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Particulate Matter Capturing Ability of Some Plant Species: Implication for Phytoremediation of Particulate Pollution Around Rourkela Steel Plant, Rourkela, India

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ABSTRACT

The particulate pollution has always been a matter of great concern because of its adverse effect on human and plant population. In the present global environmental scenario, this problem has become increasingly severe. The particulates and gaseous pollutants, alone and in combination, can cause serious setbacks to the overall physiology of plants. Results from numerous investigations of human respiratory and other diseases have shown a consistent statistical association between human exposures to the outdoor levels of particulates or dust and adverse health impacts. These hazards are more pronounced in the vicinity of industries where these particles become air-borne and inhalable. Research has shown that plant leaves being the main receptor of particulate pollution can act as biological filters, removing large quantities of particles from the urban atmosphere. This physical trait can be used to determine the level of particulate pollution in the surroundings, as well as the ability of individual plant species to intercept and mitigate particulate pollutants. In the present study, fifteen plant species (11 trees and 4 shrubs) growing around the Rourkela Steel Plant (RSP) area were selected. Particulate or dust load on leaf surfaces and leaf surface morphology as a measure of dust trapping ability of leaves were analysed. The plant species such as *Alstonia scholaris, Anthocephalus indicus, Cassia auriculata, Cassia siamea, Lagerstroemia speciosa, Mimusops elengi, Peltophorum inerme* and *Tabebuia aurea* were found to have high dust capturing capacity; *Albizia lebbeck, Bougainvillea spectabilis, Ficus religiosa, Swietenia mahagoni* and *Thevetia nerifolia* have medium, while species such as *Caesalpinea pulcherima* and *Delonix regia* have low dust capturing capacity. Results also indicate that leaf surface morphology greatly determines the dust trapping capacity of a particular plant species.

INTRODUCTION

Ambient air contains various size ranges of solid particles commonly recognized as particulates or dust, which are continuously agglomerated and deposited, on various surfaces. The deposited particulate matter is a conglomerate of chemically heterogeneous substances of many different types. Most of the Indian cities are affected by the presence of high concentrations of gaseous and particulate pollutants due to industrialization, badly maintained roads, poor maintenance of vehicles, and use of fuels with poor environmental performance and lack of awareness (Joshi & Chauhan 2008). According to an estimate, dust pollutants comprise around 40% of total air pollution problem in India (Chauhan & Sanjeev 2008, Chauhan 2010). There has been extensive interest in the health implications of fine particles in the atmosphere. Atmospheric particulate matter (PM) with aerodynamic diameter < 10 µm (PM10) or < 2.5 µm (PM 2.5) is of great concern for public health due to the presence of PAHs (NEPC 1998, 2003, Prajapati & Tripathi, 2008a-d, Prajapati 2012) and has become the standard measure of particulate pollution. Numerous epidemiologic studies have highlighted the health implications of fine particles with aerodynamic diameter less than 10 µm (Kunzli et al. 2000, Katsouyanni et al. 2001, Pandey et al. 2005, Pandey et al. 2006, Pope et al. 2002, Peng et al. 2005, Prajapati et al. 2006). The health impacts of these finest particulates (PM 2.5, aerodynamic diameter < 2.5 µm) are greater because they can be inhaled deep into the unciliated and alveolar section of lung (Chan & Kwok 2001). Results from numerous investigations of human respiratory and other diseases show consistent statistical associations between human exposure to the outdoor levels of particulates or dust and adverse health impacts. Health effects range from alveolar inflammation in the lungs and respiratory-tract infection to acute cardiovascular disorders. Because the particles deposited on the plant leaves are from the surrounding air, analysis of these particles provides information about the source of particulate air pollution in the area. The higher the concentration of particulate matter in the area, the higher the concentration of particles on the leaf surface will be. The size and chemical composition of the particles on the leaf surface is the representative of the air-borne particles in the sampled area.

