (Table 3), with *C. fistula* showing the greatest reduction. The reduction in chlorophyll content can be explained by a degeneration in the structure of chlorophyll due to substitution of Mg^{2+} or higher chlorophyllase activity in relation to higher atmospheric heavy metal concentrations.

3.2.2. *Soluble sugars*

Carbohydrates are important components of storage and structural material in plant species. Earlier research [13,28] reported a decrease in sugar content in plant species as with an increase in air pollutant level in industrial and urban areas. The majority of the species examined showed a

Table 3. Estimation of foliar biochemical constituents of both industrial and control area plant species ($n = 8$).

	Total chlorophyll		Soluble sugars		Ascorbic acids		Proline		Non-protein thiol	
Plant species	Industrial	Control	Industrial	Control	Industrial	Control	Industrial	Control	Industrial	Control
Alstonia scholaris	8.27 ± 0.12	9.12 ± 0.20	6.08 ± 0.19	8.46 ± 0.30	7.56 ± 0.07	5.66 ± 0.17	1.48 ± 0.10*	1.04 ± 0.08	0.62 ± 0.02**	0.29 ± 0.04
Acacia moniliformis	3.36 ± 0.08*	4.56 ± 0.17	3.84 ± 0.10*	7.05 ± 0.27	5.42 ± 0.04*	3.88 ± 0.16	2.86 ± 0.14*	2.03 ± 0.13	0.37 ± 0.05	0.32 ± 0.06
Lagerstomia speciosa	5.26 ± 0.08*	7.84 ± 0.17	5.76 ± 0.15*	10.28 ± 0.31	1.56 ± 0.08*	0.94 ± 0.06	3.70 ± 0.47**	1.22 ± 0.08	0.84 ± 0.09	0.66 ± 0.06
Peltophorum pterocarpum	4.16 ± 0.10	5.24 ± 0.12	2.96 ± 0.12	5.33 ± 0.23	2.25 ± 0.29	1.23 ± 0.04	1.72 ± 0.07	0.96 ± 0.06	0.73 ± 0.08*	0.54 ±
Caswsia semia	4.62 ± 0.09	5.24 ± 0.08	4.87 ± 0.10	6.34 ± 0.24	4.74 ± 0.06*	3.38 ± 0.20	3.06 ± 0.32*	1.89 ± 0.10	0.29 ± 0.07	0.22 ± 0.06
Cassia fistula	2.16 ± 0.18*	4.08 ± 0.17	3.65 ± 0.10**	8.92 ± 0.27	2.65 ± 0.03*	1.62 ± 0.08	3.10 ± 0.04*	2.13 ± 0.16	1.18 ± 0.08*	0.86 ± 0.06
Tectona grandis	8.47 ± 0.12*	9.66 ± 0.25	5.72 ± 0.22*	11.25 ± 0.38	2.04 ± 0.06**	1.06 ± 0.11	3.34 ± 0.03**	1.24 ± 0.08	1.62 ± 0.06**	0.23 ± 0.04
Delbergia sissoo	4.12 ± 0.15*	6.24 ± 0.23	4.02 ± 0.09*	6.23 ± 0.21	3.08 ± 0.12	2.74 ± 0.17	1.02 ± 0.13*	0.68 ± 0.06	1.04 ± 0.07**	0.54 ± 0.06
Shorea robusta	7.82 ± 0.18	8.67 ± 0.16	6.14 ± 0.15	8.38 ± 0.28	5.14 ± 0.13*	3.76 ± 0.17	2.50 ± 0.34	1.86 ± 0.06	1.38 ± 0.10	1.10 ± 0.07

Note: statistical significance shown by $^{*}p < 0.05$ and $^{**}p < 0.01$.

significant ($p < 0.01, 0.05$) decrease in soluble sugars in comparison with control plants (Table 3), and the greatest reduction was observed in *D. sissoo*. the decrease in soluble sugar content may correspond with a lower photosynthetic rate and higher energy requirements due to air-borne heavy metal stress.

3.2.3. *Ascorbic acids*

Ascorbic acid is a cellular antioxidant and a strong reducing agent; it reduces the effect of air pollution and protects the plant against oxidative damage. Several authors/studies have reported increased ascorbic acid levels in plants exposed to atmospheric pollutants [11,13,29]. A significant increase ($p < 0.01, 0.05$) in ascorbic acid content was observed (Table 3) in most of the plants in the vicinity of industries compared with species from the control area, and the greatest increase was observed in *T. grandis*. A higher level of ascorbic acids may correspond with oxidative stress due to a greater accumulation of particulate heavy metals.

