Chapter 5
Phytomonitoring and Mitigation of Air Pollution by Plants

Nitesh Joshi, Ambika Joshi, and Bharati Bist

Abstract The urban environment is degrading globally at a more rapid pace than seen in the last few decades. Measures are taken in order to save the environment from rapid diffusing atmospheric pollution; however, the approach seems to be too slow either due to policies by the respective governments or lack of conviction. Air pollution monitoring is the initial step toward controlling the decay of bio-sustainable air. There are various methods to monitor air quality and its components using instrumental and chemical methods. These methods prove to be expensive and do not reflect the impact on living beings. Plants are stationary; hence, they participate and indicate the changes occurring in an environment. Several studies are done globally emphasizing the role of locally available vegetation as phytomonitor. In order to do so, various morphological, visual, and biochemical parameters are employed. The concept is based on the fact that different plant species respond differently to ambient air which can be used to quantify pollution. Different plants species also react in a varied way to different air pollutants. The pattern of air pollution also differs within and between the countries. That plants act as sinks of pollution is a well-known fact. Several researchers have enormously explained the biochemical pathways of air pollutants within the plants. The current work explores the practical case studies of phytomonitoring and the function of plants in mitigating air pollution. Plants from different locations around the industrial area were studied for their morphological and biochemical changes due to air pollution. Studies carried out to know the dust-capturing efficiencies of plants are discussed. The role of plants in mitigating airborne metals, either on the surface or as accumulators, is enumerated. For development of greenbelt, several tree species are also suggested here based on their resistance to air pollutants.

Keywords Air pollution · Phytomonitoring · Greenbelts · Biomonitors · Dust load · Dust chamber studies · Air Pollution Tolerance Index

---

N. Joshi (✉) · B. Bist
Department of Botany, Rizvi College of Arts, Science and Commerce, Mumbai, Maharashtra, India

A. Joshi
Department of Botany, Jai Hind College, Mumbai, Maharashtra, India

R. Roychowdhury et al. (eds.), *Sustainable Agriculture in the Era of Climate Change*, https://doi.org/10.1007/978-3-030-45669-6_5

Abbreviations

APTI	Air Pollution Tolerance Index
CPCB	Central Pollution Control Board
MPCB	Maharashtra Pollution Control Board
MOEF	Ministry of Environment and Forestry
SPM	Suspended Particulate Matter
DRI	Dust Retention Index

1 Air Pollution: An Introduction

Presence of any air pollutant in the environment in concentrations, which have a tendency to be detrimental to man, plants, property, and surroundings, contributes to air pollution (CPCB 2011).

1.1 Sources

Level of air pollution is soaring in developing countries than in already urbanized and industrialized ones. The main culprits considered for air pollution are industrialization, fast economic development, an elevated level of energy utilization, and a gradual increase in vehicular traffic due to transportation. Also, air pollution concentrations have seasonal, for example, higher concentrations during winter and diurnal pattern due to changes in temperature stratification during day- and nighttime (MOEF 1985).

1.1.1 Particulate Sources

Air pollutants are derived from natural and man-made sources. Natural sources comprise forest flames, volcanic emissions, sandstorm, pollen scattering, etc. Anthropogenic sources on the other hand consist of substances emitted during the burning of fossil fuels in factories and thermal power plants; suspended particulate matter; harmful gases like SO_2, NO_2, and CO; dust fall; etc.

India along with different developing countries is experiencing dreadful air quality due to modernization, lack of knowledge, increase in vehicles and use of poor performance fuels, poorly maintained transportation, and futile environmental laws (Joshi and Chauhan 2008).

1.1.2 Particulate Pollution

Particulates are present in the environment in various forms. These may range from submicron aerosols to evident dirt particles. The relative impact that particulates have on vegetation depends on their individual size, their cumulative quantity, and their chemistry. There is currently significant concern over small particulates smaller than the 10 μm diameter (PM_{10}) and 2.5 μm diameter ($PM_{2.5}$) (Quarg 1996).

1.1.3 Particulate Size

While small particulates are of most concerns for human health impacts, much larger particulates are important in affecting vegetation. Particulate can impact on plants in a number of ways, and those impacts mediated via smothering of leaves or altering soil chemistry are not dependent on particle size. When particulates block leaf stomata or enter cells, the size of stomata is important. These vary between species, but the diameter generally lies between 8 and 10 μm. Hence, relatively large particulates can play important physiological roles in plant responses. Particle size is also important in determining the distance that particles might travel before deposition. A study on unpaved roads by Everett (1980) showed that particles of more than 50 μm diameter in size were deposited within 8 m edge of the road, and particles of 20 μm diameter were found at 30 m from the road.

1.1.4 Levels of Deposition

The levels of deposition on roads depend upon the number of vehicles. Unpaved roads may be covered with limestone gravel and so generate alkaline particulates. However, in urban areas, many of the particulates are derived from motor vehicle exhausts which may contain a variety of heavy metal contaminants and be potentially toxic (Santelmann and Gorham 1988). Deposition of particulate may occur through a number of processes like sedimentation, diffusion, turbulence (especially around vegetation surfaces), and removal by rainfall or occult deposition (fog or mist).

1.1.5 Global Status

Escalating energy demands linked with economic expansion and industrialization in Asia, Africa, and Latin America have caused spectacular boost in air pollutant production. In developing countries, problems arise with the nearness of industrial area and thermal power plants to housing neighborhood (Singh 1995).

Air pollution kills millions of people every year with more deaths recorded in developing countries and in Asia (UNDP 1998). Very less information is available about pollutant concentrations in many human settlements where there may be noteworthy indirect effect of air pollution on human health through abridged crop production, food quality, and revenue.

Air pollution levels are rising globally. According to the World Health Organization (WHO) report (2005), nine out of ten people breathe air contaminated with pollutants. WHO estimates that around 7 million people die annually from contact to fine particulates present in the air that make a way deep into the respiratory and cardiovascular system causing life-threatening diseases.

1.2 Effect of Air Pollution on Plants

Air pollution impacts are both local and regional and are directly lethal to plants and animals (Mukherjee and Agrawal 2018). Emissions from industrial sources and automobiles have bad effect on urban air quality which ultimately affects the health of not only humans and animals but plants too. Urban air pollution has happened to be severe ecological trouble to vegetation and crops (Joshi and Chauhan 2008). Even though certain flora can survive the much higher level of pollution, too much pollution has an effect on them also. According to Talukdar et al. (2018), increase in pollution level is a chief threat to plants which can eliminate entire vegetation of an area. Air pollution not only destroys the local vegetation of an area but also affects the tolerant plant species which can endure air pollution up to certain level.

In India, around 60–70% and 20–30% of pollution in the metropolitan environment is caused by vehicles and industries, respectively (Agrawal 1985). Pollutants absorbed by leaves cause a reduction in chlorophyll contents resulting in reduced plants productivity. Hence, roadside plants become the main receiver of different trace element and gaseous discharge from automobiles (Swami and Abhishek 2018).

Trees experience the maximum contact and are subjective to pollutant concentration due to their permanent habit (Raina and Sharma 2003). The principal ways through which pollution affects vegetation include direct deposition onto leaf surfaces, blocking leaf stomata and/or uptake into leaf tissues, deposition onto soil, and an indirect effect via changes in soil chemistry.

1.3 Effect of Air Pollution on Animals and Human

Studies done all over the world have established that air pollution causes an increase in never-ending respiratory ailment and, in some cases, initiates lung and chest disease, tuberculosis, pneumonia, and cardiovascular diseases (Pope and Dockery 2006; McCormack et al. 2011). USEPA (the United States Environmental Protection Agency) has identified six major air pollutants, their sources, and their effects on human well-being (Table 5.1).

Table 5.1 Air pollutants with their sources and effects on humans

Pollutants	Sources	Effects
Nitrogen dioxide (NOx)	Combustion processes (heating, power generation, and vehicles)	Bronchitis in asthmatic children, reduced lung function
Particulate matter (PM2.5, PM10)	Vehicles, industrial sources, domestic fuel burning, road dust resuspension	Cardiovascular and respiratory diseases, lung cancer, ALRI (acute lower respiratory infections)
Carbon monoxide (CO)	Incomplete fuel combustion (as in motor vehicles)	Reduces the oxygen-carrying capacity of the blood; causes headaches, nausea, and dizziness; can lead to death at high levels
Sulfur dioxide (SO_2)	Burning of sulfur-containing fuels for heating, power, and vehicles	Affects respiratory system and lung function; coughing, mucus, secretion, asthma, and chronic bronchitis; causes acid rain
Lead (Pb)	Petrol and industry (such as smelting and paintworks)	Affects brain development in children; at very high doses leads to poisoning; may lead to brain and organ damage
Ozone (O_3)	Formed by the reaction of NOX and VOCs in sunlight	Breathing problems, asthma, reduced lung function

Modified source: MPCB (2014a, b, c)

According to Rao (1981), air pollution effects (gaseous pollutant, acid deposition, and particulates) on ecosystem levels may be summarized as (i) pollutant assimilation and buildup in vegetation, soil surface, and groundwater; (ii) damage to flora and fauna due to pollutant accumulation like leaf necrosis in plants and dental fluorosis in animals; (iii) change in species number, species density, and species diversity along with a change in survival; (iv) loss of constancy and decrease in the reproductive capability of species; (v) disintegration of links of biotic components; (vi) disturbance in biogeochemical cycle; and (viii) expansion of barren areas in the landscape.

1.4 The Health of Trees in an Urban and Industrial Area

Urban trees grow in a stressful environment with low nutrient content, moisture-deficient soil, and intensive air and water pollution along with disease and pest infection. Ozone and different air pollutants injure plants and can lead to acid rain. Acid rain can damage vegetation and change the chemical and substantial composition of the soil (Mukherjee 2015).

Solar radiations heat up soil surfaces, thereby escalating air temperature in regions having scattered tree canopy or less plantation; however, a tree shade can decrease the air temperature and also perk up air quality as release and amalgamation of many pollutants are temperature reliant (Joshi and Joshi 2013).

2 Biomonitors

Plants are essential to preserve ecological equilibrium; however, they too get affected by air pollution. They have been balancing nature from the day life emerged on the earth by amending the concentrations of CO_2 in the atmosphere, and now they are fated to initiate a more modern and perilous role of reducing air pollution through adsorption, assimilation, accumulation, detoxification, and metabolization (Rao 1979).