The use of plants as monitors of air pollution has long been established as plants are the initial acceptors of air pollution. They act as the scavengers for many air-borne particulates in the atmosphere (Joshi & Swami 2009). It has been an established fact that plants are "living filters"; leaves and exposed parts of a plant generally act as persistent absorber in a polluted environment. Plants play an important role in combating air pollution. The plant leaves act as a passive or active collector for air-borne pollutants like gases, aerosols and dusts. Plants filter out pollutants from the air in three ways, *viz.,* absorption by the leaves, deposition of particulates and aerosols on leaf surface, and fallout of particulates on the leeward (downwind) side of the vegetation because of the slowing of the air movement (Spitsyna & Skripal' shchikova 1991, Varshney & Mitra 1993, Singh et al. 1995, Rawat & Banerjee 1996, Pal et al. 2000, Tomasevic et al. 2005, Turner et al. 2005). They act as efficient filters of air-borne particles because of their large size, high surface to volume ratio of foliage, and frequently hairy or rough leaf and bark surfaces (Chakre 2006**)**.

Stomata are microscopic pores on the underside (abaxial side) of the leaf. These allow air into and out of the leaf, which is how the plant takes in CO_2 and lets out O_2 and allows water vapour out in the process of transpiration. As air diffuses through the stomata, most of the air-borne particles will not pass through the stomata but will rather land on the leaf's outer surface. This is similar to a filter, where air is pulled through the filter by an air pump and the air-borne particles deposit on the filter surface. This air flow could not be the major cause of particles depositing on the leaf. The concentration of particles on abaxial surface of the leaf normally is not observed to be higher than that of the top surface of the leaf (adaxial surface). There is a certain amount of force needed for particles to adhere to a surface. This amount is greater depending on the size of the particle. Because the airflow through the stomata is only passive diffusion, the fine particles could stick to the bottom surface. The particles on the top surface of the leaves will mainly be from the settling of coarse particles and dust facilitated by sticky surface texture, and the presence of fine veins on leaf surface.

The various morphological features are also major factors for dust capturing by leaves. Different types of leaves tend to have differences in morphological features of leaf surfaces. Some types of leaves have greater surface rigidity or roughness than other leaves, which may affect their stickiness or particle solubility. Stickier leaves are better for collecting particles because more particles would stick to their surface. Therefore, certain plant leaves may be more useful for efficient dust capturing than other plants. The dust filtering ability of the plant species has been directly correlated with foliar surface characteristics. It has been observed that leaf morphological characteristics play a major role in the interception of dust load from the ambient air. In addition, Seinfeld & Pandis (1998) and Harrison & Yin (2000) reported the deposition of dust dependence on the physical characteristics of the particles such as size and shape and also the morphological characters of leaf surface. This particular capacity of plant leaves as dust receptors has been reported to be dependent on their surface geometry, phyllotaxy, epidermal and cuticular features, leaf pubescence and height and canopy of trees (Neinhuis & Barthlott 1988). A positive correlation has been observed between the particulate load and micro-roughness of the leaf surface. Micro-roughness of the epidermis is defined as the presence of ridges and furrows formed by epidermal cell lining, veins projections, stomata protected with wax rings, cuticular arches, hairs or scales and sunken position (Chaphekar 2000). Particulate matter interception and accumulation depends on internodal distance, petiole length, leaf area, orientation, margin, folding and arrangement, hair density, hair type and length (Varshney & Mitra 1993). The amount, distribution, and morphology of trichomes has great influence on the leaf dust-capturing capability, possibly due to the different action patterns between trichomes and particulate matters (Wang et al. 2010). There is a significant negative relationship between leaf contact angle and maximum leaf dust-capturing capability.

These observations reveal that leaf surface morphology determines the dust-capturing ability of the plant. This is consistent with previous studies by Yunus et al. (1985), Pyatt & Haywood (1989), Hegazy (1996) and Guo & James (1996). Greater the roughness of the surface, greater will be the particles trapped on the surface (Chaphekar 2000, Lei et al. 2006). Although, a large number of trees and shrubs have been identified and used as dust filters to check the rising urban dust pollution level (Rai et al. 2010), there are marked species differences in the ability of trees to capture pollutant particles. Based on this concept, the present study has been undertaken to identify the plant species, which have higher potential for dust capturing from the environment while sustaining their well-being. The particulate filtering ability of plants (dust load per unit area of leaf) was taken as an indicator of their ability to trap dust particles. Therefore, the dust load, in milligrams per square centimetre of leaf surface, was measured and related to foliar, epidermal and cuticular characteristics, and morphological features (Yunus et al. 1985).

The present study aims to identify plants (with certain traits) that can be incorporated in the green belts near the Rourkela Steel Plant (RSP) so that these may serve as biological filters and remove air-borne particles. The present study was undertaken:

1. To evaluate the amount of dust deposition/capture capacity of different plants species (shrubs and trees);
2. To identify the plant species with high potential for control of dust/suspended particulate matter in ambient air;
3. To prepare a checklist of plant species for phytoremediation of particulate matter from the ambient environment and;
4. To observe the impact of leaf morphology on dust trapping ability of selected species in order to identify their potential as tolerant species.