3.2.4. *Proline*

The stress-indicator amino acid proline play a major role in plant defence mechanisms, in particular oxidative damage, and its greater accumulation in metal-stressed plants has been reported previously [11,30]. The proline concentrations in the majority of plant species near the industrial area were significantly higher ($p < 0.01, 0.05$) than in control plants (Table 3). *L. speciosa* shows the highest proline accumulation in comparison with other species. Increased proline content in examined tree species can be explained by water-stress like conditions caused by the oxidative damage due to heavy metal stress.

3.2.5. *Non-protein thiol (NP-SH) content*

Stressed plant cells showed enhanced synthesis of NP-SH, a cellular antioxidant to counter the induced stress situation. NP-SH binds with the metal ions and thus reduces toxicity [23,30]. The study showed significant ($p < 0.01, 0.05$) enhancement in thiol (NP-SH) content in *Al. scholaris*, *P. pterocarpum*, *T. grandis* and *S. robusta* (Table 3) exposed to industrial emissions enriched with particulate heavy metals. Our observations support those of an earlier study [23], which also reported elevated thiol (NP-SH) in metal-stressed plants. The highest elevation in thiol (NP-SH) content was seen in *T. grandis*.

The overall situation revealed a decrease in total chlorophyll and soluble sugar content, with an increase in ascorbic acid, proline and non-protein thiol (NP-SH) in tree species in industrial areas (Table 3). This can be attributed to higher concentrations of air-borne heavy metals in comparison with control sites. The elevated foliar heavy metal content in tree species from industrial surroundings is associated with a reduction in chlorophyll and interferes with photosynthetic activity, thus reducing the synthesis of soluble sugars. Cellular antioxidants, viz. ascorbic acid, proline and non-protein thiol (NP-SH), play a major role in plant defence mechanisms and their higher synthesis is considered to be a signature of stress condition. The increase in ascorbic acid, proline and non-protein thiol (NP-SH) content in tree species from industrial surroundings may correspond with oxidative stress/damage due to the higher accumulation of heavy metals.

3.3. *APTI and API of plant species*

The effects of air pollution on different physiological parameters of plants are best reflected in the APTI value. Plants with a higher APTI value are more capable of combatting air pollution, but plants with a low APTI value are less tolerant and indicate levels of air pollution [12,16]. In this study (Table 2), *Al. scholaris*, *C. simea*, *A. moniliformis*, *S. robusta* and *D. sissoo* showed noticeably higher APTI values than the other examined tree species and are considered to be resistant varieties.

Linear regression analysis between the APTI and AAF value of metals (Table 2) exhibited a significant R^2 value for most of the studied plant species. The reason for this might be that plants with a high APTI value are able to accumulate higher concentrations of heavy metals, thus showing a greater AAF value for metals.

The effectiveness of greenbelt depends on selection of the appropriate plant species, particularly those tolerant of pollutants in that area [31,32]. Evaluation of API might be very useful to identify tree species best suited for planting in an industrial region to mitigate pollution. The method of classifying plant species as sensitive, intermediate and tolerant may not be entirely satisfactory, because different stages in the plant life cycle are likely to differ in their sensitivity or resistance to pollution [9,33].

Plant species commonly grown in industrial areas were evaluated (Table 4) for various morphological, socio-economic and biochemical characteristics, including APTI value. All these parameters were included in a grading scale (Table 5) to determine the anticipated performance of the examined plant species. From the investigation, *Al. scholaris* is evaluated as the 'best suited variety' for plantation in an industrial region, *A. moniliformis* and *S. robusta* are assessed as 'very good', while *L. speciosa*, *C. semia* and *T. grandis* are recognised as 'good' and thus can be used for future plantations in the vicinity of industrial areas to combat atmospheric particulate metal load.

Table 4. Gradation of plant species on the basis of air pollution tolerance index (APTI) value and other biological and socio-economic characteristics.[a]

Grading characteristics		Pattern of assessment	Grade allotted
Tolerance	APTI	6–9	+
		9.1–12	++
		12.1–15	+++
		15.1–18	++++
		18.1–21	+++++
Biochemical and socio-economic characteristics			
	Plant habit	Small	–
		Medium	+
		Large	++
	Canopy structure	Irregular/sparse	–
		Semi dense	+
		Spreading dense	++
	Type of plants	Deciduous	–
		Evergreen	+
	Laminar structure		
	(i) Size	Small	–
		Medium	+
		Large	++
	(ii) Texture	Smooth	–
		Coriaceous	++
	(iii) Hardiness	Delineate	–
		Hardy	+
	Economic value	Less than three uses	–
		Three–five uses	+
		More than five uses	++

Note: [a] Gradation characteristics adopted from Shannigrahi et al. [10]. '+' sign indicates positive grading and '–' indicates negative grading.

Table 5. Evaluation of the examined plant species on based on their air pollution tolerance index (APTI) value and various morphological and socio-economic characteristics.

