



Evaluation of plant species for air pollution tolerance and phytoremediation potential in proximity to a coal thermal power station: implications for smart green cities

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Abstract In metropolitan areas, air pollution poses a significant threat, and it is crucial to carefully select plant species that can tolerate such conditions. This requires a scientific approach based on systematic evaluation before recommending them to executive bodies. This study aimed to determine the air pollution tolerance index (APTI), dust retention capacity, and phytoremediation ability of 10 plant species growing in and around a lignite-based coal thermal power station. The results showed that *Ficus benghalensis* L. had the highest APTI, followed by *Mimusops elengi* L., *Ficus religiosa* L., *Azadirachta indica*

A. Juss., and *Annona reticulata* L. *F. benghalensis* also showed the highest pH of leaf extract, relative water content, total chlorophyll, and ascorbic acid content, as well as the highest dust capturing capacity. Among the ten plant species, *F. benghalensis*, *M. elengi*, *F. religiosa*, *A. indica* and *F. racemosa* were identified as a tolerant group that can be used for particulate matter suppression and heavy metal stabilization in and around thermal power plants. These findings can inform the selection of plants for effective green infrastructure in smart green cities, promoting the health and well-being of urban populations. This research is relevant to urban planners, policymakers, and environmentalists interested in sustainable urban development and air pollution mitigation.

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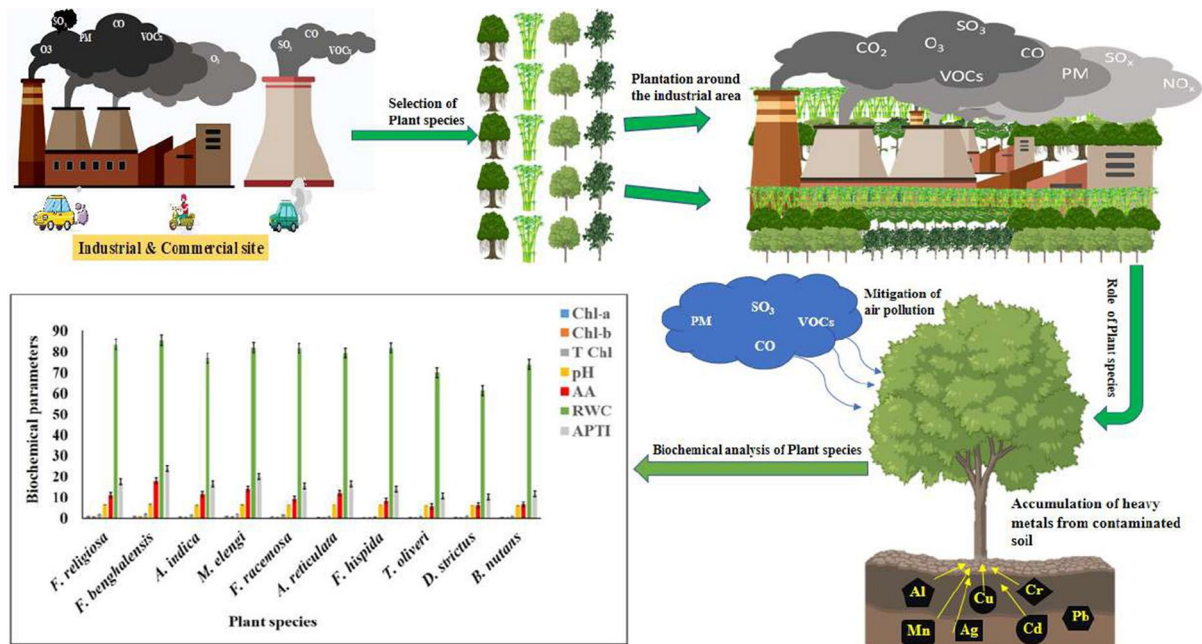
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Graphical Abstract



Keywords APTI · Dust suppression · Heavy metals · Green belt · Fly ash · Sustainability

Abbreviations

FA	Fly ash
EC	Electrical conductivity
PM _x	Particulate matter along with its size in microns
CEC	Cation exchange rate
BCF	Bioconcentration factor
MAI	Metal accumulation index
TF	Translocation factor
AA	Ascorbic acid
RWC	Relative water content
Chl	Chlorophyll
TC	Total chlorophyll
APTI	Air pollution tolerance index
DCC	Dust capturing capacity

Introduction

In several countries around the world, including India, the level of atmospheric pollution is rising at an alarming rate, posing a lurking risk to the

life forms of the earth. India, a growing nation, has experienced fast urbanization and industrialization, which has resulted in a serious deterioration of urban air quality. In general, industry, power generation, automobiles that run on fossil fuels, and other livestock farming methods, such as burning crop residues, are sources of pollutants that cause air pollution. The primary air pollutants are gases like carbon dioxide (CO₂), ammonia (NH₃), sulfur dioxide (SO₂), ozone (O₃), carbon monoxide, VOCs, as well as heavy metals like Fe, Cr, Mn, Ni, Cd, Pb, etc. (Haakman et al., 2020; Qian et al., 2023; Song et al., 2023). Tiny suspended contaminants like PM₁₀ and PM_{2.5} are also among the significant air pollutants. In India, over the past three years, all of the major cities have annual average PM₁₀ (particulate matter) concentrations that have exceeded the NAAQS (National Ambient Air Quality Standards) of 60 g/m³, with average concentrations ranging from 214 to 266 g/m³. Similar to PM_{2.5}, the annual average PM_{2.5} concentrations at all major cities have exceeded the NAAQS of 40 g/m³, with an average concentration ranging from 85 to 97 g/m³. The majority of Indian cities have suspended particle matter levels of 150 g/m³, exceeding WHO

limits of 50 g/m^3 (Central pollution control board report, 2023). Two pollutants, namely PM_x and ozone, are responsible for the highest rate of death in India (Health Effects Institute, 2019). Compared to other particles, fine particles are more poisonous and have the capacity to enter the lungs deeply, both of which represent a major health risk. According to studies, exposure to PM levels that are beyond the recommended levels can cause several health issues in people, most notably cardiac issues, lung illness, rhinitis, respiratory issues, and pulmonary diseases (Chen et al., 2023; Kamanzi et al., 2023; Kim et al., 2018; Li et al., 2023; Mestanza-Ramón et al., 2023; Xu et al., 2023). Anthropogenic activities have resulted in significant environmental problems with water, land, and air that have disrupted the usual habitat for both developed and developing countries (Arihilam et al., 2019; Chakraborty et al., 2023; Gopinathan et al., 2022a, 2022b, 2022c; Islam et al., 2023; Pillai et al., 2023; Santosh et al., 2023). Several studies have specifically investigated the capacity of roadside plants of different kinds to accumulate PM and improve air quality (Lokowski et al., 2020).