MATERIALS AND METHODS

Study site and pollution source: The present study was conducted around the Rourkela Steel Plant located in the north-western part of the Indian state of Odisha, which is one of the major industrial centres of India. Rourkela is famous for its prestigious steel and occupies a place of pride on the industrial map of India. It is located at 84°54' E longitudes and 22°12 N latitude in Sundargarh district of Odisha at an elevation of about 219 meters above the mean sea level. The climate of Rourkela is characterized as tropical monsoon climate, where the minimum temperature is 9.4-9.8°C in December, and maximum 44-44.2°C in May. There are mainly three seasons,*viz.* summer, rainy and winter. The hot summer lasts from the month of March to the middle of June, rainy season from the middle of June to September with an average rainfall of 120-160 cm. The winter season is of short duration which extends from November to the middle of February. The integrated iron and steel unit, the Rourkela Steel Plant of the Steel Authority of India Ltd., and a number of ancillary medium and small-scale industries, the thermal power plant, the refractories, the chemical plant and pigments, the cement factory, and the engineering and sponge iron industries are major sources of pollution in and around Rourkela (Das & Prasad 2010a). Studies reveal that Rourkela is a high pollution potential zone (Das et al. 2010).

Vegetation is an effective indicator of the overall impact of air pollution, and the effect is observed in a time-averaged result that is more reliable than the one obtained from direct determination of the pollutants in air over a short period. So the particulate mitigating ability of different plant species around the Rourkela Steel Plant was done in three different seasons i.e., summer (May 2011), rainy (August 2011) and winter (November 2011). Preliminary vegetation surveys around the Rourkela Steel Plant showed that the leaves of the plants growing along the road have major deposition of dust. The source of dust deposition on road side plants was found to be dispersed by the point source of Rourkela Steel Plant and automobiles.

Sampling area and species sampled: Fifteen dust-loaded plant species (11 trees and 4 shrubs) were selected for assessment from different sites. The selection was done on the basis of local availability. For sampling, particular plants were marked per species and leaf samples were taken for analysis. The leaves were randomly selected and carefully detached from the plant using scissors and kept in separate sampling polythene bags to avoid dust loss from leaf surface. Sampling was done in the morning (7 a.m. to 9 a.m.) in different sampling seasons. The plant species which were selected from different sites along with their leaf characters are given in Table 1.

Determination of dust load: Six leaves were taken from each of the marked plant species for determination of leaf area and dust load. The leaves with the dusts were weighted with the help of a digital balance. The dust adhering on the leaf surface was then washed carefully with the help of a brush and distilled water and the leaves were blotted dry and reweighed thereafter, in order to determine the amount of dust present on the surface of leaf. The leaf area was calculated with the help of a graph paper. Finally, the amount of dust (in mg) deposited per cm^2 of leaf area was calculated. The typical leaf sample outline was drawn on a graph paper and the number of squares was counted in cm^2 to obtain the leaf area. The amount of dust was calculated by the following equation:

$$W = (W_1 - W_2)/A$$

Where,

W = amount of dust (mg/cm^2)

W_1 = initial weight of the leaf with dust

W_2 = final weight of the leaf without dust

A = total area of the leaf (cm^2)

The dust load (mg/cm^2) on different plant species along with corresponding sampling seasons are given in Table 2.

The sum of average dust deposits of different sampling sites (mg/cm^2) was calculated with respective sampling seasons (Table 3).

Particle size and their concentrations: Particle size and their concentrations in the urban dust used in this study with respect to different sites were obtained by suspending dust in water (W/V). Samples were taken while shaking the suspension and mounting them on a slide beneath a cover slip. Measurement was done by calculating the maximum diameter of 500 randomly chosen particles in each of the five drops per suspension, with the help of micrometers of the light microscope. The data are presented in Table 4.

Percentage (%) of dust capture: The percentage efficiency

Table 1: Description of plant species sampled for the study.