Plant species	APTI value	Tree habit	Canopy structure	Type of tree	Laminar structure			Economic importance	Grade allotted		API gradation	Assessment
					Size	Texture	Hardiness		Total	% Score		
Alstonia scholaris	+++++	++	++	+	++	−	+	++	15	93.75	7	Best
Acacia moniliformis	+++	++	+	+	+	+	+	++	12	75	5	Very good
Lagerstomia speciosa	++	+	++	−	++	+	+	+	10	62.50	4	Good
Peltophorum pterocarpum	++	++	+	−	−	−	−	−	5	31.25	1	Very poor
Cassia semia	+++	+	+	+	+	+	+	+	10	62.5	4	Good
Cassia fistula	++	+	+	−	+	−	+	+	7	43.75	2	Poor
Tectona grandis	++	++	+	−	++	+	+	+	10	62.5	4	Good
Delbergia sissoo	+++	++	++	−	−	−	+	+	9	56.25	3	Moderate
Shorea robusta	+++	++	+	−	++	+	+	++	12	75	5	Very good

Notes: '+' sign indicates positive grading and '−' indicates negative grading; API, anticipated performance index.

4. Conclusion

The APTI rankings of the examined plant species do not coincide with the calculated API gradation because morphological characters and socio-economic importance can also be major determining factors. Within a natural environment, the effect of pollutants is always in combination, i.e in an antagonistic or synergistic form, and it is therefore difficult to differentiate and evaluate the effect of individual heavy metals on exposed plants. Moreover, the effects of gaseous pollutants may also be taken into account. A toxicity test for each heavy metal may be useful in evaluating the the potential contribution of individual heavy metals to phytotoxic damage. Screening of appropriate plant species might be useful for plantations, to mitigate atmospheric pollution and maintain a social–aesthetic balance in environments surrounding industrial areas, and also for future plantations and greenbelt development.

Acknowledgements

The authors thankfully acknowledge the assistance from Miss P. Sen, Department of Botany, University of Burdwan, throughout this research work.

References

[1] A.D. Bhatnakar, P.S. Rao, D.G. Gaghate, and P. Nema, *Inventory of* SO_2*, PM and toxic emissions from industrial sources in Greater Mumbai, India*, Atmos. Environ. 39 (2005), pp. 3851–3864.

[2] S. Hippeli and E.F. Elstner, *Effects of air pollutants on man, animals, plants and buildings: mechanisms and dose–response effects*, Stud. Environ. Sci. 55 (1993), pp. 13–22.

[3] D. Voutsa, A. Grimanis, and C. Sharma C, *Trace elements in vegetables grown in an industrial area in relation to soil and air particulate matter*, Environ. Pollut. 94 (1996), pp. 325–335.

[4] R.K. Singh and M. Agarwal, *Atmospheric deposition around a heavily industrialized area in a seasonally dry tropical environment of India*, Environ. Pollut. 138 (2005), pp. 142–152.

[5] R.K. Sharma, M. Agarwal, and F.M. Marshall, *Heavy metal (Cu, Zn, Cd and Pb) contamination of vegetables in urban India: a case study in Varanasi*, Environ. Pollut. 154 (2008), pp. 254–263.

[6] J. Pandey, R. Pandey, and K. Shubhashish, *Air-borne heavy metal contamination to dietary vegetables: a case study from India*, Bull. Environ. Contam. Toxicol. 83 (2009), pp. 931–936.

[7] N. Srinivas, S. Ramakrishna Rao, and K.S. Kumar, *Metal accumulation in vegetables grown in industrial and semi urban areas – a case study*, Appl. Ecol. Environ. Res. 7 (2009), pp. 131–139.

[8] D.N. Rao, *Sulphur dioxide pollution versus plant injury with special reference to fumigation and precipitation*, in *Proceedings of the Symposium on Air Pollution Control*, Vol. 1, Indian Association for Air Pollution Control, New Delhi, India, 1983, pp. 91–96.

[9] N. Joshi, A. Chauhan, and P.C. Joshi, *Impact of industrial air pollutants on some biochemical parameters and yield in wheat and mustard plants*, Environmentalist 29 (2009), pp. 398–404.

[10] A.S. Shannigrahi, T. Fukushima, and R.C. Sharma, *Anticipated air pollution tolerance of some plants species considered for green belt development in and around an industrial/urban area in India: an overview*, Int. J. Environ. Stud. 61 (2004), pp. 125–137.

[11] F. Van-Assche and H. Clisjsters, *Effects of metals on enzyme activity in plants*, Plant Cell Environ. 13 (1990), pp. 195–206.

[12] S. Gupta, D. Bhattacharya, J.K. Datta, S. Nayek, and S. Satpati, *Effects of vehicular emissions on biochemical constituents of leaves*, Pollut. Res. 28 (2009), pp. 157–160.