Bioindicator can be a flora or fauna which discloses the occurrence of a substance in its neighborhood by showing warning signs which can be differentiated from natural or anthropogenic stresses (Steubbing et al. 1989).

2.1 Plants as Indicators of Air Pollution

Falla et al. (2000) and Garrec and Haluwyn (2002) have modified the concept of biomonitoring and have described different terms as given below:

(i) **Bioindicators** (reactive or response indicators) are individual plants showing visible symptoms such as necrosis, chlorosis, physiological disturbances such as wilting of flowers and fruits, abridged number and thickness of flowers, epinasty of leaf lamina and petioles, and decline in growth.

(ii) **Biosensors or biomarkers** react to the presence of air pollutants with hidden effects. Those effects are non-visible changes at the cellular, molecular, biochemical, and physiological levels. Detection of effects needs to be carried out by using microscopic and physiological methods, as well as biochemical analysis.

(iii) **Bio-accumulators** (accumulative indicators) are floras that are in common less susceptible to air pollution, but they collect airborne dust particles and gases onto and into their tissues. Gaseous pollutants mostly enter the leaves; particulates are in general accumulated on the leaf surface.

(iv) The **ecological indicator** concept is mainly devoted to the plant population or community level and deals with modification in species composition, appearance and disappearance of species, and changes in density. Not only is the integration of climate and pollution effects over a long period important but also competition between species.

Sensitive plants are the ones which show apparent symptoms of effects of pollutants even in the lowest concentrations, whereas accumulator plants are those which readily collect particular air pollutants that can be analyzed in the plant matter frequently by physicochemical methods. This quantifies pollution load as that plant then acts as a receiver or absorber of pollutant, without showing any damage, and gets actively involved as a specific capturer of pollutants (Posthumus 1983).

Keller (1982) recognized two aspects of bioindicators in plants as (i) use of *visual symptoms of injury* in plants sensitive to a pollutant and (ii) use of *chemical tissue analysis* of accumulator plants.

2.2 Visual Symptoms

According to Posthumus (1982), some visible symptoms of plants in response to pollutants include (i) necrosis of the margins and tips of leaves in gladioli in the presence of fluoride accumulation, (ii) undersurface bronzing and leaf necrosis of *Urtica urens* L. (small nettle) in the presence of peroxyacetyl nitrate (PAN), (iii) necrosis indicating SO_2 pollution in *Medicago sativa* L. (alfalfa) showing intercostal chlorosis, (iv) speckle necrosis due to O_3 on the upper surface of the leaf of *Nicotiana tabacum* L. (tobacco), and (v) intercostal necrosis in the presence of NO_2 in *Spinacia oleracea* L. (spinach).

2.3 Biochemical Parameters

Many plants don't show visible injury symptoms, but this does not mean they are not affected by various pollutants. The physiological parameters thus play an important role as they indicate the invisible injury to plants. Biosynthesis in plants is adversely affected by pollution, so changes in peroxidase activity (Keller 1974), in catalase activity and protein content (Nandi et al. 1980), in ascorbic acid content (Rao 1981), or by the use of a grouping of parameters like total chlorophyll content, relative water content, ascorbic acid content, and leaf extract ph collectively called as Air Pollution Tolerance Index or APTI also serve as a better indicator of pollution (Singh and Rao 1983).

Verma and Singh (2006) noticed that obvious changes in photosynthetic pigments and protein content in leaf lamina were due to auto exhaust pollution. Correspondingly, as a consequence of increased dust deposition, a reduction in chlorophyll content was also recorded by Prajapati and Tripathi (2008).

2.4 Morphological Parameters for Air Pollution

Some plants can collect air pollutants that have extremely low concentrations and are difficult to determine precisely with physical and chemical techniques to a point that is easier to analyze (Temmerman et al. 2001). A number of such parameters used for phytomonitoring of air quality are mentioned below:

2.4.1 Plant Development

Manning and Fedder (1980) quoted the altered growth rates; changes in rates of maturation; reduction in flower, fruit, and seed formation; alterations in reproductive processes; and ultimately depression in productivity and yield as effects of pollution. Bist et al. (2016) also demonstrated the use of *Tithonia diversifolia* as a phytomonitor on a relative scale in an industrial region, and Joshi (1990) worked on the successful use of the same plant in Mumbai.

2.4.2 Macro Characters

The leaf is an organ which is sensitive to pollution, and any damage to it affects the vitality of the entire plant. Visible effects mainly are characterized as epinasty on some plant species like curling of strawberry leaves; the changed angles between stem and petiole by tomato plants have been reported by many workers. Ozone biomonitoring with tobacco Bel-W3 (*Nicotiana tabacum* L.) plant has been done for many years in different countries, for example, France (Vergé et al. 2002), the Netherlands (Posthumus 1982), Germany (Kerpen and Faensen-Thiebes 1985; Reiner et al. 1985), Estonia (Koppel and Sild 1995), Greece (Saitanis and Karandinos 2001), Spain (Peñuelas et al. 1999), Italy (Nali et al. 2001), and Brazil (Klumpp et al. 1996).

2.4.3 Micro Characters

Stomatal frequencies, the appearance of stomatal and epidermal cells, stomatal pore size and cuticular damage, and trichome density and length have been used as indicators of pollution in the past (Sharma and Butler 1973; Wagoner 1975; Garg and Varshney 1980; Rao 1985; Desai and Kapoor 2013). Biomonitoring of ozone injury using *Abies religiosa* trees has been done in Mexico by studying microscopic symptoms on the needles (Alvarez et al. 1998).

3 Phytomonitoring

One of the reasonably economical ways of screening pollution is by using plants that are susceptible to pollutants. Vegetation is significant to maintain ecological balance, but it also get affected by air pollution (Steubbing et al. 1989). Plant organs, when exposed to pollutants in the atmosphere, reflect changes in their health as they are the primary acceptors of air pollution (Joshi and Swami 2009). When exposed to subacute doses of air pollution, plants tend to indicate the same by a decrease in their growth (Banerjee and Chaphekar 1978; Rao 1981). The response of the vegetation to environmental stresses differs from species to species depending upon genetic makeup and the phenological phases of the plants, concentration of pollutants, and existing ecological conditions (Farooq and Beg 1980).

Plants which grow along the road of metropolitan cities function as a sieve for atmospheric pollutants, which extensively reduce their toxic effects and mitigate their blow on the surroundings. Leaf surface characteristics and the anatomical modifications occurring in leaves of many plant species may potentially be used as biological indicator for the occurrence of air pollution (Kushwaha 2018).

3.1 Concept

Various levels of association of the plant can be used for phytomonitoring, varying from a sole plant (leaf or even plant cell) to the plant organization and the ecosystem. Plants can also be used for examining pollution loads in different vicinity and time (Posthumus 1983). Phytomonitoring can be carried out in two ways (Steubbing 1982): observation and analysis of local flora (*passive biomonitoring*) and exposing indicator species under standard conditions (*active biomonitoring*). Passive monitoring includes the use of plants from their natural habitat where the reaction assessed is generally based on the leaf injury or accumulation of the substance deposited on the selected species. This technique is most frequently used in source identification or monitoring networks.

3.2 Lichens as Indicators of Pollution

The epiphytic lichen *Lecanora conizaeoides* was used in an industrial area in Denmark to monitor heavy metals and SO_2 (Pilegaard 1978) because of its high tolerance to air pollution. It is often the only species surviving in an area with high SO_2 concentrations. *Xanthoria parietina* was used in northeastern Italy to monitor airborne heavy metals (Nimis et al. 2000).

3.3 Plants as Indicators of Different Air Pollutants

Plants can efficiently be used as inexpensive and naturally existing monitoring systems (Steubbing 1982; Steubbing et al. 1989; Hawksworth 2001; Nash and Egan 1988). For example, in *Pinus* young needles, chlorosis indicates SO_2 pollution, necrosis indicates hydrogen fluoride pollution, bleaching indicates NO_2 pollution, while chlorotic mottle signifies Cl_2 pollution in the environment. Similarly, browning in moss leaves indicates fluoride accumulation. The plant species to be used in pollution monitoring should have certain features such as (1) easy identification of species in the field and easy handling for injury analysis; (2) species should have a broad range of distribution to be used in different regions; (3) sensitive species should be used to examine diverse group of pollutants in the area; and (4) species ought to show precise injury symptoms in response to particular types and concentrations of pollutants.

Sensitive species like mosses, lichens, ferns, algae, and aquatic plants are generally more useful in pollution screening as their array of pollutant specificity is generally much superior to that of higher vascular plants (Chaphekar 1972; Posthumus 1982; Steubbing 1982; Rao 1985; Joshi 1990).

3.3.1 Bryophytes

Thomas (1986) quoted that bryophytes are useful bio-accumulators of inorganic and particulate organic pollutants. Bryophytes are also important in biomonitoring of heavy metal deposits (Steinnes 1995); their growth and efficiency for element uptake have been studied by Sucharova and Suchara (1998).

3.3.2 Mosses

Feather mosses, *Pleurozium schreberi* and *Hylocomium splendens,* have been recognized as collectors of heavy metals in Scandinavia (Rühling and Tyler 1973) and Poland (Grodzinska 1978), and the epiphytic moss *Hypnum cupressiforme* in the UK (Goodman and Roberts 1971; Lee and Tallis 1973) and in Germany by Thomas (1983). *Pinnatella alopecuroides* and *Bryum* spp. has been identified as useful biomonitors of elemental pollution in and around Mumbai region (Chakrabortty and Paratkar 2006).

3.3.3 Higher Plants

Nearly all higher plants capture air pollutants with their aboveground plant parts. The leaves are the most important parts to absorb or adsorb pollutants, but in the case of trees, the bark can also be used for monitoring organic and inorganic pollutants (Schulz et al. 2000). *Acacia arabica* (Babul), *Citrus* sp., *Diospyros* sp., *Ficus benghalensis* (Banyan), *Ficus religiosa* (Peepal), *Lilium* sps. (Lily), *Polyalthia longifolia* (Ashok), *Tamarindus indica* (Imli), *Thuja occidentalis* (Cedar), *Ziziphus jujuba* (jujube), etc. are some of the plant species suggested by MOEF (2005) for their possible potential in pollution control.