Studies on the structure, metabolism, and molecular characterization of trees are essential resources to think of an alternative and environmentally friendly technology for ecosystem restoration (Kumar et al., 2022). In addition to their important role in mitigating air pollution, plants can also influence city microclimates through the physical characteristics of their natural vegetation and planting methods (Hami et al., 2019). To sustain the aesthetic and environmental value of a metropolitan area and enhance the microclimate of urban expansion, it is important to describe some specific green regions for plant species that tolerate air pollution as a sustainable green-filtration unit. In recent years, it has been widely accepted that using the right vegetation significantly improves air quality by removing suspended particulate matter (SPM) (Zhang et al., 2022). Urban trees and forests can minimize particulate matter (PM) emissions by covering the soil surface, reducing PM concentration and re-suspension by directly absorbing particles through their large leaf area, and promoting particulate deposition by improving micrometeorological conditions (Zhang et al., 2019). PM deposition on leaves is controlled by five mechanical processes: Brownian diffusion, inertial impaction, sedimentation

under gravity, interception, and turbulent impaction (Amicarelli et al., 2021). Various plant species have been used in extensive biomonitoring investigations over history (Kumar et al., 2021; Kumar et al., 2021; Yayla et al., 2022). One of the most effective and environmentally beneficial ways to reduce and monitor air pollution in metropolitan areas is to use plants as biomonitors. Individual plant species vary in their level of sensitivity and resistance to pollution, ranging from sensitive species that serve as bioindicator species, to tolerant ones that are used to support greenbelt development. Modern versions of green infrastructure, such as breathing walls, and green walls are contributing to the development of the urban landscape and include such mitigation techniques.

The ability of plants to mitigate the negative impacts of air pollution is expressed by the Air Pollution Tolerance Index (APTI) (Molnar et al., 2020). As a result, the APTI values of regional plant species can be used to determine the level of air pollution. The APTI model was first presented by Singh and Rao (1983), and more recently, it has been used by researchers and planners working in the landscape industry all around the world. Most studies on APTI use come from Asian nations where urban vegetation is employed to reduce air pollution from vehicles and industrial pollutants. The most effective plant species for this purpose have high APTI values, whereas sensitive plants with low APTI values are typically used as bioindicators. The components of ascorbic acid content, total chlorophyll content, relative water content, and pH of leaf extract are included in the calculation of APTI because they are frequently impacted by air pollution and are simple to quantify. As urbanization and industrial activity can result in severe air pollution, it was discovered that APTI and each of its parameters varied among land-use types (Baranyai et al., 2015). Anthropogenic contamination at urban and industrial locations typically results in an overall increase in plant tolerance. Additionally, it is unknown whether the APTI connects with environmental factors such as emission sources.

Researchers have conducted numerous studies on plant APTI for air pollution reduction; as a result, it is necessary to determine the tolerance level for the construction of a sustainable green eco-management system. To investigate and determine the amount of tolerance for sustainable eco-management, this research paper evaluates the APTI of recurring indigenous

plants throughout the Koradi thermal power plant. The goal of the study was to identify the most widespread plants that display high levels of APTI values for reducing air pollution during any season, under any environmental conditions, including weather and climatic variations. Sustainable eco-management could promote the cultivation of more native plants that can improve air quality by removing pollutants. The major goal of the current study was to determine how well dust deposition affected widely found trees around the thermal power station. Additionally, several biochemical characteristics were calculated and utilized to evaluate the APTI to classify the selected plant species according to their level of tolerance. This study will be useful in determining the best species combinations for the development of green-belt and urban vegetation as well as their use in the cleanup of pollutants.

Methodology

Study site

The most recent study about air pollution tolerance index (APTI) was carried out in Koradi, an urban sprawl in Nagpur, Maharashtra, which is situated at the confluence of the Kolar and Khanan Rivers (21.2479°N, 79.1203°E). Koradi is a village in the Nagpur District in the Indian state of Maharashtra (Fig. 1). It is located in Kamptee Taluka under Nagpur Division. Koradi is the major cosmopolitan village in Nagpur, with a total area of 250.18 hectares, an irrigated area of 297.11 hectares, and a population of 8400–8600. (Census, 2022). The climatic condition in Koradi is tropical savanna. Each month is hot and there is both a moist and a dry season. Koradi experiences a mean annual temperature of 34 °C and receives about 403 mm of precipitation. With an overall humidity of 63%, there are 220 dry days per year (Kumar et al., 2021a, 2021b). A highly travelled area in the western portion of Nagpur's Koradi power station was chosen for the current investigation. The Maharashtra pollution control board's report on air pollution load is used to determine the study area. Around Koradi, there are numerous sources of pollution, including the lignite-based Koradi thermal power plant, a railroad station, and heavily traveled roads.

Soil and plant sampling

Ten different species, including *Ficus religiosa* L., *Ficus benghalensis* L., *Azadirachta indica* A. Juss., *Mimusops elengi* L., *Ficus racemosa* L., *Annona reticulata* L., *Ficus hispida* L. f, *Thyrsostachys oliveri* Gamble, *Dendrocalamus strictus* (Roxb.) Nees and *Bambusa nutans* Wall. ex Munro, were selected from the plantation in and around the thermal power station. Using pressmud (30 kg pit⁻¹) and farmyard manure (10 kg pit⁻¹) to prepare the 1 m×1 m pits, which were spaced 4 m×5 m apart, the seedlings were planted. There was daily removing weeds, irrigation, and replacing dead seedlings with new ones. Three samples of each species were collected for testing both before and after one year of plantation. After removing the litter from the soil's surface, the soil samples were gathered from the study sites at a height of 0 to 15 cm in triplicate of each sample (Roy et al., 2020). For observing the morphological effects of pollution on the leaves, the orientation of moving air, the abundance of plants, and the economic and environmental importance of the particular plant species were taken into consideration when identifying plants. For the assessment of bio-concentration and translocation factor, fresh roots and shoot samples of specified plant species were collected in the morning and preserved. Additionally, three replicates of mature young leaves from a few different plant species were also collected. Collected leaves were placed immediately in a cold storage box after being wrapped in polythene bags for the examination of several biochemical parameters, including the ascorbic acid, pH of the leaf extract, relative water content, and total chlorophyll.

Physicochemical analysis of soil from a fly ash dumpsite

According to chemical analysis, representative samples of the initial soil were taken, air-dried, and crushed to a one-millimeter thickness. A 10-g sample of soil was dried overnight at 105 °C in order to determine the gravimetric soil moisture content (Reynolds, 1970). A percentage (%) was used to show the moisture content. Estimations of water holding capacity (%), porosity (%), and bulk density (g/cm³) were done using the Keen–Raczkowski box method (Viji & Prasanna, 2012).