Sl. No.	Scientific name	Family	Habit	Leaf morphology
1	*Albizia lebbeck* (L.) Benth.	Fabaceae	Evergreen tree	Compound leaves, bipinnate, glabrous or slightly hairy on the axis; pinnae in 2-4 pairs, each with 2-11 pairs of obliquely oblong leaflets 15-45 × 8-22 mm, shortly stalked; glabrous glands are raised, elliptic to circular.
2	*Alstonia scholaris* L.R.Br.	Apocynaceae	Evergreen tree	The upperside of the leaves is glossy, while the underside is greyish. Leaves occur in whorls of 3-10; petioles are 1-3 cm; the leathery leaves are narrowly obovate to very narrowly spathulate, base cuneate, apex usually rounded.
3	*Anthocephalus indicus* (Roxb.) Miq	Rubiaceae	Deciduous tree	Leaves glossy green, opposite, simple more or less sessile to petiolate, ovate to elliptical (15-50 × 8-25 cm).
4	*Bougainvillea spectabilis* Wild.	Nyctaginaceae	Semievergreen shrub	The leaves are alternate, simple ovate acuminate, 4-13 cm long and 2-6 cm broad.
5	*Caesalpinea pulcherima* (L.) SW.	Fabaceae	Semievergreen shrub	The leaves are bipinnate, 20-40 cm long, bearing 3-10 pairs of pinnae, each with 6-10 pairs of leaflets 15-25 mm long and 10-15 mm broad.
6	*Cassia auriculata* L.	Fabaceae	Semievergreen	The leaves are alternate, paripinnate compound, closely placed, rachis 8.8-12.5 cm long, slen der, pubescent, leaflets 16-24, very shortly stalked 2-2.5 cm long 1-1.3 cm broad, slightly overlapping, oval oblong, obtuse, at both ends, mucronate, glabrous.
7	*Cassia siamea* Lam.	Fabaceae	Evergreen medium- sized tree	Leaves alternate, pinnately compound, 23-33 cm long, with slender, green-reddish, tinged axis; leaflets 6-12 pairs on short stalks of 3 mm, ob long, 3-7 cm long, 12-20 mm wide, rounded at both ends, with tiny bristle tip.
8	*Delonixregia*	Fabaceae	Evergreen tree	Leaves compound and biparipinnate, alternate, light green, feathery, 20-60 cm long; and have 20-40 pairs of primary leaflets or pinnae on it, and each of these is further divided into 10-20 pairs of secondary leaflets or pinnules, 5-12 cm long, each bearing 12-40 pairs of small oblong-obtuse leaflets that are about 0.5-2 cm long and 0.3 cm wide, very minutely hairy on both sides.
9	*Ficus religiosa* L.	Moraceae	Evergreen tree	The leaves are simple, cordate in shape with a distinctive extended tip; they are 10-17 cm long and 8-12 cm broad, with a 6-10 cm petiole.
10	*Lagerstroemia speciosa* (L.) Pers.	Lythraceae	Evergreen medium- sized tree	Leaves simple, opposite, distichous, simple, and entire.
11	*Mimusops elengi* L.	Sapotaceae	Evergreen tree	Simple, alternate, shiny, smooth, lanceolate and ovate in shape. Leaves are 5-10 cm long and 2.5-5cm wide.

Table cont....

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12	*Peltophorum inerme* (Roxb.) Navesex Fernandez Villar	Fabaceae	Deciduous	Leaves large, 30-60 cm long, with 8-10 pairs of pinnae each bearing 10-20 pairs of oblong leaf lets 0.8-2.5 cm long with oblique bases.
13	*Swietenia mahagoni* (L.) Lacq.	Meliaceae	Evergreen tree	Broad round symmetrical crown. The leaves are pinnately compound, ovate-lanceolate and small
14	*Tabebuia aurea* Benth and Hook.f.ex S. Moore	Bignoniaceae	Deciduous medium sized tree	Palmate, opposite, 11 inches long and 4 inches wide with 5-7 oblong-elliptic to oblong-lanceolate Leaflets.
15	*Thevetia nerifolia* Juss Ex. Steud	Apocynaceae	Evergreen shrub	Its leaves are willow-like, linear-lanceolate, and glossy green in colour, They are covered in waxy coating to reduce water loss.

of dust capture of plant species was calculated by the following formula:

$$\text{\% of dust capture} = \frac{\text{Dust deposits on the leaf area of a particular plant (mg/cm}^2)}{\text{Sum of average dust deposits of all the plants of different sampling sites (mg/cm}^2)} \times 100$$

The plant species have been classified based on the percentage dust capture into three frequency classes (CPCB 2007):

Low: < 10% dust capture
Medium: 11-20% dust capture
High: > 21 % dust capture

The percentage efficiency of dust capture of various plant species along with their frequency classes of dust capturing plants are given in Table 5.