3.4 Plant Parameters Used for Monitoring

3.4.1 Leaf Injury

The common misconception is that there is no injury to vegetation unless visible symptoms have developed. However, air pollutants have shown to reduce the plant development and yield before any visible symptoms appeared. Chaphekar (1990) stated that injury in case of plants initially starts at biochemical level (interference with photosynthesis, respiration, lipids and protein biosynthesis, etc.), sequentially progressing to the ultrastructure level (disorganization of cellular membranes) and then to the cellular level (cell wall, mesophyll, and nuclear breakdown). Thus, visible injury symptoms like chlorosis and necrosis of foliar tissues develop as a result of many subtle injuries getting magnified. *Nicotiana tabacum* L. cv. Bel-W3, a tobacco variety, has been used by many researchers globally since 1962 as an ozone-responsive bioindicator plant due to its supersensitive nature to exhibit characteristic symptom like grayish necrotic spots on laminar surfaces based on ambient levels of ozone (Heggestad 1991; Cheng and Sun 2013). Stomatal index, length and breadth of stomata, and trichome density have been shown to reduce in areas of pollution (Ahmed and Yunus 1985).

3.4.2 Morphological Indicators

The consequences of air pollution on plant growth and development with respect to height, leaf and fruit size, number of leaves, fruits, and dry matter accumulation values also provide a basis for monitoring pollutants. Chaphekar et al. (1980) located areas of comparatively poor air quality around fertilizer factory premises based on biomass values of *Commelina benghalensis*.

3.4.3 Biochemical Parameters

Biochemical injuries result when pollutant concentration exceeds the capacity of tissues to detoxify it through their normal metabolism, and reduction observed in plant growth and yield because of air pollution may be more serious than generally suspected (Treshow 1984). The protein content serves as a useful parameter for O_3 and SO_2 pollution (Agrawal 1985). The response of plants in terms of protein contents was found to be an indicator of auto exhaust fumes (Banerjee et al. 1983). Constant exposure to SO_2 decreases the ascorbic acid content in plants much before the emergence of visible damage (Keller and Schwager 1977). Chaudhary and Rao (1977) related pollution tolerance of plants with their ascorbic acid and concluded that the higher the ascorbic acid level, the greater was their tolerance. A decline in chlorophyll content has often been recommended as a marker of air pollution. In sensitive lichens, chronic exposure of too low concentrations (0.01 ppm) of SO_2 resulted in the loss of chlorophyll (Gilbert 1968).

3.5 Standardization of Plants

Plants used for active biomonitoring should be grown in pots filled with soil, offering most favorable conditions for plant growth, and supplied with a watering facility to avoid differences from indirect effects. Deficiency of essential elements should not occur. The necessity to use genetically standardized material and consistent culturing practices is also important. Such systems have been used by Chaphekar (1978), Posthumus (1982), Arndt (1982), Joshi (1990), etc. Standardization of techniques is also necessary to compare outcomes at different sites, months, or years.

4 Plants for Mitigation of Air Pollution and Greenbelt Development

Vegetation functions as a proficient gas exchange scheme. Their anatomical construction allows quick dispersal of water-soluble gases. This distinctiveness let the plant to breathe and photosynthesize and to eliminate pollutant from the air.

Hosker and Lindberg (1982) reported that air pollution levels are abridged when windblown particulates (PM2.5 and PM10) adhere to the foliage of plants. Likewise, gaseous air pollutants chiefly carbon dioxide can be impounded through stomata on leaf lamina (Currie and Bass 2008). Wei et al. (2017) suggested that plant leaves retain PM and act as biofilters in the environment.

Akbari (2002) considered that day temperature decrease due to trees would reduce the reliance on air-conditioning and lessen emissions of NO_x from coal-fired power plants causing an expected 10% decrease in smog originator or a drop of 350 tons of NO_x per day.

Vegetation acts as natural "air conditioners," at least with regard to the microclimate of the city (Rowntree 1986). Urban trees can improve environmental variables by preventing solar radiation from warming the surrounding buildings and exteriors, cooling the air by evapotranspiration, and dropping wind velocity (Akbari et al. 2001).

Nowak and Heisler (2010) suggested that vegetation influences air pollution by dropping air temperatures and air pollution and reducing ultraviolet radiation and carbon dioxide.

Importance of plantations as suggested by Moef (2005) is that trees are good SO_2 absorbers and parks with vegetation have lesser SO_2 level than urban roads. Street side shelterbelts can decrease airborne load generated by traffic on the backside of the plantation. Trees around the industrial area help to purify industrial emissions.

Total dust retention can be attained by a 30 m belt of plants where only a single line of trees can cause about 25% decline in airborne particles. Vegetation also helps in controlling pollution when other methods have been insufficient.

4.1 Stress Faced by Urban Trees

Urban trees are at a great disadvantage when compared to the trees growing in the wild. They have limited exposure to sunlight, have subnormal water supply, and have to adjust with the ambient atmosphere which generally varies. The limited quantum of sunlight is sometimes accentuated with smog. The small volume of soil available lacks in humus and is so compact that the air spaces between the soil particles scarcely allow either water or air to reach the root systems.

The ambient environment in which the urban tree thrives often includes toxins like SO_2 from industries and NO_2 from automobiles and contaminants like hydrogen fluorides, particulates, and other heavy metals. Tall buildings, narrow roads, limited water supply, vehicular traffic, and industries make it difficult for a tree to stay alive, but in spite of all these stresses, a tree in the urban area manages to survive (Joshi 1990).

4.2 Tolerant Plant Species

Individual plants vary with their susceptibility to air pollutants. Trees with good pollution tolerance are tolerant species, and those with low tolerance turn out to be sensitive species. Hence, tolerant species serve as pollution “sink” by providing a number of ecological benefits and should be planted in polluted zones (Chaphekar et al. 1980). Cultivation of tolerant and sensitive species in polluted habitats leads to improvement of the polluted environment by these plants acting as scavengers and pollutant indicators (Tiwari and Tiwari 2006). Thus, an assessment of plants in terms to their tolerance level to air pollution becomes important. The purpose of pollution reduction is best accomplished by pollution-tolerant flora; hence, for an industrial area where tree plantation is a site-specific activity, a thorough understanding of tolerance level of vegetation to pollution is necessary.

4.3 Forest as Sinks of Air Pollution

As per the norms of Moef (2005), three key norms for the choice of plants for controlling air pollution are (i) vegetation with thick foliage and large leaf lamina because leaves take up pollutants; (ii) evergreen trees are most efficient; and (iii) the plant species selected must be tolerant to pollutants, even during the initial stages of their development.

According to Moef (2005), some of the suitable plants having potential for pollution control include *Acacia arabica* (Babul), *Citrus species*, *Diospyros species*, *Ficus benghalensis* (Banyan), *Ficus religiosa* (Peepal), *Lilium* sp. (Lily), *Polyalthia longifolia* (Ashok), *Tamarindus indica* (Imli), *Thuja occidentalis* (Cedar), *Prosopis juliflora* (Mesquite), and *Ziziphus jujuba* (jujube). Smith (1987) in his book *Air Pollution and Forests* has given elaborative discussions on the role of trees in air pollution abatement as well as the impact on vegetation.

4.4 Dust Chamber Studies

The increased human activity in the field of development in India has created huge amounts of air pollutants (Abbasi 1998). Forty percent of the total air pollution problems in India are contributed by dust (Das et al. 1981; Lone et al. 2005). Chemical dust is more dangerous, and their phytotoxicity increases under humid conditions (Chaphekar 1972).

Plants intercept tons of dust on busy highways and absorb noise near the noisy factory area (Warren 1973). But the quantity of dust is by no means steady in the environment. It keeps varying with respect to difference in location, time of the year, weather, etc. Wind velocity, air temperature, inversions, cloud cover, and woodland openings all influence particulate movements (Fritschen et al. 1970; Edmonds and Driver 1974). The trees are the best sinks for particulate pollutants like radioactive trace elements, pollen, spore, salt particles, dust, etc. (William 1990). The greenbelts and shelterbelts are the best solutions to the problems of pollution in urban and industrial areas (Agrawal and Tiwari 1997).

In order to control dust pollution, nature of trees, type of canopy, branching pattern, the surface of the bark, phyllotaxy, venation, trichomes, etc. have a significant role (Mancharkar 2001). The canopies of alfalfa have been investigated for the uptake of ordinary pollutants like SO_2 and NO_2 (Hill 1971).

Various factors such as leaf shape, phyllotaxy, leaf texture, presence of trichomes, length of petioles, wind velocity, climatic conditions, height and canopy, etc. affect the dust interception/accumulation capacity of different plants (Younis et al. 2013). The influence of leaf distinctiveness on dust retention has been studied by numerous researchers (Somashekar et al. 1999; Garg et al. 2000).

External features of leaf such as cuticular waxes, epidermal cells, trichomes, stomata, and cuticular lignin give coarseness to leaves (Pal et al. 2002). Rough-leaf surfaces not only cause higher particulate deposition but also reduce the potential for these particulates to be washed away with rainfall. Also, leaves with longer life span have a greater time period to accumulate pollutants. Morphological and anatomical leaf features get changed by an intense dust fall (Somashekar et al. 1999; Gostin 2009; Sukumaran 2012).

In order to establish the finest plant for accumulating and capturing dust, examining of dust on plants under controlled conditions was carried out. A unique dust fumigation chamber was made based on the lines developed by Mancharkar (2001) and subsequently Joshi (2014) in India to study the plants under constrained conditions. Plants were rated according to their Dust Retention Indices (DRI), and the following plants were considered to be good dust capturers.

Mancharkar and Chaphekar (2005) have concluded that some plant species can behave as very good dust capturers as they showed higher values of DRI ranging from 70 to 90. Following plant species showed higher DRI values: *Abutilon indicium*, *Calotropis gigantea*, *Ficus benghalensis*, *Ficus glomerata*, *Gmelina arborea*, *Mangifera indica*, *Terminalia bellerica,* and *Thespesia populnea*.

The wind shows continuous variation in its speed and direction. The average wind speed can vary throughout the year from 3 km/h to 9 km/h (Tyagi et al. 2011). Also, the wind speed varies from location to location and ranged between 28 m/s and 44 m/s in Mumbai city (Kumar et al. 2012). Such chambers have been used in the past as a major tool in analyzing the efficiency of plants in monitoring and measuring pollutants under controlled conditions (Darley 1966; Hill 1971; Mancharkar 2001).