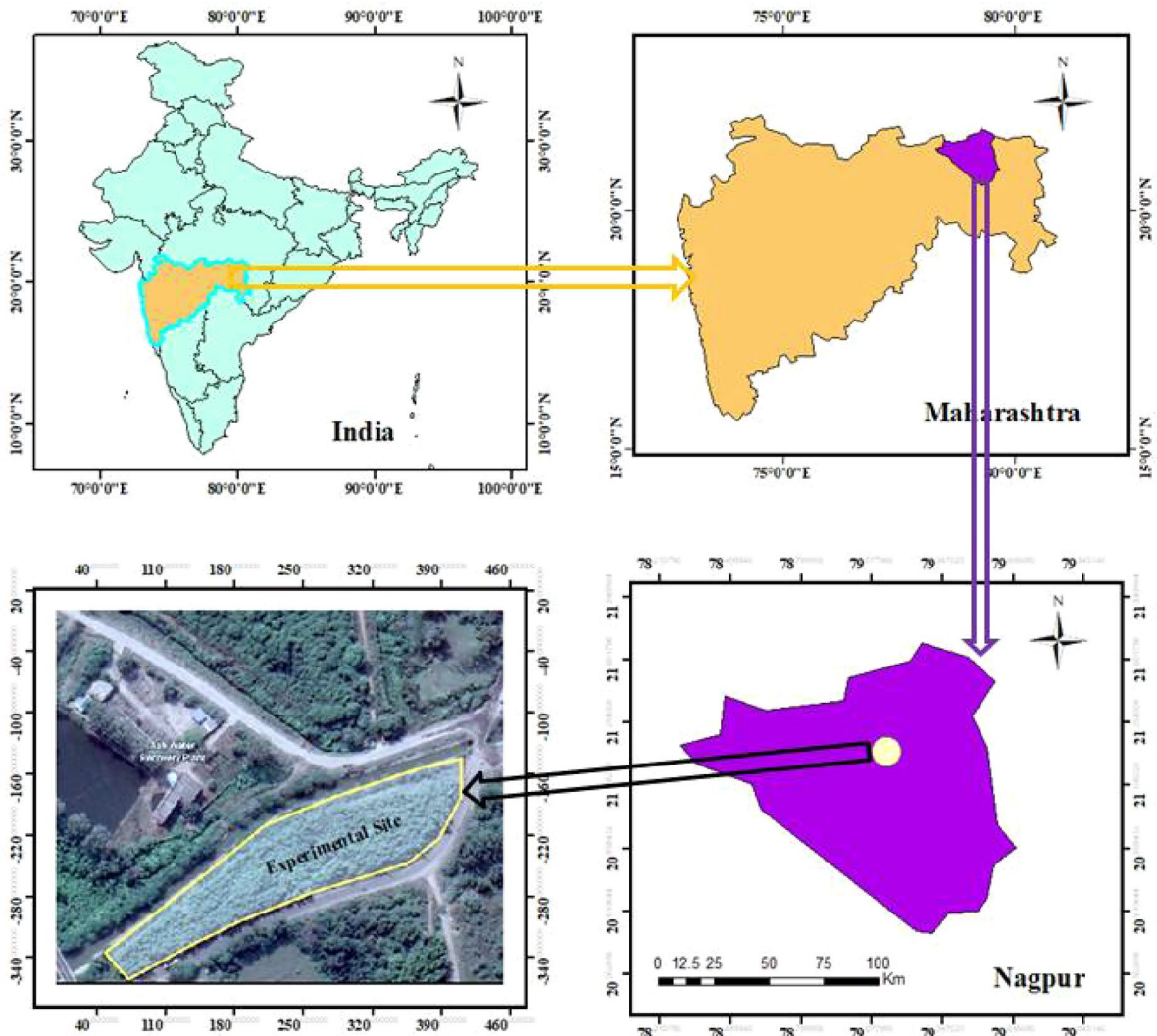


Fig. 1 Map of the study site in Koradi thermal power plant, Nagpur, Maharashtra, India

A glass electrode pH meter and electrical conductivity meter (pH HI1131, EC HI76310, HANNA Instruments and Woonsocket, RI, USA) were used to measure the pH (soil: deionized water=1:2.5 w/v) and electrical conductivity (soil: deionized water=1:5 w/v) of the sample. Walkley and Black’s study (1934), was used to calculate the % of organic carbon, i.e., OC and organic matter obtained by multiplying the volume of organic carbon by 1.72.

The Kjeldahl formula was followed to calculate total N (Nitrogen) (Kjeldahl, 1883). Available

nitrogen was calculated by using a standardized procedure given by Subbaiah and Asija’s (1956). Using the method described by Williams et al., (1967), the total P (phosphorous) content was calculated. Using the Olsen technique, the amount of available phosphorus (P) was estimated (Olsen, 1954). Following the methodology used by Sawarkar et al., (2022), the soil sample was evaluated for total potassium and available potassium, Ca^{+} , Mg^{+} , K^{+} , and Na^{+} (exchangeable cations), and cation exchange capacity.

$$\text{TOC}(\%) = \frac{10 * B - T/20 - 20 * 0.5(N) * 0.0038 * 100}{\text{Wt. of sample}}$$

where

B = Blank.

T = Titrant sample.

N = Normality FAS solution.

$Wt.$ = Weight of sample in gm

$$\text{OM}(\%) = \text{OC} * 1.72$$

$$\text{TN} \left(\frac{\text{mg}}{\text{kg}} \right) = \frac{(R - B) * 0.02(N) * 14 * 1000}{\text{wt. of sample}}$$

where

R = Reading of sample.

B = Blank.

N = Normality of H_2SO_4 solution.

T = Titrant sample.

$Wt.$ = Weight of sample in gm

$$\text{TP}(\%) = \left(\frac{\text{Con.}}{1000000} \right) * \left(\frac{50}{\text{wt. of sample}} \right) * \left(\frac{50}{10} \right) * 100$$

$$\text{TP} \left(\frac{\text{mg}}{\text{kg}} \right) = \frac{\text{TP}(\%)}{10000}$$

$$\text{TK} \left(\frac{\text{mg}}{\text{kg}} \right) = \frac{R * 100}{\text{wt. of sample}}$$

where

R = Reading of sample.

$Wt.$ = Weight of sample in gm

$$\text{CEC} \left(\frac{\text{meq}}{100\text{gm}} \right) = R * 0.02(N) * \left(\frac{250}{20} \right) * \left(\frac{100}{\text{wt. of sample}} \right)$$

where

R = Reading of sample.

N = Normality of H_2SO_4 solution.

$Wt.$ = Weight of sample in gm.

Evaluation of heavy metal concentration of soil from a fly ash dumpsite

For metal estimation (Al, Cu, Ni, Cr, Mn, Co, Zn, Cd, Pb, Fe, Ba, B, Li, Ag), 0.5 g of air-dried ground soil was crushed and combined with 30 mL of the digestive mixture in a ratio of 9:4 (HNO_3 : HClO_4) at 100 °C for 4 h (Tripathi et al., 2012). An inductively coupled

plasma emission mass spectrophotometer was used to measure the concentration of these metals (ICP-OES 7000, iCap 7300 DUO, Thermo Fisher, England). All trials were performed in triplicate, and the predicted average was used to get accurate results. For the metal analysis of fly ash and plant samples (Root, Shoot, Leaf), internal and blank standards were utilized for quality control.

Determination of bioconcentration and translocation factor

Plant tissues were examined for the bioconcentration factor (BCF) and the translocation factor (TF). The phytoremediation parameters were determined by using the following formulas that were given by various researchers (Amin et al., 2019; Mohanty & Kumar Patra, 2020; Sawarkar et al., 2022).

Metal accumulation index

The overall effectiveness of heavy metal accumulation in plants was evaluated using the metal accumulation index (MAI).

$$\text{MAI} = \left(\frac{1}{N} \right) \sum_{j=1}^N I_j$$

$$I_j = \frac{x}{\sum x}$$

The value of N represents the total number of metals that have been analyzed. Meanwhile, the sub-index for variable j is denoted as I_j . It is possible to provide additional definition for I_j by introducing the variables x , which denotes the average concentration of an element, and $\sum x$, which represents its standard deviation.