Leaf internode and petiole length: Leaf internode (cm) and petiole length (cm) of different plant species in different sampling seasons were measured and their average values (cm) are given in Table 6.

Leaf morphological characters: Particulate matter interception and accumulation depends on the internodal distance, petiole length, leaf area, orientation, margin, folding and arrangement, hair density, hair type and length (Varshney & Mitra 1993). The crown area of plant depends on the morphological features of leaf like shorter internode, shorter petiole, high leaf surface area (leaf area and margin), leaf margin (non-entire), leaf arrangement (non-opposite) and leaf orientation (non-erect). The leaves with greater surface rigidity or roughness or coarse structure of leaves are due to the leaf hair (length, type, density) and prominent leaf veins. So the various leaf morphological characters, ***viz.*** leaf arrangement, margin, orientation, pubescence, prominent veins, internode length, petiole length and leaf lamina size were taken into consideration and accordingly plus (+) or minus (-) signs are given to show their presence or absence, respectively (Table 7). All the plant species taken into consideration are evaluated on the basis of these above-mentioned leaf morphological characteristics and final grades were calculated (Table 8).

RESULTS AND DISCUSSION

The particulates suspended and re-suspended in the roadside air, from the traffic and from the point source of Rourkela Steel Plant were studied in this work. The sizes of the suspended particles ranged from < 0.5µ to >1µ in diameter and were classified into three different classes on the basis of their diameter. The distribution pattern of these dust particles are given in Table 4. The dominant class of particles was within the diameter of ≥1µ, and up to 41%. Particles of such diameters were frequently observed on the surface of most plant leaves examined in the study area.

The particle deposition on the plant leaves and analysis of particles from the ambient air has provided the information of particulate air pollution in the sampled area. It is observed that the higher the concentration of particulate matter in the air of sampled area, the higher the concentration of particles deposited on the leaf surfaces. When the average dust load on different plant species of different sites were taken into consideration and a sum was calculated, the average dust load was found to be 2.59 mg/cm^2 (Table 3). The average dust load on the leaf surfaces of all the plant species was found to be maximum in winter season (5.929 mg/cm^2)

Table 2: Dust load (mg/cm^2) on different plant species in corresponding sampling seasons.

Plant species	Dust load (mg/cm^2) in different sampling seasons			
	Summer	Rainy	Winter	Average
Albizia lebbeck	0.355	0.175	0.687	0.405
Alstonia scholaris	0.435	0.273	3.35	1.352
Anthocephalus indicus	0.483	0.293	1.455	0.743
Bougainvillea spectabilis	0.145	0.173	0.994	0.437
Caesalpinea pulcherima	0.08	0.098	0.36	0.179
Cassia auriculata	0.41	0.269	0.961	0.546
Cassia siamea	0.412	0.236	1.075	0.574
Delonix regia	0.144	0.09	0.178	0.137
Ficus religiosa .	0.19	0.105	1.186	0.493
Lagerstroemia speciosa	0.505	0.253	3.172	1.310
Mimusops elengi	0.307	0.269	1.381	0.652
Peltophorum inerme	0.06	0.181	1.947	0.729
Swietenia mahagoni	0.217	0.122	1.12	0.486
Tabebuia aurea	0.41	0.295	0.951	0.552
Thevetia nerifolia	0.073	0.305	0.689	0.355

Table 3: The sum of average dust deposits of different sampling sites (mg/cm^2) in different sampling seasons.

Summer	Rainy	Winter	Average
1.081	0.771	5.929	2.593

Table 4: Frequency of different size of particles in urban dust (total of 500 particles).

Particle Size (µm)	Frequency	Percentage (%)
< 0.5 µm	100	20.0
≥ 0.5 and < 1 µm	195	39.0
≥ 1 µm	205	41.0

Table 5: The percentage (%) efficiency of dust capture of various plant species along with their frequency classes of dust capturing plants.