Dust Retention Index (DRI): For effective comparison between different species for their efficiency to retain dust that falls on the laminar surface, an index has been recommended which is called as Dust Retention Index – DRI (Mancharkar 2001). The index is calculated as:

$$\text{DFI} / \text{DRI} = \left(A / B\right) \times 100$$

where DFI = Dust Fall Index, DRI = Dust Retention Index, A = dust captured/retained by a leaf, and B = dust captured/retained by the same area of the greased plate.

In order to study the dust retaining capacities of different plant species, a fan was connected to the dust chamber and allowed to run for 3 min at the speed of 4 km/hr. After 3 min, the plant and greased plates were removed. The greased plate was reweighed, and three leaves were detached from the plant sapling. DRI of the leaves was calculated. This value is the dust-holding capacity of plants under controlled windy conditions, henceforth called as DRI or Dust Retention Index.

The plants were examined to understand dust under restricted conditions. The quantity of dust was estimated to establish dust-capturing and dust-holding capacities of the plants under study. The DFI is same as DRI (Mancharkar 2001) under still conditions in the chamber, while the DRI is dust measured under simulated conditions. The ability to capture dust on leaf surface was calculated in terms of DFI (Dust Fall Index), while the dust retained by the plant under windy conditions was termed as DRI (Dust Retention Index).

DFI and DRI values are percentage values of dust captured and dust retained on the leaf surfaces of different plant species. The foliage was then screened for dust fall within the dust chamber and was examined for their DFI and DRI. The values

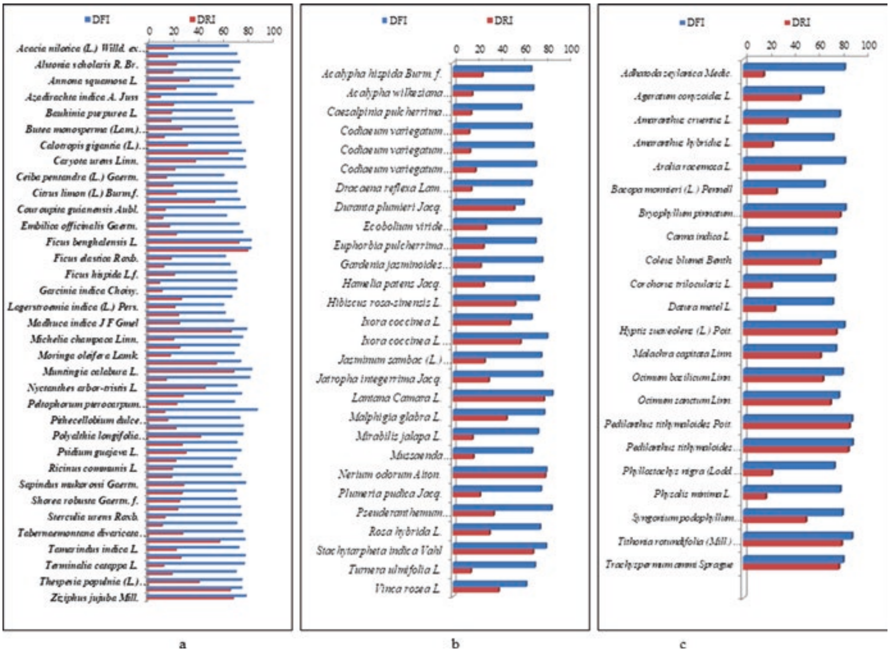

Fig. 5.1 DFI and DRI values for (**a**) trees, (**b**) shrubs, and (**c**) herbs

are represented in Fig. 5.1. For each plant species, Dust Fall Index and Dust Retention Index were calculated (Joshi 2014).

The current study revealed that trees, shrub, herbs, and climbers all engage in a significant task in phytomonitoring and phytoremediation. The best tree species to retain dust on its foliar surface was *Ficus benjamina* L. var. *nuda* (Miq.) M. F. Barrett. Similarly, the best shrub species to retain dust on its foliar surface was *Nerium odorum* Aiton, whereas the best dust retainer herb and climber were *Pedilanthus tithymaloides* Poit. and *Bougainvillea spectabilis* Wild., respectively (Fig. 5.1). *Ficus benjamina* L. had been discovered as an active indicator of air pollution and found to be sensitive at residential, industrial, and heavy traffic areas as it showed APTI<10 (Thambavani and Sabitha 2011). Also, *Bougainvillea* species had been reported as one of the tolerant species to air pollution (Radhapriya et al. 2012).

The work done by Joshi (2014) is a means for selecting the most appropriate plants for greenbelt development in Mumbai city on a morphological basis. *Bougainvillaea spectabilis* Willd., *Ficus benjamina* L. var. *nuda* (Miq.) M. F. Barrett, *Hyptis suaveolens* (L.) Poit., *Ixora coccinea* L., *Lantana camara* L., *Nerium odorum* Aiton., *Pedilanthus tithymaloides* Poit., and *Tithonia rotundifolia* (Mill.) S.F. Blake which require low maintenance but are best performers can be used as phytomonitors and phytoremediators on road dividers on highways and main roads. Similarly for beautiful avenues, *Trema orientalis* (L.) Blume, *Ficus benghalensis* L., *Mangifera indica* L., and *Ziziphus jujuba* Mill. can be cultivated on either side of highways and main roads. Plants like *Bryophyllum pinnatum* (Lam.) Oken, *Duranta plumieri* Jacq., *Stachytarpheta indica* Vahl, and *Trachyspermum ammi* Sprague can be cultivated in residential areas because they are suitable for controlling dust pollution but require regular attention watering.

Beckett et al. (1998) have emphasized that vegetation plays an essential role in enhancing air quality in urban areas. Trees either act as particle trap or create locally altered climatic condition (due to the action of transpiration) which reduces particulate concentrations. The city of Mumbai in India faces a severe problem of dust pollution as has been reported by various agencies in the past. The city has and is experiencing, just like other cities in the country, a surge in construction activity. Air is monitored in the city at a few selected locations by government agencies. There is also an awareness within the general citizens regarding the importance of plants in the city, and in their effort to make the city green, tree plantation drives along the roads and beautification of road dividers and traffic islands are carried out. These plantations include just not the trees but also ornamental shrubs and seasonal flowers. Thus, often questions are asked as to the type of plants to be selected for reducing pollution, and the air quality in areas not monitored is often written or spoken about. The work addresses the problem of dust pollution in the city and the possible role the existing vegetation can play in an urban ecosystem.

4.5 Air Pollution Tolerance Index (APTI)

The ambiance of an urban area is polluted by several pollutants, and plants growing there are open to a mixture of pollutants. So it is feasible to measure, on the whole, the effect of a great number of pollutants by evaluating changes in the plants. There is the likelihood of the synergistic action of pollutants by using vegetation as a marker for atmospheric pollution (Lakshmi et al. 2009). The effectiveness of plants in captivating pollutants is such that it can generate pockets of fresh air. Plants maturing in a contaminated environment often respond and show considerable changes in their structure, functioning, and biochemistry. This reaction of plants toward air can be evaluated by Air Pollution Tolerance Index (Gilbert 1968). Similar studies on APTI of plants has been done in the past by many researchers who suggested many tolerant plant species (Singh and Rao 1983; Tripathi et al. 2009; Patel and Kousar 2011; Govindaraju et al. 2012; Hallale and More 2013). Thus, the main aim of performing APTI is to suggest plant species for greenbelt expansion in order to avoid or reduce the air pollution troubles, in traffic noise reduction, and in mitigating pollution along roadsides and in industrial areas. The response of vegetation to pollutants at a physiological and biochemical level can be understood by evaluating the factors that decide sensitivity and tolerance (Suvarna et al. 2008). Singh and Rao (1983) made a brave attempt in proposing a technique of determining Air Pollution Tolerance Index (APTI) by synthesizing the values of four different biochemical parameters such as ascorbic acid, total chlorophyll content, leaf extract pH, and relative water content to establish the resistance and susceptibility of plants to air pollution. Various plants show significant difference in their receptiveness to air pollution. The plants with elevated and reduced APTI value can function as tolerant and sensitive species accordingly (Lohith et al. 2018). Plants with higher APTI value are more proficient to fight against air pollution and can be used to lessen pollution, while those with low index value show less tolerance and can be used to indicate levels of air pollution (Joshi and Bora 2011). In our work carried out in Tarapur industrial area by the Bist et al. (2017), fully grown leaf samples were collected from 30 tree species during two dry seasons, i.e., summer and winter (Fig. 5.2). The collected leaves were brought to the laboratory with care and were cleaned with distilled water to get rid of dust particles, and fresh weight was taken right away. Fresh leaf samples were then analyzed for ascorbic acid (Sadasivam and Manickam 2009), leaf extract pH (Singh and Rao 1983), total chlorophyll (Arnon 1949), and relative water content (Weatherly 1950).

In an industrialized surrounding, an array of pollutants is seen originating from various sources. So using only one biochemical parameter to estimate the vulnerability of plants to pollutants does not turn out to be a feasible method. But a combination of an assortment of biochemical parameters can give a more trustworthy outcome. Air Pollution Tolerance Index (APTI) study is thus important in understanding the tolerant and susceptible character of plants to pollutants in the surroundings. High APTI values indicate tolerant nature of the plant species, and less APTI value indicates the sensitivity of the plant species (Joshi et al. 2016a, b).