Biochemical parameter

Ascorbic acid (AA)

Using a simplified colorimetric 2, 6-dichlorophenol indophenol approach, the amount of ascorbic acid (mg/g) was calculated (Keller & Schwager, 1977). A titrating medium consisting of oxalic acid (4%) was utilized. Ten milliliters of 4 percentage oxalic acid

was prepared from a 1-g sample that was isolated. It followed a five-minute centrifugation at 5000 rpm. A pipette was used to add 10 ml of oxalic acid, then remove 5 ml of the residue, and then measure the amount of dye. The titration process is repeated till a pink hue appears.

$$AA \left(\frac{\text{mg}}{100\text{g}} \right) = \frac{0.5(\text{mg}) * V2(\text{ml}) * 20(\text{ml})}{V1(\text{ml}) * 5(\text{ml}) * \text{weight of sample}(\text{g})}$$

where AA = Ascorbic acid

V1 = Reference standard was titrated against the amount of dye.

V2 = Sample titrated in relation to amount of dye.

Relative water content (RWC)

RWC is a significant aspect in evaluating the air pollution tolerance index. By weighing the freshly harvested leaves, new values were obtained. The relevant weights were dried at 105 °C for three hours in a heated air oven to bring out their dry weights, which were determined by submerging them in demineralized water for the overnight (Timilsina et al., 2021).

$$RWC(\%) = \frac{(\text{Fresh weight} - \text{Dry weight})\text{g}}{(\text{Turgid weight} - \text{Dry weight})\text{g}} * 100$$

where RWC = Relative water content

pH of leaf extract

The previously mentioned technique was used to measure the pH of the leaf extracts (Tak & Kakde, 2017). In a gist, 10 ml of demineralized water was used to homogenize 1 gm of leaf samples before centrifuging. In a label tube, the supernatant was taken. A buffer solution with pH values of 4, 7, and 9 is used to calibrate the pH meter. The acidity of the solution was measured with the help of a pH meter (pH HI1131, HANNA Instruments, Woonsocket, RI, USA).

Total chlorophyll content

A leaf sample weighing 1 gm was mixed with 10 ml of 80% acetone. Ten milliliters of 80% dimethyl ketone was appended to the mixture after it had been filtered using filter paper, resulting in a total volume of 20 ml. After being placed into a clean centrifuge tube, the leaf

extract was swirled at 2500 rpm for 5 min. In order to calculate the sample’s volume and get absorbance readings at 645, 663, and 750 nm, a separate tube was used to transfer the solution. The total amount of chlorophyll was determined by applying the formula shown below (Arnon, 1949).

$$\text{Chl} - a \left(\frac{\text{mg}}{\text{g}} \right) = \frac{12.7 * A663 - 2.69 * A645 * V}{1000 * W}$$

$$\text{Chl} - b \left(\frac{\text{mg}}{\text{g}} \right) = \frac{22.9 * A645 - 4.68 * A663 * V}{1000 * W}$$

T-chlorophyll (mg/g) = Chlorophyll-a + Chlorophyll-b, where W stands for the sample’s weight in grams.

Air pollution tolerance index

Biochemical parameters, particularly the pH of leaf extract, TC, AA & RWC, were then put to the method given by Singh, (1991) for determining the air pollution tolerance index.

$$APTI = \frac{[A * (T + P) + R]}{10}$$

where T = total chlorophyll (mg/g)

A = content of leaf in ascorbic acid (mg/g).

P stands pH of leaf extract.

R is a relative water content (%).

Calculation of dust capturing capacity

The filter paper was dried in a hot air oven and weighed to obtain its initial weight (W1) for calculating its dust accumulating capacity (DAC). The dust that was adhered to the leaf sample was cleaned with a brush and double-distilled water. The dust-containing water was filtered through the pre-weighed filter paper, dried (at 75 °C for 3 h) and weighed subsequently. W2 is the filter paper’s wet mass after the particle has been removed. To calculate each leaf’s area, the leaves were mapped onto the graph paper. The algorithm below was used to calculate dust collection efficiency (Manisha & Pal, 2014):

$$DCC \left(\frac{\text{mg}}{\text{cm}^2} \right) = \frac{W1 - W2}{\text{leaf area}}$$

where DCC = Dust capturing capacity

W1 = leaf weight with dust.

W2 = leaf weight after rinsing.

Statistical analysis

Data are shown as the average over three independent replicates, with standard deviation and p (0.05) values obtained using the Tukey's test. To determine the correlation between APTI and biochemical variables, linear regression analysis was used. Principal component analysis was then carried out using Origin 2021b. All data are shown as mean \pm standard deviation (mean \pm S.D.).

Results and discussion

This investigation aimed to evaluate APTI, dust suppression capacity, and phytoremediation potential of plants planted around a lignite-based thermal power plant. The selected 10 plant species belonging to 7 genera under 5 families were planted around the thermal power station. Out of the total, 7 species belong to dicotyledons and 3 species belong to monocotyledons (Table 1). In this study, the author aimed to evaluate the air pollution tolerance index, dust retention capacity, and phytoremediation ability of plant species growing in and around thermal power station. The selection of three woody grasses among the all plant species was based on their potential ecological importance and their ability to adapt to the environmental conditions around the thermal power station. Woody grasses have unique characteristics and growth patterns that could provide valuable information on their ability to cope with air pollution and other atmospheric stress conditions. Plants are essential in the defense against air pollution. Dust, aerosols, and other airborne contaminants are passively or actively "captured" by the plant's leaves. Leaves are most sensitive to air pollution as compared to other plant's parts (Molnár et al., 2020; Rai & Panda, 2014). Leaves of the plant have been investigated in several studies to determine the temporal and regional distribution of pollutants (Barroso et al., 2019; Cai et al., 2017). However, the dust's distribution on the foliage of various tree species is affected by weather, wind direction, and plant leaves structure in addition to the sources of environmental contaminants (Chaudhary & Rathore, 2019).

Realizing the diversity of trees in urban areas has led to the development of environmentally friendly tools for monitoring and reducing air pollution. Whether urban sprawl is environmentally sustainable relies on how well-resilient the metropolis is to pollution. This study revealed the effectiveness of various plants in removing dust significantly.