Plant species	% efficiency of dust capture	Frequency classes of dust capturing plants
Albizia lebbeck	15.61	Medium
Alstonia scholaris	52.14	High
Anthocephalus indicus	28.65	High
Bougainvillea spectabilis	16.85	Medium
Caesalpinea pulcherima	6.90	Low
Cassia auriculata	21.05	High
Cassia siamea	22.13	High
Delonix regia	5.28	Low
Ficus religiosa .	19.01	Medium
Lagerstroemia speciosa	50.52	High
Mimusops elengi	25.14	High
Peltophorum inerme	28.11	High
Swietenia mahagoni	18.74	Medium
Tabebuia aurea	21.28	High
Thevetia nerifolia	13.72	Medium

Table 6: Leaf internode (cm) and petiole length (cm) of different plant species.

Plant species	Leaf internode length (cm)	Petiole length (cm)
Albizia lebbeck	3.66	1.27
Alstonia scholaris	6.10	1.30
Anthocephalus indicus	3.43	2.90
Bougainvillea spectabilis	4.00	1.21
Caesalpinea pulcherima	6.61	4.76
Cassia auriculata	3.87	4.42
Cassia siamea	4.79	2.94
Delonix regia	7.10	8.28
Ficus religiosa .	4.66	8.04
Lagerstroemia speciosa	3.36	1.23
Mimusops elengi	3.64	1.56
Peltophorum inerme	3.97	3.97
Swietenia mahagoni	3.00	5.08
Tabebuia aurea	3.67	4.43
Thevetia nerifolia	1.64	0.21
Average	4.22	3.44

followed by summer (1.081 mg/cm^2) and rainy season (0.771 mg/cm^2). This trend was also found to be true for individual sampled plants of the study area (Table 2). The data of Table 2 were further analysed by two-way ANOVA which exhibited a significant variation (α = 0.01 and α = 0.05) within the dust load (mg/cm^2) of leaf samples in different sampling seasons, but the dust load on the leaf surface of different plant species did not show any significant variation (α = 0.01 and α = 0.05) within themselves. The high dust accumulation in the winter season may be due to the wet surfaces of leaves which help in capturing dust, with a gentle breeze and foggy condition preventing particle dispersion (Das & Prasad 2010b). Despite high concentration of dust in summer, high wind speed may be the reason for

Table 7: Assessmentof plant species on the basis of their leaf morphological characteristics.

Grading characters	Pattern of assessment	Grades allotted
1. Leaf arrangement	Alternate, spiral and whorled	+
	Opposite and opposite decussate	–
2. Margin	Crenate, dentate and serrate(non-entire)	+
	Entire	–
3. Leaf orientation	Horizontal	++
	Semi-erect	+
	Erect	–
4. Pubescence	Trichome present	+
	Trichome abesent	–
5. Prominent leaf veins	Present	+
	Abesent	–
6. Leaf internode	< Average (4.22 cm)	+
	≥ Average (4.22 cm)	–
7. Petiole	< Average (3.44 cm)	+
	≥ Average (3.44 cm)	–
8. Leaf lamina	Large	++
	Medium	+
	Small	–

relatively lower dust accumulation in the summer than in the winter (Das & Prasad 2010b). The heavy rains during monsoon months act as "scrubber" scavenging the atmosphere of air pollution loads. Besides, in the rainy season dust accumulation is least due to the washing of leaves. However, a deviation was found in four plant species, *viz., Bougainvillea spectabilis, Caesalpinea pulcherima, Peltophorum inerme* and *Thevetia nerifolia*, where maximum dust accumulation was found in winter season followed by rainy and summer season. When compared, the average dust load on different plant species (Table 2) varied between 1.352mg/cm^2 (*Alstonia scholaris*) and 0.137mg/cm^2 (*Delonix regia*).

The percentage (%) of dust capture of various plant species (Table 5) showed variation between 52.14% by *Alstonia scholaris* and 5.28% by *Delonix regia*. After the calculation of percentage (%) of dust capture, different plant species have been classified into different frequency classes of dust capture. Plants such as *Alstonia scholaris*, *Anthocephalus indicus*, *Cassia auriculata*, *Cassia siamea*, *Lagerstroemia speciosa*, *Mimusops elengi*, *Peltophoru minerme* and *Tabebuia aurea* were found to lie within the high frequency class of dust capturing plants, while plants such as *Albizia lebbeck, Bougainvillea spectabilis, Ficus religiosa, Swietenia mahagoni* and *Thevetia nerifolia* were found to be medium and *Caesalpinea pulcherima*, *Delonix regia* were found to be low on the basis of their dust capturing efficiency.