From the plant species collected for the experimental study, the range of plants tolerant to air pollution can be stated as *Putranjiva roxburghii*, *Mangifera indica, Ficus racemosa*, *Ficus hispida*, *Morinda citrifolia*, *Pongamia pinnata*, *Ficus benghalensis*, *Polyalthia longifolia, Cassia fistula*, and *Acacia auriculiformis*. Tolerant

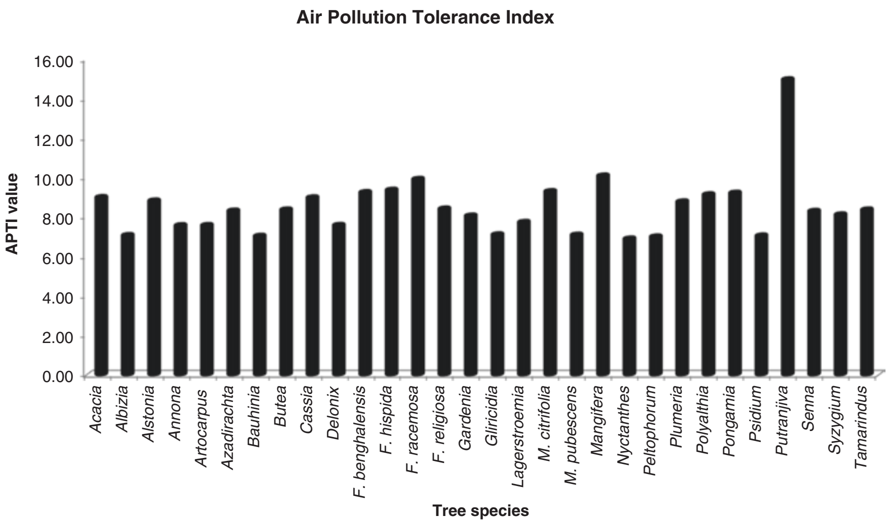

Fig. 5.2 Average APTI of 30 plant species from the industrial area of Tarapur

plant species can be used in greenbelt development as they tend to serve as barriers and act as a sink for air pollutants. These can thus be planted in and around industrial vicinity and traffic islands to control the level of air pollution. Similarly, the order of sensitive species can be given as *Nyctanthes arbor-tristis*, *Bauhinia purpurea*, *Peltophorum pterocarpum, Psidium guajava, Morinda pubescens*, *Albizia saman*, *Gliricidia sepium*, *Annona squamosa*, *Artocarpus heterophyllus*, and *Delonix regia*. Sensitive plant species on the other hand act as bioindicators of air pollution and thus can be planted in order to check the environmental health from time to time.

Urbanization and industrialization have led to a massive loss in the crop yield and to the financial system of many regions. Hence, APTI evaluation of different crops provides information regarding their tolerance capacity to air pollutants, and such crops may be suggested to the farmers in industrialized, urban, and semi-urban areas (Bakiyaraj and Ayyappan 2014).

Soaring pollution levels can lead to deforestation in the long run, and thus this kind of study proves useful in understanding the plant's susceptibility and resistance to pollution loads. Also, the trees with high tolerance to air pollutants can be used for planting in greenbelt areas so as to mitigate pollution from surrounding to some degree.

4.6 Guidelines for Greenbelt

Greenbelts are the lungs of the city as they function as a sink for a number of the detrimental gases released by automobiles and industries working in the metropolitan. Greenbelt development plan for a particular zone largely depends upon (i) nature and amount of pollution load, (ii) sinking capacity of the ecosystem, (iii) climatic factors, and (iv) soil and water quality (Horaginamani et al. 2012).

4.7 Objectives of Greenbelt Development

The objectives of greenbelt development range from the micro level air pollution abatement to improvement of the socioeconomic position of the area (Gupta et al. 2008). The main objective of greenbelt development is reduction in air and noise pollution. It also serves as a measure to decrease the soil erosion and to improve aesthetic value of the area. It enhances the socioeconomic status of the region by generating employment and also helps in environmental protection. The thickness of the greenbelt and the species used for planting varies from industry to industry depending on nature and concentration of air pollutants. Greenbelt also serves five purposes which include to ensure the unrestricted sprawl of large built-up areas, to prevent neighboring towns merging into one another, to assist in safeguarding the countryside from encroachment, to preserve the setting and special character of historic towns, and to assist in urban regeneration by encouraging the recycling of ruined and another urban land. Shannigrahi et al. (2004) and Gupta et al. (2008) recommended that an ideal tree for use in greenbelt should have quick development rate for canopy growth, thick and strong canopy with sturdy branches to withstand storm conditions, and large foliar area and dense foliage for better pollutant retention; perennial and evergreen trees are preferred for longevity of the greenbelt; indigenous tree species should be selected; and resistance to disease, pest, and specific air pollutants, ability to maintain hydrological and environmental balance of the area along with tolerance to urban soil conditions, and Air Pollution Tolerance Index (APTI) should be evaluated in order to identify the tolerance nature of tree species. Different plant species show different APTI scores; for an instance, a study revealed that the maximum APTI is observed in *Azadirachta indica* and minimum is *Psidium spicigera* (Horaginamani et al. 2012). Another study at Varanasi revealed that *Ficus benghalensis* L. and *F. religiosa* are outstanding performers in urban forest; *Polyalthia longifolia*, *F. glomerata* (Roxb.), *A. indicus,* and *Mangifera indica* are excellent performers in the marble industrial areas of Potwar region; and in the similar fashion, *Cassia fistula* L., *D. roxburghii*, *T. arjuna*, *P. guajava* L., *M. hortensis,* and *D. sissoo* perform well in urban forest with respect to their API (Pandey et al. 2015). When suggesting plants for greenbelt development in industrial complex, points to be considered (Tiwari and Tiwari 2006) are that both types of trees should be planted: one with high APTI value to serve as sink and other with low APTI value to serve as bioindicators. Plants with economic value should be selected. Plants releasing less pollen in the atmosphere should be chosen. Canopy structure should be dense and leaf area should be large. Aesthetic plants should be selected. The innermost belt should lie close to the industry with plants having high APTI value. The second belt should have a few trees with high APTI and majority with moderate APTI values. The third belt should have trees with moderate APTI values but with high aesthetic significance. A few sensitive species should be planted in all three vegetation belts to act as indicators. The distance of 1.0 m from plant to plant and row to row should be maintained. The choice of tree species for greenbelt development is based on the local extent of the pollution load along with soil quality, precipitation, temperature, and human interactions. In any greenbelt development, monoculture is not sensible due to its climatic factor and other ecological limitations.

Pollution-sensitive species like *Bauhinia purpurea, Delonix regia, Gliricidia sepium, Nyctanthes arbor-tristis*, *Peltophorum pterocarpum,* and *Psidium guajava* must be planted around the human settlements in order to examine pollutant levels as these plants act as bioindicators of pollution. Also, these tree species have thick canopies and stunning flowers which enhance their aesthetic value (Bist et al. 2017). Evergreen pollution-tolerant trees with dense foliage, beautiful flowers, leaves with larger surface area, and wide canopies like *Ficus religiosa, Manilkara zapota, Pongamia pinnata,* and *Putranjiva roxburghii* along with fairly tolerant tree species like *Alstonia scholaris, Azadirachta indica, Butea monosperma, Ficus religiosa, Gardenia jasminoides, Lagerstroemia speciosa, Plumeria obtusa, Senna siamea, Syzygium cumini,* and *Tamarindus indica* must be planted along the pollution sources so that they can soak up more pollutants and help in purifying the surroundings. Roadside plants serve as efficient bioindicators by capturing a considerable amount of harmful particles from the atmosphere, thereby cleaning the air quality (Rai and Panda 2015). Sources such as industrialized areas, factories, or highways become the root cause of air pollution in urban regions. Foliage barrier can help lessen the pollution buildup in cities by acting as sinks. Greenbelts can be used as a visual screen and partial noise blockade next to infirmary, educational organizations, playgrounds, parks, and housing societies close to main road networks.

4.8 Trees in an Industrial Area and Its Role

Trees function as natural "air conditioners" in urban area (Rowntree 1986). Urban plants can enhance ecological variables by preventing solar energy from warming up the surrounding buildings and exteriors, cooling the air by evapotranspiration, and reducing wind velocity (Akbari et al. 2001). Nowak and Heisler (2010) suggested that vegetation and parks influence air pollution by dropping air temperatures and UV radiation, maintaining carbon dioxide level, and ultimately reducing air pollution.

4.9 Monitoring Dust in a City

Mumbai city is heavily inhabited and polluted. The pollutants vary from NOx, CO, and SPM (Joshi and Chauhan 2008). This metropolitan shows a high range of SPM levels from190μg/m^3 to 500 μg/m^3 (Municipal Corporation of Greater Mumbai 2013). The hazardous emissions from industries and vehicles are mainly responsible for increasing air pollution in the city, whereas the rapid construction activities and ever-increasing traffic conditions make it more vulnerable to dust pollution.

Intense vehicular traffic leads to movement of suspended particulate matter in the surrounding air, which settles on ruderal plants. It is well-known fact that vegetation can be used efficiently for screening dust (Yunus et al. 1985; Joshi 1990). In the past for scrutinizing air pollution in the city, urban vegetation has been used successfully by many researchers (Chaphekar et al. 1980). It is a frequent practice in urbanized countries to use plants to clean out dust, soot, and particulates from the environment. Vegetation acts as biofilter and takes in huge quantities of particulates from the surroundings (Central Pollution Control Board 2007).

Urban air quality can be enhanced by planting vegetation along the streets (Beckett et al. 2000; Freer-Smith et al. 2005; Raupach et al. 2001). The foliage acts as steady absorbers for suspended particulate pollutants (Samal and Santra 2002). The dust accumulations differ with difference in time of year (Prajapati and Tripathi 2008).

In plants, the dust-retaining ability depends on its leaf shape, leaf arrangement, and leaf epidermal appendages such as trichomes, cuticle, and lengths of petioles, tree cover, and the existing climatic conditions with wind direction and velocity (Prajapati and Tripathi 2008). Pollutants commonly found in cities include dust from the roads which can be potentially injurious to ruderal vegetation, animals, birds, and the neighboring mankind (Bhattacharya et al. 2011).

An enormous amount of work is done using trees to study air pollution levels in urban areas by many researchers. Shetye and Chaphekar (1980) provided information about various locations on roads with high dust loads using *Erythrina indica*, *Mangifera indica*, *Thespesia populnea,* and *Polyalthia longifolia*. Giridhar (1984) investigated the ascorbic acid contents of some common trees of Mumbai and tried to trace the relationship between their ascorbic acid levels and pollution levels in the city. The growth performance of some common trees near a fertilizer factory emitting various pollutants was studied by Chaphekar et al. (1980). An increase in the intensity of dust causes the reduction in growth, i.e., to shoot length and chlorophyll content. Thus, it can be stated that shoot length and chlorophyll content are more reliable parameters for air quality indication (Nitesh and Bharati 2019). The experiments carried out by Hareesh et al. (2018) on *Phaseolus mungo* L. (black gram) revealed that a raise in different dust pollutants causes a decline in total chlorophyll and transpiration rate in vegetation which additionally decreases their yield.