Physicochemical properties of soil from a Fly Ash (FA) dumpsite

The physicochemical characteristics of the fly ash dumping site before and after one year of plantation are shown in Table 2. The FA dumpsite's moisture level improved from 1.04 to 10.95%. Before the plantation, the bulk density of the fly ash dumpsite was estimated to be 1.36 gm/cm³ before plantation, and after one year of the plantation, it had fallen to 1.31 gm/cm³. The total porosity, as well as water holding capacity (WHC), increased, ranging from 37.30 and 17.76% to 54.05 and 25.76%, respectively. The addition of FYM+pressmud led to the gluing of soil particles with more stable soil aggregates, a reduction in the number of micropores, and an increase in the volume of macropores in the soil through the activation of microbial growth, which is responsible for the improvements in porosity, WHC, and bulk density (Sawarkar et al., 2022). The pH of the fly ash dumpsite was 7.30 initially, but it increased to 8.09 after the one-year plantation, indicating that it was slightly alkaline because applied amendment Pressmud+FYM increases the availability of the cations like Ca²⁺, Mg²⁺, Na⁺, and K⁺ (Shakeel et al., 2019). Correspondingly the electrical conductivity enhanced as well, ranging from 104.25 to 183.36 S/cm. Before the plantation, the dumping site had organic matter and carbon contents of 0.68 and 0.39%, respectively. After the plantation, there was an increase in the concentration of organic matter (1.18%) and organic carbon (OC) (0.69%). After one year of the plantation, there was a noticeable change in the organic matter and nutrient composition of the FA dumpsite. This is consistent with the FYM and pressmud's abundance of organic materials and vital plant nutrients (Danek et al., 2021). Additionally, after one year of planting, an increase in organic matter at the FA dumpsite may have been a result of the deposition and decomposition of litter caused by the plantation. The total N, P, and K were 429.25, 503.16,

Table 1 List of the plant species planted in and around the Koradi thermal power plant

Sr. No	Botanical name	Family	Common name	Habit	Leaf morphology
1	<i>Ficus religiosa</i> L	Moraceae	Peepal	Tree	Leaves alternate, broadly ovate, 8.16 × 6–13 cm, caudate-acuminate at apex, with 2–9 cm long acumen, truncate at base, undulate, coriaceous, shining, glabrous; petioles 4–8 cm long
2	<i>Ficus benghalensis</i> L	Moraceae	Bargad	Tree	Leaves alternate, elliptic to ovate, 10–20 × 6–12 cm, obtuse at apex, rounded at base, entire, coriaceous, glabrous above, puberulous beneath, with abundant cystolith
3	<i>Azadirachta indica</i> A. Juss	Meliaceae	Neem	Tree	Leaves pinnate; leaflets serrate, oblique, up to 30 cm long; leaflets 5–13, obliquely lanceolate, 3–7 × 1–3 cm, acuminate at apex, cuneate at base, dentate at margins
4	<i>Mimusops elengi</i> L	Sapotaceae	Molshree	Tree	Leaves coriaceous; primary nerves numerous, spreading. Leaves elliptic ovate or lanceolate, 4–12 × 3.5–5.5 cm, acute to shortly acuminate at apex, acute at base, subcoriaceous, exstipulate; petioles up to 4 cm long
5	<i>Ficus racemosa</i> L	Moraceae	Umar	Tree	Leaves alternate, ovate oblong, 6–15 × 3–6 cm, obtuse or acute at apex, rounded or acute at base, entire, subcoriaceous, smooth, glabrous, stipulate. Receptacles in clusters on main branches of trunk or on leafless branches, pedunculate, subglobose or pyriform, 2–3 cm across, green to red
6	<i>Annona reticulata</i> L	Annonaceae	Ramphal	Small deciduous tree	Leaves pellucid dotted. Leaves 10–20 cm, acuminate, glabrous
7	<i>Ficus hispida</i> L. f	Moraceae	-	Small size Tree	Leaves opposite, decussate, ovate or oblong-elliptic, 8–23 × 4–10 cm, abruptly acute at apex, rounded or truncate at base, entire or minutely dentate, coriaceous, scabrid, hispid beneath; petioles 2–4 cm long
8	<i>Thyrsostachys oliveri</i> Gamble	Poaceae	Baans	Woody grass	Culm leaves are slow to fall off and may persist on the plant for a long time. They have short, membranous ligules, and lack auricles. The margins of culm leaves are ciliate, and the blades are typically erect, linear or triangular in shape. Foliage leaves, on the other hand, have short pseudo-petioles. However, foliage leaves differ from culm leaves in that their blades are lanceolate
9	<i>Dendrocalamus strictus</i> (Roxb.) Nees	Poaceae	Katang Baans	Woody grass	The leaves of this plant are lanceolate in shape, with a linear appearance. In arid regions, they tend to be small, whereas in moist areas, they can grow up to 25 cm in length and 3 cm in width. The leaves are attached to the stem by a short petiole that rounds off at the base. At the top, the leaves sharply taper to a twisted point
10	<i>Bambusa nutans</i> Wall. ex Munro	Poaceae	Baans	Woody grass	The length of the leaves ranges from 10 to 2 cm, while their width varies from 0.5 to 1.5 mm. These leaves are attached to a petiole that measures two to three millimeters in length

and 671.67 mg/kg, respectively, before the plantation, and there were drastic changes (1026.67, 853.77, and 1291.67 mg/kg) just after one year of the plantation. In terms of available nitrogen, phosphorous, and potassium before the plantation and after one year of the plantation, there is a considerable variation in the total nutrients in the FA-degraded land. The rise in nitrogen content is the result of the amendment, which is a significant source of N input that helps in biological nitrogen fixation (Reimer et al., 2020). Thus, biologically fixed nitrogen can help a plant grow and fulfill its nutritional needs, enhancing the plant's fertility over time and in a sustainable way. Applied amendment Pressmud + FYM, which aids in phosphate immobilization and solubilization, leads to an increase in the phosphate content (Lwin et al., 2018). The fact that the available nitrogen (N), phosphorous (P), and potassium (K) concentrations were so poor before plantation (31.74, 10.51, and 32.2 mg/kg). However, one year after the plantation, there was a significant change in the concentration of nutrients (93.33, 14.11, and 73.83 mg/kg).

Heavy metals concentration of soil from a FA-dump site

Table 3 shows the metal concentration in FA samples and compares it to levels both before as well as one year after planting. Several heavy metals were detected in substantially higher concentrations at the FA-dump site than they had been before the plantation. A comparison of the amounts of all heavy metals before and after the plantation revealed a considerable reduction in their concentrations. The concentration of Ag decreased by three times the initial level among the heavy metals. The Cd was not available at the fly ash dumpsite. The concentration of Al (1053.93 mg/kg) was observed maximum before plantation, which reduced the concentration of metal (mg/kg) as follows: Fe (862.45) > Cr (780.53) > Mn (432.48) > Ba (120.28) > Zn (93.88) > Cu (61.93) > Ni (47.00) > B (37.45) > Pb (17.35) > Co (13.08) > Li (9.00) > Ag (7.58). These heavy metals contaminated the surrounding area's surface and groundwater, negatively affecting its quality and causing serious environmental concerns. A decrease in the concentration of heavy metals was seen after one year of the plantation. Successful plantation growth reduced the level of certain heavy metals at the fly ash dumpsite.

Heavy metal levels were reduced after one year of the plantation; it is possible that the plants in the area were able to absorb and detoxify some of the heavy metals from the soil. However, it is important to note that the effectiveness of phytoremediation depends on several factors, such as the type of plants used, the concentration and type of pollutants present, and the soil characteristics. The concentration (mg/kg) of Al reduced from 1053.93 to 854.65 followed by Fe 862.45–431.75, Cr 780.53–440.13, Mn 432.48–274.28, Ba 120.28–95.90, Zn 93.88–60.10, Cu 61.93–23.43, Ni 47.00–25.33, B 37.45–21.00, Pb 17.35–7.25, Co 13.08–8.95, Li 9.00–4.60, and Ag reduced from 7.58 to 1.80.