The leaf internode and petiole length (cm) of different plant species has been measured in different sampling sites and during summer, rainy and winter seasons. Finally, averages internode length and petiole lengths for individual plant species were calculated (Table 6). The internode length of plant species varied from 3.00 cm (*Swietenia mahagoni*) to 6.61 cm (*Alstonia scholaris*) with an average value of 4.22 cm. Similarly, the petiole length of plant species varied from 0.21 cm (*Thevetia nerifolia)* to 8.28 cm in *Delonix regia* with an average of 3.44 cm. A correlation was assessed for the internode length (cm) with the amount of dust accumulation (mg/cm^2) on the leaf surfaces of various plant species at the study sites. It showed a negative correlation with the value of r = - 0.45. Similarly, the petiole length (cm) and the amount of dust accumulation (mg/cm^2) on the leaf surfaces exhibited a negative value of correlation (r = -0.93).

Finally, the evaluation of all the 15 plant species around the Rourkela Steel Plant was done on the basis of their leaf

Table 8: Evaluation of 15 plant species around the Rourkela Steel Plant on the basis of their leaf morphological characteristics.

Plant species	Assessment Parameters								Total (+) grades
	Arrangement	Margin	Orientation	Pubescence	Prominent veins	Leaf internode	Petiole	Leaf lamina	
Albizia lebbeck	–	–	+	+	–	+	+	+	5
Alstonia scholaris	+	–	+	–	–	–	+	++	5
Anthocephalus indicus	–	–	+	+	+	+	+	++	7
Bougainvillea spectabilis	+	–	+	–	–	+	+	+	5
Caesalpinea pulcherima	–	–	+	–	–	–	–	–	1
Cassia auriculata	+	–	+	–	–	+	–	+	4
Cassia siamea	+	–	+	+	–	–	+	+	5
Delonix regia	+	–	+	+	–	–	–	–	3
Ficus religiosa	+	–	–	–	+	–	–	+	3
Lagerstroemia speciosa	–	–	+	+	–	+	+	++	6
Mimusops elengi	+	–	+	–	–	+	+	+	5
Peltophorum inerme	+	–	+	+	–	+	–	–	4
Swietenia mahagoni	+	–	+	–	–	+	–	+	4
Tabebuia aurea	–	–	+	+	–	+	–	++	5
Thevetia nerifolia	+	–	+	–	–	+	+	+	5

morphological characteristics, *viz.*, leaf arrangement, margin, orientation, pubescence, prominent veins, internode length, petiole length and leaf lamina size (Table 7) and their final grades (+ signs) were calculated (Table 8). Plant species like *Anthocephalus indicus* showed a maximum grade (i.e., 7) followed by *Lagerstroemia speciosa* with final grade of 6 and *Caesalpinea pulcherima* showed minimum grade, i.e., 1 followed by *Delonix regia* and *Ficus religiosa.* When final grade (+ signs) scored by various plant species were correlated with the amount of dust deposition on various plant species, they showed a positive correlation ($r = + 0.56$). The examined results have supported the fact that leaf morphological characters play a major role in the interception of dust load from ambient air and the dust capturing capacity of plant leaves as dust receptors are found to be dependent of their surface geometry, phyllotaxy, epidermal and cuticular features.

CONCLUSIONS

- The present study reveals that the sticky particulate matter emitted from the automobile exhausts and the point source of Rourkela Steel Plant is the major constituent of particulate pollution, which is deposited on the leaf surface of common roadside plants.
- The present study has shown that the presence of certain plant traits like alternate, spiral and whorled leaf arrangement, non-erect orientation, presence of trichomes, prominent veins, shorter internode and shorter petiole along with broader lamina result in effective trapping of particulate matter, which helps the plant species to act as potential barrier to the particulate pollution.
- The 'Green Belt' development with dense plantation of effective dust capturing plant species such as medium (*Albizia lebbeck, Bougainvillea spectabilis, Ficus religiosa, Swietenia mahagoni, Thevetia nerifolia*) and high (*Alstonia scholaris, Anthocephalus indicus, Cassia auriculata, Cassia siamea, Lagerstroemia speciosa, Mimusops elengi, Peltophorum inerme, Tabebuia aurea*) dust capturing efficiency plants may reduce the particulate problem around residential areas/industrial area. The 'Green Belt' with efficient dust capturing plants can act as an efficient biological filter, removing significant amounts of particulates from urban atmosphere and may prove not only as a cost-effective technology, but also enhance aesthetic value in urban agglomerations.

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