According to their research, Chaudhary and Rathore (2018) stated that elevated dust fall had harmful effect on leaf functioning, biomass, and micromorphological attributes of tree species. Also, dust fall is usually maximum at the industrialized area as compared to traffic and housing area.

Faqih (2014) explored the potentials of urban plant species, commonly grown along roadsides in the city, as phytomonitors of dust. As a preliminary part of the research, a survey was conducted to study the plant diversity in the city. Four plant species *Bougainvillea spectabilis* Willd., *Ficus benjamina L. var. nuda* (Miq.) M. F. Barrett, *Nerium odorum* Aiton. and *Pedilanthus tithymaloides* Poit. were found to have relatively high dust-capturing capacities and were chosen for investigations on dust distribution at some traffic signals in the city. Considerable work has been done in the city by the authors, under a Major UGC Research Project entitled "Studies on monitoring Suspended Particulate Matter using urban plants and understanding their Green Belt Potentials." In plants like *Nerium odorum*, *Pedilanthus tithymaloides*, *Bougainvillaea spectabilis*, and *Ficus benjamina*, the elemental composition of dust was analyzed and electron diffusion spectrum was studied for urban dust (Joshi 2014).

Vehicular traffic was monitored using a Sony digital camera (Model No. DSC – W150). Traffic count was calculated on hourly basis by examining the film recording taken during field inspection. Vehicular count has been expressed in terms of total number of vehicles/minute (Kadiyali 1996). The amount of captured foliar dust correlated well with the vehicular count along different roads in the city of Mumbai. In a study carried out by Joshi (2014) on dust-capturing capacities of four plant species, viz., *Nerium odorum, Pedilanthus tithymaloides, Bougainvillaea spectabilis, and Ficus benjamina,* throughout the dry seasons at 67 different sites

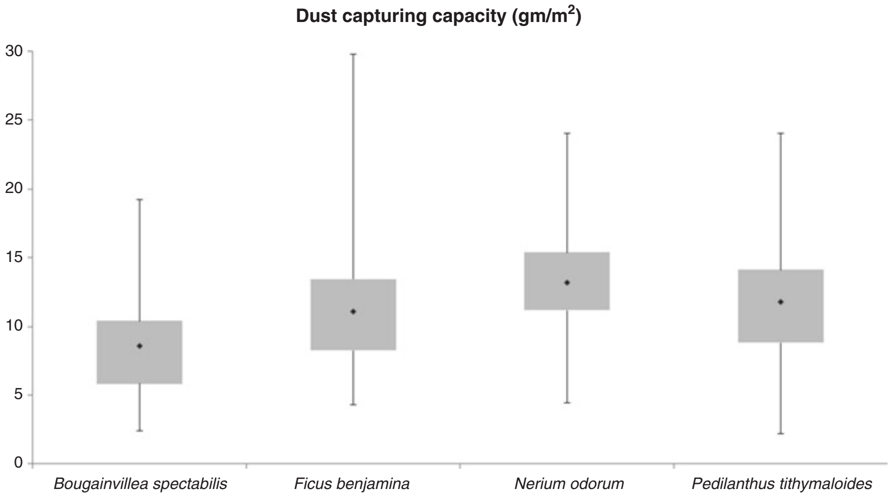

Fig. 5.3 Box plot expressing seasonal dust-capturing capacities of four different plants in g/m^2

spread over Mumbai city, the dust fall values showed the following trend: *Nerium odorum*>*Pedilanthus tithymaloides*>*Ficus benjamina*> *Bougainvillea spectabilis* (Fig. 5.3).

From the work, it was established that *Nerium odorum* Aiton. is the best plant species for phytomonitoring and phytoremediation. Also, its easy availability and maintenance make it suitable for growing all over the city on the roadsides and road dividers (Joshi 2014; Faqih 2015).

4.10 Basic Issues in Defining Guidelines

The four key steps in defining air quality guidelines are (i) identifying the appropriate sensitive species or ecosystem on which to base the guideline, (ii) identifying the response parameter of concern and deciding what size of the change in this parameter can be judged as adverse, (iii) identifying the method of characterizing pollutant exposure, and (iv) using appropriate experimental data, field data, or models to determine the threshold pollutant exposure for the identified species and response parameter. Complexities begin from three key reasons: (1) theoretical problems in defining "adverse effect," both logically and in terms of community judgment; (2) the bad effects of air pollution might be apparent in conditions where they are present in elevated concentrations and have remarkable effects, and also after reaching a "threshold" concentration, the effects steadily become more fine and are not easy to spot in field observations; and (3) constant exposures of the vegetation to air pollution cause effects that may be the consequence of long-term buildup of pollutants or long-term chemical changes in soil and flora. There are no clear experimental techniques of testing the consequences of these increasing effects directly. The unconventional approach adopted to identify dangerous loads of acidity to avoid long-term harm to ecosystems is to characterize a vital chemical concentration in the appropriate mediums likes soil or freshwater and then to build up statistical models to measure the level of deposition being exceeded.

5 Conclusion and Future Perspective

Air pollution is no more restricted to countries and continents. Air quality shows differences at microclimatic levels, irrespective of the class of cities or areas. The air in its purest form has become a rare commodity accepted in forests and mountains. Plants being stationary, thus, are the first one to respond any changes in the environment, be it air, water, or soil. Plants due to its diversity in morphological, biochemical, and growth responses express the nature of the environment and thus can be used as indicators. Plants known to be sensitive to pollutants can be used easily as monitors of air pollution. In cities, it becomes difficult to place instruments to measure pollutants at street levels or block levels due to the vulnerable nature of the region itself. Moreover, it also becomes economically an unviable proposition to do so. Phytomonitoring as a tool thus becomes the most promising tool in urban climatic conditions with minimum inputs and its aesthetic value also. Studies carried out in the city of Mumbai has proved the same. The very nature of some trees makes them ideal solutions for reducing particulate matter in tropical cities which has become a chronic problem. Development of greenbelts and sustainable urban development in cities has become an urgent need. It is in this area where green architecture plays an important role along with plant ecologist and urban ecologist.

References

Abbasi SA (1998) Environmental pollution and its control. Cogent Int Pondicherry 9:445

Agrawal M (1985) Plant factors as indicator of SO_2 and O_3 pollutants. Proceedings of international symposium on biological monitoring of the state environment (bio-indicator). Indian National Science Academy, New Delhi, pp 225–231

Agrawal S, Tiwari S (1997) Susceptibility level of few plants on the basis of Air Pollution Tolerance Index. Indian Forester 123:319–322

Ahmed KJ, Yunus M (1985) Leaf surface characteristics as indicators of air pollution. Symp. Biomonitoring State Environ. 254–257. In: Biological monitoring of the state of environment: bioindicators for I.C.S.U. by R.W. Press, 1986

Akbari H (2002) Heat island reduction: an overview—effects of trees and implementation issues. Presentation by Lawrence Berkeley Laboratory at the University of Pennsylvania, LAPR 760, November 13th, 2002

Akbari H et al (2001) Cool surface and shade trees to reduce energy use and improve air quality in urban areas. Sol Energy 70(3):259–310

Alvarez D et al (1998) Macroscopic and microscopic symptoms in Abies religiosa exposed to ozone in a forest near Mexico City. Environ Pollut 103(2):251–259
Arndt UL (1982) Comparability and standardization of biological processes. In: Steubing L, Jager HJ (eds) Monitoring of air pollutants. Dr. Junk Publishers, The Hague, pp 29–30
Arnon DI (1949) Copper enzyme in isolated chloroplasts. Polyphenol oxidase in Beta vulgaris. Plant Physiol 24:1–15
Bakiyaraj R, Ayyappan D (2014) Air pollution tolerance index of some terrestrial plants around an industrial area. Int J Mod Res Rev 2(1):1–7
Banerjee A, Sarjar RK, Mukherji S (1983) Reduction in soluble protein and chlorophyll contents in a few plants as indicators of automobile exhaust pollution. Int J Environ Stud 20:239–243
Banerjee AK, Chaphekar SB (1978) Observations of foliar injury to plants by SO_2. Geobios 5:8–11
Beckett KP et al (1998) Urban woodlands: their role in reducing the effects of particulate pollution. Environ Pollut 99:347–360
Beckett KP, Freer-Smith PH, Taylor G (2000) Particulate pollution capture by urban trees: Effect of species and windspeed. Global Change Biol 6:995–1003
Bhattacharya T et al (2011) Heavy metal concentration in street and leaf deposited dust in Anand city, India. R J Chem Sci 1(5):61–66
Bist B, Joshi N, Joshi A (2016) Dust retaining potential of Tithonia diversifolia (Hemsl.) A. Gray, International J of Life Sciences 4(2):235–240
Bist B, Joshi N, Mule P, Joshi A (2017) Choice of selection of tree species for green belt development in Tarapur Industrial area. IJBPAS 6(9):1619–1628
Central Pollution Control Board (CPCB) (2007) "Phytoremediation of particulate matter from ambient environment through dust capturing plant species", a report under Central Pollution Control Board. Ministry of Environment and Forests, Delhi. http://www.cpcb.nic.in/upload/NewItems/NewItem_87_NewItem_87_phyto_package.pdf
Central Pollution Control Board (CPCB) (2011) "Current air quality issues in India", a paper presented by Central Pollution Control Board. Ministry of Environment and Forests, Delhi
Chakrabortty S, Paratkar G (2006) Biomonitoring of trace element air pollution using mosses. Aerosol Air Qual Res 6(3):247–258
Chaphekar SB (1972) Effects of atmospheric pollutants on plants in Bombay. J Biol Sci 15–126
Chaphekar SB (1978) Biological indicators: The concept and new additions. Int J Ecol Environ Sci 4:45–52
Chaphekar SB (1990) Effects of air pollution on plants in bombay metropolitan region. Final Report to the Min. of Environ, and Forests, New Delhi.
Chaphekar SB et al (1980) Plants for air monitoring in industrial area. In: Furtado JI (ed) Tropical ecology and development. I.S.T.E, Kuala Lampur, pp 669–675
Chaudhary CS, Rao DN (1977) Study of some factors in plant controlling their susceptibility to SO_2 pollution. Proc India Natl Sci Acad Part B 46:211–236
Chaudhary, Rathore (2018) Phytomonitoring of dust load and its effect on foliar micro morphological characteristics of urban trees. Plantica 2(3):170–179
Cheng J, Sun E (2013) Factors affecting ozone sensitivity of tobacco Bel-W3 seedlings. Bot Stud 54:21
Currie BA, Bass B (2008) Estimates of air pollution mitigation with green plants and green roofs using UFORE model. Urban Ecosyst 11:409–422
Darley EF (1966) Studies on the effect of cement-kiln dust on vegetation. J Air Pollut Control Assoc 16:145–150
Das TM et al (1981) Trees as dust filters. Sci Today 19:19–21
Desai Y, Kapoor M (2013) Effect of building construction-dust on foliar micromorphology and biochemistry of Peltophorum pterocarpum (DC) Baker. Bionano Frontier 6(1):53–56
Edmond RL, Driver CH (1974) Dispersion and deposition of spore fumes and fluorescent particles. Phytopathology 64:1313–1321
Everett KR (1980) Distribution and properties of road dust along the northern portion of the haul road. In Environmental Engineering and Ecological Baseline Investigations along the Yukon