Bioconcentration (BCF) and translocation factor (TF)

BCF and TF are two important parameters used to evaluate the potential of plants to accumulate and transport contaminants from the soil to the above-ground plant parts. Bioconcentration factor (BCF) is the ratio of the concentration of an element in the plant tissue to its concentration in the soil. It is used to evaluate the potential of a plant to absorb and accumulate a contaminant from the soil. A BCF value greater than 1 indicates that the plant has the ability to accumulate the contaminant. In the present investigation, the BCF value towards Ni was > 1 in all species, which indicates that this metal can be accumulated by all plant species. The highest BCF value was observed in *M. elengi* (4.87) for Ni, followed by *F. benghalensis* (4.53) for Al, *F. hispida* (4.16) for Ni, *A. reticulata* (4.05) for Ni, *A. indica* (3.26) for Cu and other species which indicate that mobility of metals from fly ash to plants parts. The value of BCF in the case of Pb, Co, B, and Ba was less than one in all plant species. Translocation factor (TF) is the ratio of the concentration of a chemical in the above-ground plant parts (e.g., leaves, stems) to its concentration in the roots. It is used to evaluate the potential of a plant to transport a contaminant from the roots to the above-ground plant parts. A TF value greater than 1 indicates that the plant can efficiently translocate the contaminant to the above-ground plant parts. This study also observed that the TF value was highest in *A. indica* (3.61) toward Ni, followed by *B. nutans* (3.32) towards B, *F. religiosa* (3.28) towards Cu, *D. strictus* (2.98) towards Al, *A. reticulata* (2.70) towards Zn and other species (Table 4).

Table 2 Physicochemical characterization of fly ash dump site around Koradi thermal power plant

Parameter	Before plantation	After 1-year plantation
Physical parameters		
Moisture (%)	1.04 ± 0.04	10.95 ± 0.12
Bulk density (gm/cm ³)	1.36 ± 0.02	1.31 ± 0.04
Porosity (%)	37.30 ± 0.43	54.05 ± 5.31
Water holding capacity (%)	17.76 ± 0.16	25.76 ± 1.38
Chemical parameters		
pH	7.30 ± 0.10	8.09 ± 0.14
EC (µS/cm)	104.25 ± 1.10	183.36 ± 3.74
OC (%)	0.39 ± 0.03	0.69 ± 0.08
OM (%)	0.68 ± 0.05	1.18 ± 0.14
TN (mg/kg)	429.33 ± 0.00	1026.67 ± 40.32
AN (mg/kg)	31.74 ± 2.64	93.33 ± 2.64
TP (mg/kg)	503.16 ± 8.22	853.77 ± 15.73
AP (mg/kg)	10.51 ± 0.37	14.11 ± 0.16
TK(mg/kg)	671.67 ± 2.35	1291.67 ± 45.42
AK (mg/kg)	32.20 ± 1.70	73.83 ± 4.36
Exchangeable cations (mg/100 g)		
Na	1.20 ± 0.14	5.20 ± 0.63
K	0.82 ± 0.04	1.89 ± 0.11
Ca	1.54 ± 0.19	7.98 ± 0.85
Mg	3.07 ± 0.09	7.70 ± 1.88
CEC	4.54 ± 0.19	14.46 ± 0.85

Data are shown as the average ± standard deviation of three different experimental replicates

Table 3 Heavy metal concentration of fly ash dumpsite in and around Koradi thermal power plant

Elements	Before plantation (mg/kg)	After 1 year plantation (mg/kg)
Al	1053.93 ± 7.95	854.65 ± 3.39
Ag	7.58 ± 0.67	1.80 ± 0.07
Cd	ND*	ND*
Co	13.08 ± 0.67	8.95 ± 0.71
Cr	780.53 ± 1.10	440.13 ± 0.74
Cu	61.93 ± 0.95	23.43 ± 2.09
Fe	862.45 ± 1.13	431.75 ± 4.45
Ni	47.00 ± 0.42	25.33 ± 1.38
Mn	432.48 ± 2.65	274.28 ± 2.44
Zn	93.88 ± 0.04	60.10 ± 1.06
Pb	17.35 ± 0.49	7.25 ± 0.42
Ba	120.28 ± 1.17	95.90 ± 0.35
Li	9.00 ± 0.14	4.60 ± 0.28
B	37.45 ± 0.78	21.00 ± 0.57

ND—Not detectable

Metal accumulation index (MAI)

The MAI values of the selected plants species are summarized in Table 4. Our findings indicate that *M. elengi* had the highest MAI, followed by *B. nutans*, *A. reticulata*, *T. oliveri*, *A. indica*, *F. racemosa*, *F. benghalensis*, *F. hispida*, *F. religiosa* and *D. strictus*. The maximum mean MAI value of 137.91 was observed in *M. elengi*. On the other hand, *D. strictus* had the lowest MAI values. The results indicated that *M. elengi* had a highest accumulator capacity. Plants with a high MAI value can serve as effective barriers between polluted areas and susceptible regions, such as residential areas, schools, and parks.

Biochemical properties of plants species

Tables 5 and 6 show the biochemical properties of the plant’s species along with their APTI values. The highest total chlorophyll content at the initial stage and after one year in *F. benghalensis* was 1.62 and 2.07 mg/g followed by *M. elengi* 1.62 and 1.97; *F. religiosa* 1.35 and 1.76; *F. racemosa* 1.14 and 1.56;

A. indica 1.07 and 1.50 mg/g, respectively, and other species (Table 5). Roadside dust can have a multitude of adverse impacts on plant health and productivity. The dust from roads can contain a variety of pollutants, including heavy metals, polycyclic aromatic hydrocarbons (PAHs), and other harmful compounds, which can negatively impact plant growth and development. According to Najafi Zilaie et al., (2022), retained dust on the surface of leaves reduces the amount of solar radiation necessary for leaf development and chlorophyll production. Dust pollution decreased the leaf size and photosynthetic rate of the collected plant species, which also slowed the rate of carbon absorption. This reduction has been demonstrated that the accumulation of dust particles on leaf surfaces during a dusty environment alters leaf characteristics, especially surface reflectance in the visible and shortwave infrared radiation spectrums, which limits the quality and quantity of light that reaches chloroplasts for plant photosynthesis activities (Nawaz et al., 2022). The dusty carbon coating

that covers the plant tissues obstructs the stomata and interferes with gas exchange (Rai & Singh, 2015). Consequently, net photosynthesis and transpiration decline, which lowers growth and biomass. The qualities of tree leaves are affected by atmospheric dust pollution, which also reduces leaf area, and consequently hampers the photosynthetic rate by reducing the stomatal pore size and density of stomata (Łukowski et al., 2020). The current experiment demonstrates that the plant *Ficus benghalensis* has the highest total chlorophyll content than other plant species. Plants with more chlorophyll content may be superior able to tolerate pollution (Dadkhah-Aghdash et al., 2022).