[13] A.P. Sharma and B.D. Tripathi, *Biochemical response in tree foliage exposed to coal-fired power plant emission in seasonally dry tropical environment*, Environ. Monit. Assess. 158 (2009), pp. 197–212

[14] S.E. Allen, H.M. Grimshaw, and A.P. Rowland, *Chemical analysis*, in *Methods in Plant Ecology*, P.D. Moore and S.B. Chapman, eds., Blackwell Scientific, Oxford, 1986, pp. 285–344.

[15] R.M. Harrison and M.B. Chirgawi, *The assessment of air and soil as contributors of some metals to vegetable plants. Use of a filtered growth cabinet*, Sci. Total Environ. 83 (1989), pp. 13–34.

[16] K. Chandra Sekhar, K. Rajini Supriya, C.T. Kamala, N.S. Chary, T. Nageswara Rao, and Y. Anjaneyulu, *Speciation accumulation of heavy metals in vegetation grown sludge amended soils and their transfer to human food chain – a case study*, Toxicol. Environ. Chem. 82 (2001), pp. 33–34.

[17] S.K. Singh and D.N Rao, *Evaluation of plants for their tolerance to air pollution*, in *Proceedings of a Symposium on Air Pollution Control*, Vol. 1, Indian Association for Air Pollution Control, New Delhi, India, 1983, pp. 218–224.

[18] D.I. Arnon, *Copper enzyme in isolated chloroplasts. Polyphenoloxidase in* Beta vulgaris, Plant Physiol. 24 (1949), pp. 1–15.

[19] E.W. Yemm and A.J. Willis, *The estimation of carbohydrates in plant extracts by anthrone*, Biochemistry 57 (1954), pp. 508–514.

[20] S.P. Mukherjee and M.A. Chaudhuri, *Implications of water stress induced changes in levels of endogenous ascorbic acid and hydrogen in* Vigna *seedlings*, Physiol. Plant. 58 (1983), pp. 166–170.

[21] L.S. Bates, R.P. Waldern, and J.D. Teare, *Rapid determination of proline for water stress studies*, Plant Soil 39 (1973), pp. 205–207.

[22] G.L. Ellman, *Tissue sulfhydryl groups*, Arch. Biochem. Biophys. 82 (1959), pp. 70–77.

[23] S. Sinha, A. Basant, A. Malik, and K.P. Singh, *Iron induced oxidative stress in a macrophyte: a chemometric approach*, Ecotoxicol. Environ. Safe. 72 (2009), pp. 585–595.

[24] M.P. Benavides, S.M. Gallego, and M.L. Tomaro, *Cadmium toxicity in plants*, Braz. J. Plant Physiol. 17 (2005), pp. 21–34.

[25] A.S. Shannigrahi and K.M. Agarwal, *An overview on optimum green belt development for industrial project*, Indian J. Environ. Protect. 17 (1996), pp. 253–561.

[26] S.K. Chaulya, M.K. Chakarborty, and R.S. Singh, *Air pollution modelling for a proposed limestone quarry*, Water Air Soil Pollut. 126 (2001), pp. 171–191.

[27] M. Rajput and M. Agarwal, *Biomonitoring of air pollution in a seasonally dry tropical suburban area using wheat transplant*, Environ. Monit. Assess. 101 (2005), pp. 39–53.

[28] N. Tzvetkova and D. Kolarvo, *Effects of air pollution on carbohydrate and nutrient concentration in some deciduous tree species*, Bul. J. Plant Physiol. 22 (1996), pp. 53–56.

[29] S. Tiwari, M. Agarwal, and F.M. Marshal, *Evaluation of ambient air pollution impact on carrot plants at a sub-urban site using open top chamber*, Environ. Monit. Assess. 119 (2006), pp. 15–30.

[30] fS. Sinha and R. Saxena, *Effect of iron on lipid peroxidation, and enzymatic and non-enzymatic antioxidants and bacoside – a content in medicinal plant* Bacopa monnieri *L*., Chemosphere 62 (2006), pp. 1340–1350.

[31] S.C. Sharma and R.K. Roy, *Green belt – an effective means of mitigating industrial pollution*, Indian J. Environ. Protect. 17 (1997), pp. 724–727.

[32] A.S. Shannigrahi, R.C. Sharma, and T. Fukushima, *Air pollution control by optimal green belt development for Victoria Memorial Monument, Kolkata (India)*, Int. J. Environ. Stud. 60 (2003), pp. 241–249.

[33] S.K. Prajapati and B.D. Tripathi, *Anticipated performance index of some tree species considered for green belt development in and around an urban area: a case study of Varanasi city*, Indian J. Environ. Manage. 88 (2008), pp. 1343–1349.