River-Purdhoe Bay Haul Road, ed. J. Brown & R. Berg. US Army Cold Regions Research and Engineering Laboratory, CRREL Report 80–19, pp. 101–28

Falla J et al (2000) Biological air quality monitoring: a review. Environ Monit Assess 64(3):627–644

Farooq M, Beg M (1980) Effect of aqueous sulphur dioxide on the membrane permeability of common Indian tree leaves. New Botanist 7:213–217

Faqih AG (2015) Studies on foliar dust deposition on urban plants in Mumbai. Thesis submitted to the University of Mumbai

Freer-Smith PH et al (2005) Deposition velocities to Sorbus aria, Acer campestre, Populus deltoides X trichocarpa 'Beaupre', Pinus nigra and X Cupressocyparis leylandii for coarse, fine and ultrafine particles in the urban environment. Environ Pollut 133:157–167

Fritschen J et al (1970) Dispersion of air traces into and within a forested area (3). Report No. OSD 1366, College of Forest Resources, Washington Univ., Seattle, WA:53

Garg KK, Varshney CK (1980) Effect of air pollution on the leaf epidermis at submicroscopic level. Exp Dermatol 368:1364–1366

Garg SS et al (2000) Ind J Environ Prot 20:326–328

Garrec JP, Van Haluwyn C (2002) Biomonitoring of the quality of the air. Editions Tec & Doc, Paris, p 117

Goodman GT, Roberts TM (1971) Plants and soils as indicators of metals in the air. Nature 231, 287–292.

Govindaraju M, Ganeshkumar RS, Muthukumaran VR, Visvanathan P (2012) Identification and evaluation of air-pollution-tolerant plants around lignitebased thermal power station for greenbelt development. Environ Sci Pollut Res 19:1210–1223

Gostin IN (2009) Air pollution effects on the leaf structure of some Fabaceae species. Not Bot Hort Agrobot Cluj 37:57–63

Gilbert OL (1968) Bryophytes as indicators of air pollution in the Tyne Valley. New Phytol 67:15

Giridhar BA (1984) Study of interactions between industrial air pollutants and plants. PhD thesis, Univ. Bombay

Grodzinska K (1978) Mosses as bioindicators of heavy metal pollution in Polish National Parks. Water Air Soil Pollut 9(1):83–97

Gupta RB et al (2008) Overview on attenuation of industrial air pollution by Green belt development. J Ind Pollut Control 24(1):1–8

Hallale BV, More PG (2013) Biomonitoring of air pollution around urban and industrial sites of Washim city (Maharashtra). Asian J Contemp Sci 2(1):13–15

Hareesh B et al (2018) Assessment of different dust pollutants effect on total chlorophyll content, transpiration rate and yield of blackgram (*Phaseolus mungo* L.). Int J Curr Microbiol App Sci 7(04):2890–2896. https://doi.org/10.20546/ijcmas.2018.704.329

Hawksworth DL (2001) The magnitude of fungal diversity: the 1.5 million species estimate revisited. Mycol Res 105:1422–1432

Heggestad HE (1991) Origin of Bel-W3, Bel-C and Bel-B tobacco varieties and their use as indicators of O_3. Environ Pollut 74:264–291

Hill AC (1971) Vegetation: a sink for atmospheric pollutants. J Air Pollut Cont Assoc 21:341–346

Horaginamani SM et al (2012) Air pollution tolerance of selected plant species considered for urban green belt development in Trichy. World J Environ Biosci 1(1):51–54

Hosker RP, Lindberg SE (1982) Review: atmospheric deposition and plant assimilation of gases and particles. Atmos Environ 16(5):889–910

Joshi NC (1990) Experiments in phytomonitoring of urban atmosphere. Dissertation, University of Mumbai

Joshi N (2014) Studies on monitoring suspended particulate matter using urban plants and understanding their green belt potentials. Final report to the University Grants Commission. Ref: No. F. No. 40-320/2011 (SR) Date: 1 Jul 2011

Joshi N, Bora M (2011) Impact of air quality on physiological attributes of certain plants. Report and Opinion, 3(2):42–47

Joshi PC, Chauhan A (2008) Performance of locally grown rice plants (Oryza sativa L.) exposed to air pollutants in a rapidly growing industrial area of district Haridwar, Uttarakhand, India. Life Sci J 5(3):41–45
Joshi N, Joshi A (2013) Dust monitoring potentials of ruderal vegetation of Mumbai. J Ind Pollut Contr 29(2):269–274
Joshi PC, Swami A (2009) Air pollution induced changes in the photosynthetic pigments of selected plant species. J Environ Biol 30(2):295–298
Joshi N et al (2016a) Determining Air Quality Index of an industrial area using plants. J Ecol Photon 111:446–456
Joshi N et al (2016b) Air pollution tolerance index of some trees species from the industrial area of Tarapur. Int J Life Sci Scienti Res 2(2):173–182
Kadiyali RL (1996) Traffic engineering and transport planning, vol 5. Khanna Publication, Delhi, p 499
Keller T (1974) The use of peroxidase activity for monitoring and mapping air pollution areas. Eur J For Pathol 4:11–19
Keller T (1982) Physiological bioindicators of an effect of air pollution on plants. In: Steubing L, Jager J (eds) Monitoring of air pollutants by plants. Methods and problems. Dr. Junk Publishers, The Hague
Keller T, Schwager H (1977) Air pollution and ascorbic acid. Eur J For Pathol 7:338–350
Kerpen J, Faensen-Thiebes A (1985) Bioindicator tobacco Bel–W3. With simultaneous exposure to ozone and climate chamber measurements. Dust Air Pollut Prev 45(3):127–130
Klumpp A et al (1996) Bio-indication of air pollution in the tropics – the active monitoring programme near Cubatao. Brazil Gefahrstoffe – Reinhaltung Luft 56:27–31
Koppel A, Sild E (1995) Bioindication of ozone in Estonia by using tobacco variety Bel W3. Water Air Soil Pollut 85:1515–1519
Kumar KS et al (2012) Assessment of design wind speeds for metro cities of India. The Seventh International Colloquium on Bluff Body Aerodynamics and Applications (BBAA7) Shanghai, China, September 2–6
Kushwaha U (2018) Dust pollution effects on the leaves anatomy of Catharanthus roseus and Nerium Oleander growing along the road side of Rewa city (M.P.). Int J Eng Sci 7(9):01–07
Lakshmi PS, Sravanti KL, Srinivas N. (2009) Air pollution tolerance index of various plant species growing in industrial areas. J Environ Sci 2:203–206
Lee JA, Tallis JH (1973) Regional and historical aspects of lead pollution in Britain. Nature 245(5422):216–218
Lohith K et al (2018) Assessment of air pollution impact on micromorphological and biochemical properties of Pentas lanceolata Forssk. and Cassia siamea Lam. Trop Plant Res 5(2):141–151. https://doi.org/10.22271/tpr.2018.v5.i2.019
Lone PM et al (2005) Study of dust pollution caused by traffic in Aligarh city. Indian J Environ Health 47(4):33–36
Maharashtra Pollution Control Board (MPCB) (2014a) Air quality status of Maharashtra. (Compilation of air quality data recorded by MPCB 2013–2014.) http://mpcb.gov.in/ereports/pdf/Air%20Quality%20Report_MPCB_2013-14.pdf
Maharashtra Pollution Control Board (MPCB) (2014b) Air quality status of Maharashtra. (Compilation of air quality data recorded by MPCB 2012–2013.) http://mpcb.gov.in/ereports/pdf/Air%20Quality%20Report_MPCB_2012-13_TERI.pdf
Maharashtra Pollution Control Board (MPCB) (2014c) Air quality status of Maharashtra. (Compilation of air quality data recorded by MPCB 2011–2012.) http://mpcb.gov.in/ereports/pdf/AirQualityReport_MPCB_2011-12.pdf
Mancharkar AR (2001) Assessment of characters of plants to optimize green belt efficiency. Dissertation, University of Mumbai
Mancharkar AR, Chaphekar SB (2005) Morphological basis of green belt efficiency. A.W. College, Otur

Manning WJ, Feder WA (1980) Biomonitoring air pollutants with plants. Applied Science Publishers, London, p 142

McCormack MC et al (2011) Indoor particulate matter increases asthma morbidity in children with non-atopic and atopic asthma. Ann Allergy Asthma Immunol 106:308–315

Ministry of Environment and Forests (MOEF) (1985) Air pollution and plants: a state of the art report. In: Subrahmanyam GV, Rao DN, Varshney CK, Biswas DK (eds). Department of Environment, Government of India, New Delhi, p 193

Ministry of Environment and Forests (MOEF) (2005) Manual on norms and standards for environment clearance of large construction projects. Government of India, New Delhi. http://envfor.nic.in/divisions/iass/Construction_Manual.pdf

Mukherjee A (2015) Importance of urban forestry with reference to Kolkata. IOSR J Humanit Soc Sci 2(8):89–94

Mukherjee A, Agrawal M (2018) Ecotoxicol Environ Saf 152:42–54

Municipal Corporation of Greater Mumbai (MCGM) (2013) Report on Environment Status Air Quality Monitoring and Research Laboratory, Santacruz Pers. comm

Nali C et al (2001) Monitoring and biomonitoring of surface ozone in Florence, Italy. Environ Monit Assess 69(2):159–174