The value for leaf extract of all plant species that had acidic pH initially varied from 5.10 to 6.22, and after one year of the plantation, values ranged from 5.96 to 6.50. The pH significantly increased after one year of planting; the reason behind is that dust builds up more during the winter and summer, which can lead to dust particles dissolving in cell

Table 4 Bioconcentration factor and translocation factor of selected plant species grown in and around the fly ash dumped site

Plant species		Heavy metals												Metal accumulation index	
		Cu	Cr	Fe	Ni	Mn	Pb	Co	B	Zn	Al	Ba	Li		Ag
<i>F. religiosa</i>	BCF	0.10	0.13	0.34	1.44	0.24	0.18	0.20	0.34	0.36	0.76	0.21	0.18	1.81	23.56
	TF	3.28	0.00	2.22	2.57	0.19	1.72	0.78	2.04	1.27	0.41	0.57	1.76	0.69	
<i>F. benghalensis</i>	BCF	0.06	0.33	0.27	1.45	0.51	0.16	0.29	0.46	0.32	4.53	0.44	0.31	2.81	30.07
	TF	0.97	0.00	1.87	2.67	0.07	0.00	0.38	2.21	0.98	0.04	0.71	0.50	0.33	
<i>A. indica</i>	BCF	3.26	0.00	1.44	1.07	0.10	0.26	0.02	0.27	0.76	0.72	0.13	0.05	0.43	38.56
	TF	0.02	0.84	0.26	3.61	0.15	0.00	2.67	1.04	0.31	0.38	0.65	0.00	1.88	
<i>M. elengi</i>	BCF	0.26	2.06	0.46	4.87	1.14	0.55	0.90	0.68	1.66	0.26	0.26	1.51	1.16	137.91
	TF	0.20	0.00	1.50	0.87	0.02	0.67	0.18	0.68	0.42	0.48	0.10	0.08	0.70	
<i>F. racemosa</i>	BCF	0.84	1.05	1.41	2.48	0.15	0.66	0.02	0.33	0.71	1.01	0.32	0.13	2.46	36.36
	TF	0.17	1.61	1.70	1.72	0.98	0.00	1.25	2.44	0.66	0.16	0.83	0.33	0.38	
<i>A. reticulata</i>	BCF	0.49	0.00	0.60	4.05	0.05	0.01	0.09	0.83	0.16	0.15	0.28	0.14	0.81	53.82
	TF	0.19	0.93	0.45	0.99	1.69	1.50	1.47	0.67	2.70	1.86	0.43	0.69	1.33	
<i>F. hispida</i>	BCF	0.22	0.00	0.33	4.16	0.06	0.00	0.02	0.46	0.50	0.26	0.13	0.04	1.11	27.44
	TF	1.29	1.43	1.59	0.52	0.49	0.00	1.67	1.47	0.16	0.42	0.94	0.75	0.73	
<i>T. oliveri</i>	BCF	0.59	0.00	0.61	1.15	0.13	0.00	0.04	0.26	0.41	0.36	0.15	0.07	0.86	49.48
	TF	0.29	0.40	0.16	0.91	0.90	0.00	2.14	1.34	1.00	0.37	0.47	1.14	1.00	
<i>D. strictus</i>	BCF	0.22	0.00	0.29	2.93	0.06	0.00	0.12	0.26	0.25	0.07	0.13	0.03	0.92	21.02
	TF	1.26	1.04	1.94	2.40	2.15	0.00	1.26	2.35	1.76	2.98	1.17	1.67	0.97	
<i>B. nutans</i>	BCF	0.27	0.00	0.52	2.72	0.13	0.30	0.24	0.20	0.26	0.08	0.14	0.09	0.59	112.36
	TF	0.76	1.06	0.62	1.14	1.14	0.90	0.29	3.32	1.80	1.70	1.15	1.33	1.14	

sap and elevating pH levels (Lohe et al., 2015). Due to air pollution, the shift in leaf extract may have an impact on stomatal sensitivity. According to Anake et al., (2022), sensitive plants had leaf extracts with a higher pH than tolerant plants. It is possible that the differences in pH of leaf extracts between sensitive and tolerant plants could be related to their ability to regulate their internal pH in response to environmental stresses. Among all plant species, *F. benghalensis* was the most tolerant with a 6.53 pH value. Furthermore, Bui et al., (2021) suggested that high pH values in plants improve their tolerance and the transformation of glucose to ascorbic acid, whereas low pH values in leaf extracts of the plants demonstrated a high degree of sensitivity to air quality.

The present study resulted that ascorbic acid is noted in significant amounts in all plant species, with initial ranges of 4.03–8.63 mg/100 g and 5.5–7.9 mg/100 g after one year of plantation. In plant cells, ascorbic acid operates as a potent reductant, activates several plant processes, and also offers a defensive mechanism against stress. Ascorbic acid can detoxify the plant’s body from free radicals caused by pollution and natural biochemical by-products (Sindhu et al., 2022). Thus, the plant’s sensitivity is directly correlated with the amount of ascorbic acid reduction (Bui et al., 2022). The current investigation revealed a considerable ascorbic acid rise at locations with high dust loads. According to Dadkhah-Aghdash et al., (2022), a plant’s increased ascorbic acid concentration is a sign of its resistance to pollution because ascorbic acid is an antioxidant that is present in growing areas of plants and affects a plant’s ability to withstand harmful environmental factors, such

as air pollution. Since it is a powerful reductant, it prevents the accumulation of H₂O₂, O₂⁻, and OH⁻ in chloroplast caused by particulate matter, and also protects inactivation of the CO₂ fixation cycle enzymes and chlorophyll. Hence, plant tolerance is indicated by greater ascorbic acid levels in plants (Sharma et al., 2017). The results of the current study indicate that *Ficus benghalensis* (17.9 mg/100 g) and *Mimosa elengi* (14.1 mg/100 g) were more tolerant to pollution because they contain high ascorbic acid levels. Even though the ascorbic acid level in the leaf of *Thyrsostachys oliveri* (5.5 mg/100 g) was the lowest, which has sensitive nature to contaminants, especially airborne suspended particulate matter.

Relative water content (RWC) is a measure of the water status of a plant, which is calculated as the ratio of the actual water content of the plant to the maximum water content it can hold. RWC can be used to assess the water balance of plants and their ability to cope with water stress. The RWC of plants can vary depending on various factors, including environmental conditions such as temperature, humidity, and water availability, as well as the stage of plant growth and the species itself (Fig. 2).