Nandi PK et al (1980) Effect of ozone, sulphur dioxide and their mixture on germination of Phaseolus aureus seeds. Indian J Air Pollut Contr 3(2):50–55

Nash TH, Egan RS (1988) The biodiversity of lichens and bryophytes. In: Lichen, bryophytes and air quality. Thomas Nash III & Vilkmar Wirth (eds). Bibl. Carmer in der Gebr. Borntra. Verlag. Berlin, Stuttgart. Lichenol 30: 11–22

Nimis PL et al (2000) Biomonitoring of trace elements with lichens in Veneto (NE Italy). Sci Total Environ 255(1):97–111

Nitesh, Bharati B (2019) Impacts of ambient air quality of an industrial region on a member of asteraceae and its potentials as a phytomonitor. Environ Risk Assess Rem 3(1):8–14

Nowak DJ, Heisler GM (2010) Air quality effects of urban trees and parks. www.nrpa.org

Patel AM, Kousar H (2011) Assessment of relative water content, leaf extract pH, ascorbic acid content and total chlorophyll of some plant species growing in Shimoga. Plant Archives 11(2):935–939

Pal A, Kulshreshtha K, Ahmad KJ, Behl HM (2002) Do leaf surface characters play a role in plant surface resistance to auto exhaust pollution? Flora 197:47–55

Pandey AK, Pandey M, Mishra A, Tiwary SM, Tripathi BD (2015) Air pollution tolerance index and anticipated performance index of some plant species for development of urban forest. Urban forestry and Urban greening (14):866–871

Peñuelas J et al (1999) Dependence of ozone biomonitoring on meteorological conditions of different sites in Catalonia (N.E. Spain). Environ Monit Assess 56(2):221–224

Pilegaard K (1978) Airborne metals and SO_2 monitored by epiphytic lichens in an industrial area. Environ Pollut 17:81–92

Pope CA, Dockery DW (2006) Health effects of fine particulate air pollution: lines that connect. J Air Waste Manage Assoc 56:709–742

Posthumus AC (1982) Biological indicators of air pollution. In: Unsworth MH, Ormrod DP (eds) Effects of gaseous air pollution in agriculture and horticulture. Butterworth Scientific, London, pp 27–42

Posthumus AC (1983) Higher plants as indicator and accumulator of gaseous air pollution. Environ Monit Assess 3:263–274

Prajapati SK, Tripathi BD (2008) Seasonal variation of leaf dust accumulation and pigment content in plant species exposed to urban particulates pollution. J Environ Qual 37:865–870

Quarg (1996) Airborne particulate matter in the United Kingdom. Third report of the quality of urban air review group. Department of the Environment, London

Radhapriya P, Navaneetha GA, Malini P, Ramachandran A (2012) Assessment of air pollution tolerance levels of selected plants around cement industry, Coimbatore, India. J Environ Biol 33:635–641

Rai PK, Panda LS (2015) Roadside plants as bio indicators of air pollution in an industrial region, Rourkela, India. Int J Adv Res Technol 4(1):14–36
Raina AK, Sharma A (2003) Effect of vehicular pollution on the leaf micro-morphology, anatomy and chlorophyll contents of Syzygium cumini L. Indian J Environ Prot 23:897–902
Rao DN (1979) Plants as a pollution monitoring device. Fertilizer News 24:25–28
Rao DN (1981) Phytomonitoring of air pollutants. Proc. WHO workshop biol. indicators indices of environmental pollution. Osmania University, Hyderabad, Cent. Bd. Prev. Cont. Water Poll., 1–8
Rao DN (1985) Plant and air pollutant mixture. In: Air pollution and plants: a state-of-the-art report. Department of Environment Ministry of Environment and Forests, Government of India, New Delhi, p 67
Raupach MR et al (2001) The entrapment of particles by windbreaks. Atmos Environ 35:3373–3383
Reiner C et al (1985) The use of Nicotiana tabacum L. Bel-W3. Staub – Reinhaltung der Luft 45(2):59–61
Rowntree AR (1986) Ecology of the urban forest-introduction to part II. Urban Ecol 9:229–243
Rühling A, Tyler G (1973) Heavy metal deposition in Scandinavia. Water Air Soil Pollut 2(4):445–455
Sadasivam S, Manickam A (2009) Biochemical methods. New Age International Pvt. Ltd. Publishers, New Delhi, p 284
Saitanis CJ, Karandinos MG (2001) Instrumental recording and biomonitoring of ambient ozone in the Greek countryside. Chemosphere 44(4):813–821
Samal AK, Santra SC (2002) Ind J Environ Health 44:71–76
Santelmann MV, Gorham E (1988) The influence of airborne road dust on the chemistry of Sphagnum mosses. J Ecol 76:1219–1231
Schulz H, Schulz U, Huhn G, Schüürmann G (2000) Biomonitoring of airborne inorganic and organic pollutants by means of pine tree barks. I Deposition types and impact levels. J Appl Bot 74(5–6):248–253
Shannigrahi AS et al (2004) Anticipated air pollution tolerance of some plant species considered for green belt development in and around an industrial/urban area in India: an overview. Int J Environ Stud 61(2):125–137
Sharma GK, Butler J (1973) Leaf cuticular variation in Trifolium repens L. as indicator of environmental pollution. Environ Pollut 5(4):287–293
Shetye RP, Chaphekar SB (1980) Some estimations on dust fall in the city of Bombay, using plants. Vol. 4: pp. 61–70. In: Progress in Ecology. V. P. Agarwal and V.K. Sharma (Eds.). Today and Tomorrow's Printers and publishers, New Delhi
Singh ON (1995) Local air pollution in India. Pure Appl Chem 67:1462–1465
Singh SK, Rao DN (1983) Evaluation of plants for their tolerance to air pollution. In: Proceedings symposium on air pollution control, vol 1. Indian Association for Air Pollution Control, New Delhi, pp 218–224
Smith WH (1987) Air pollution and forests. Interaction between air contaminants and forest ecoscystems. Springer-Verlag New York Inc.
Somashekar RK et al (1999) Pollut ResPollut Res 18:445–451
Steinnes E (1995) A critical evaluation of the use of naturally growing moss to monitor the deposition of atmospheric metals. Sci Total Environ 160-161:243–249
Steubbing L (1982) Problems of bioindication and the necessity of standardization. In: Steubing L, Jager J (eds) Monitoring of air pollutants by plants. Dr. Junk Publishers, The Hague, pp 19–24
Steubbing L, Fangmier A, Both R (1989) Effects of SO_2, NO_2 and O_3 on population development and morphological and physiological parameters of nature herb layer species in a beech forest. Environ Pollut 58:281–302
Sucharova J, Suchara I (1998) Atmospheric deposition levels of chosen elements in the Czech Republic determined in the framework of the International Bryomonitoring Program 1995. Sci Total Environ 223:37–52

Sukumaran D (2012) Effect of particulate pollution on various tissue systems of tropical plants. Central Pollution Control Board (CPCB), Zonal Office, Kolkata
Suvarna LP et al (2008) Air pollution tolerance index of various plant species growing in industrial areas. The Ecoscan 2(2):203–206
Swami, Abhishek (2018) Impact of automobile induced air pollution on road side vegetation: A Review. ESSENCE Int J Env Rehab Conserv IX(1):101–116
Talukdar P et al (2018) Effect of air pollution on plant growth and pollen viability. World Sci News 109(2018):131–142
Temmerman LD et al (2001) Biomonitoring with plants – considerations for the future. EuroBionet – Urban Air Pollution, Bioindication and Environmental Awareness, pp 337–373
Thambavani SD, Sabitha MA (2011) Variation in air pollution tolerance indexand anticipated performance index of plants near a sugar factory: implications for landscape-plant species selection for industrial areas. Journal of research in Biology 7:494–502
Thomas W (1983) Using plants in spatial trace substance analysis for emission monitoring. Staub–Reinhalt Luft 43(4):142–148
Thomas W (1986) Representativity of mosses as biomonitor organisms for the accumulation of environmental chemicals in plants and soils. Ecotoxicol Environ Saf 11:339–346
Tiwari S, Tiwari M (2006) Air pollution tolerance indices of few plants growing near Raigarh (India). J Environ Res Develop 1(2):129–135
Treshow M (1984) Effects of air pollutants on plants. In: Englund, S. and Calvert, S. (eds), Hand-Book on Air Pollution Control Technology, pp. 7–24. John Wiley and Sons, Chichester and New York
Tripathi A, Mahima, Tiwari PB, Singh D (2009) Assessment of air pollution tolerance index of some trees in Moradabad city, India. J Environ Biol 30(4):545–550
Tyagi A et al (2011) Climate of Jaipur, meteorological centre, Jaipur India meteorological department, Ministry of Earth Sciences, Government of India
UNDP (1998) Human development report 1998. United Nations Development Program. Oxford University Press, New York
Vergé X et al (2002) Bioindicator reliability: the example of Bel W3 tobacco (Nicotiana tabacum L.). Environ Pollut 118:337–349
Verma A, Singh SN (2006) Biochemical and ultrastructural changes in plant foliage exposed to auto-pollution. Environ Monit Assess 120(1):585–602
Wagoner KF (1975) Leaf cuticular and morphological variations in Plantago lanceolata as indicators of environmental pollution. J Tenn Acad Sci 50(3):79–83
Warren, JL (1973) Green space for air pollution control. School of Forest Resources, Tech. Rep. No. 50, North Carolina State Univ., Raleigh, NC:118
Weatherly PE (1950) Studies in the water relations of the cotton plant. The field measurement of water deficits in leaves. New Phytol 49:81–87
Wei X et al (2017) Phytoremediation of air pollutants: exploiting the potential of plant leaves and leaf-associated microbes. Front Plant Sci 8:1318
William HS (1990) Interaction between air contaminants and forest ecology. In: Air pollution and forest, 2nd edn. Springer, New York. Resour. Tech. Rep.50. Raleigh NC from Novak (1988)
World health organization (WHO) (2005) Air quality guidelines, global update. WHO Regional Publications, Germany, 484
Younis U et al (2013) Variations in leaf dust accumulation, foliage and pigment attributes in fruiting plant species exposed to particulate pollution from Multan. Int J Agri Sci Res 3(3):1–12
Yunus M et al (1985) Dust falling on some common plants near Lucknow city. Env Pollut (Series B) 9:71–80