The present study showed that *F. benghalensis* (85.46%) has a relatively high RWC compared to other species of plants after one year of the plantation, followed by *F. religiosa* (83.57%), *M. elengi* (82.02%), *F. hispida* (81.9%), *F. racemosa* (81.72), *A. reticulata* (79.37%), *A. indica* (76.84%) and other species. The relative water content of a tree is proportional to its body’s water content, which is determined by the ratio of water molecules absorbed and released (Karmakar et al., 2021). Sensitive plants

Table 5 Chlorophyll content of all selected plant species grown in and around the fly ash dumped site

Plant species	Chlorophyll-a (mg/g)		Chlorophyll-b (mg/g)		Total chlorophyll (mg/g)	
	Initial	After 1 year	Initial	After 1 year	Initial	After 1 year
<i>F. religiosa</i>	0.63 ± 0.01	0.87 ± 0.01	0.54 ± 0.01	0.62 ± 0.01	1.35 ± 0.15	1.76 ± 0.25
<i>F. benghalensis</i>	0.75 ± 0.03	0.97 ± 0.03	0.67 ± 0.02	0.81 ± 0.01	1.62 ± 0.19	2.07 ± 0.26
<i>A. indica</i>	0.50 ± 0.00	0.73 ± 0.01	0.44 ± 0.01	0.54 ± 0.02	1.07 ± 0.12	1.50 ± 0.21
<i>M. elengi</i>	0.71 ± 0.02	0.94 ± 0.02	0.65 ± 0.00	0.74 ± 0.00	1.55 ± 0.19	1.97 ± 0.27
<i>F. racemosa</i>	0.54 ± 0.01	0.77 ± 0.01	0.43 ± 0.01	0.52 ± 0.02	1.14 ± 0.13	1.56 ± 0.22
<i>A. reticulata</i>	0.27 ± 0.01	0.36 ± 0.08	0.23 ± 0.00	0.33 ± 0.03	0.58 ± 0.06	0.81 ± 0.16
<i>F. hispida</i>	0.21 ± 0.00	0.28 ± 0.01	0.11 ± 0.00	0.19 ± 0.01	0.40 ± 0.08	0.56 ± 0.08
<i>T. oliveri</i>	0.32 ± 0.00	0.42 ± 0.01	0.21 ± 0.00	0.26 ± 0.02	0.64 ± 0.09	0.83 ± 0.12
<i>D. strictus</i>	0.33 ± 0.00	0.51 ± 0.01	0.29 ± 0.00	0.36 ± 0.01	0.71 ± 0.07	1.03 ± 0.15
<i>B. nutans</i>	0.31 ± 0.00	0.44 ± 0.00	0.21 ± 0.00	0.31 ± 0.00	0.62 ± 0.08	0.89 ± 0.13

Data are shown as the average ± standard deviation of three different experimental replicates

Table 6 Assessment of air pollution tolerance index (APTI) of selected plant species in and around of thermal power station

Plant species	Ascorbic acid (mg/100 g)		pH		Relative water content (%)		Total chlorophyll (mg/g)		APTI	
	Initial	After 1 year	Initial	After 1 year	Initial	After 1 year	Initial	After 1 year	Initial	After 1 year
<i>F. religiosa</i>	5.95 ± 0.00	11.2 ± 1.21	6.07 ± 0.06	6.26 ± 0.01	51.85 ± 3.21	83.57 ± 4.70	1.35 ± 0.15	1.76 ± 0.25	9.6	17.34
<i>F. benghalensis</i>	8.63 ± 0.25	17.9 ± 1.07	6.22 ± 0.01	6.53 ± 0.06	81.76 ± 5.09	85.46 ± 4.78	1.62 ± 0.19	2.07 ± 0.26	14.94	23.94
<i>A. indica</i>	6.85 ± 0.16	11.64 ± 0.46	5.73 ± 0.05	6.04 ± 0.07	55.56 ± 4.81	76.84 ± 3.73	1.07 ± 0.12	1.50 ± 0.21	10.21	16.46
<i>M. elengi</i>	7.61 ± 0.63	14.1 ± 2.22	5.83 ± 0.12	6.32 ± 0.01	79.29 ± 5.74	82.02 ± 8.71	1.55 ± 0.19	1.97 ± 0.27	13.55	19.89
<i>F. racemosa</i>	6.03 ± 0.25	9.46 ± 0.60	5.71 ± 0.01	6.17 ± 0.12	71.48 ± 5.7	81.72 ± 1.67	1.14 ± 0.13	1.56 ± 0.22	11.28	15.48
<i>A. reticulata</i>	6.76 ± 0.16	12.21 ± 0.53	5.4 ± 0	6.13 ± 0.02	65.28 ± 2.41	79.37 ± 6.87	0.58 ± 0.06	0.81 ± 0.16	10.57	16.41
<i>F. hispida</i>	6.41 ± 0.00	8.48 ± 0.25	5.1 ± 0	6.17 ± 0.12	76.4 ± 4.45	81.9 ± 3.30	0.40 ± 0.08	0.56 ± 0.08	11.17	13.9
<i>T. oliveri</i>	4.03 ± 0.11	5.5 ± 0.10	5.33 ± 0.06	5.93 ± 0.06	60.71 ± 3.09	70 ± 0.00	0.64 ± 0.09	0.83 ± 0.12	8.48	10.72
<i>D. strictus</i>	4.67 ± 0.08	6.03 ± 0.13	5.2 ± 0	5.97 ± 0.01	48.15 ± 3.21	61.21 ± 2.10	0.71 ± 0.07	1.03 ± 0.15	7.57	10.34
<i>B. nutans</i>	4.95 ± 0.09	6.58 ± 0.15	5.43 ± 0.12	5.81 ± 0.01	63.26 ± 0.66	73.81 ± 2.06	0.62 ± 0.08	0.89 ± 0.13	9.32	11.79

Data are shown as the average ± standard deviation of three different, experimental replicates

suffer more as a result of the large amounts of water that is released from their bodies by different morphological changes.

Air pollution tolerance index (APTI)

The APTI values of various plant species were evaluated, and it was found that *F. benghalensis* had the highest APTI value (23.94), followed by *M. elengi* (19.89), *F. religiosa* (17.34), *A. indica* (16.46), *A. reticulata* (16.41), and other species. These findings suggest that *F. benghalensis* is the most resilient plant species for growing near thermal power stations, according to Table 6. The APTI is an effective tool for identifying plant species that can withstand poor air quality and air pollution (Bharti et al., 2018). The APTI was calculated based on four variables: relative water content (RWC), pH, total chlorophyll concentration, and ascorbic acid. The presence of sulfur and nitrogenous oxides in the air may contribute to the acidic nature of plant samples in polluted areas, increasing the levels of acids in leaves (Rahman & Husen, 2022). Sulfur dioxide (SO₂) and nitrous oxide (NO) are not themselves acidic compounds, but they can contribute to the formation of acidic substances in the atmosphere (Shammas et al., 2020). When SO₂ and NO are released into the air by human activities such as burning fossil fuels or by natural sources like volcanoes, they can react with water, oxygen, and other chemicals to form sulfuric acid (H₂SO₄) and nitric acid (HNO₃) (Abaje et al., 2020). These acids are commonly referred to as acid rain. Sulfuric acid and nitric acid are strong acids because they dissociate completely in water, releasing hydrogen ions (H⁺). The hydrogen ions can then react with other substances to form acidic solutions. So, while SO₂ and NO themselves are not acidic, their ability to contribute to the formation of sulfuric acid and nitric acid makes them important precursors to acid rain. The regression analysis graph in Fig. 3 shows that ascorbic acid has a significant and strong relationship with APTI ($R^2=0.9403$), while chlorophyll content, RWC, and pH of leaf extract have a weak relationship ($R^2=0.5450, 0.4125, \text{ and } 0.0166$, respectively). This analysis suggests that the amount of ascorbic acid in plant leaves increases to resist stress as pollution levels rise. Principal component analysis of *F. benghalensis*, *M. elengi*, *F. religiosa*, *A. indica*, and *F. racemosa* revealed a significant positive relationship

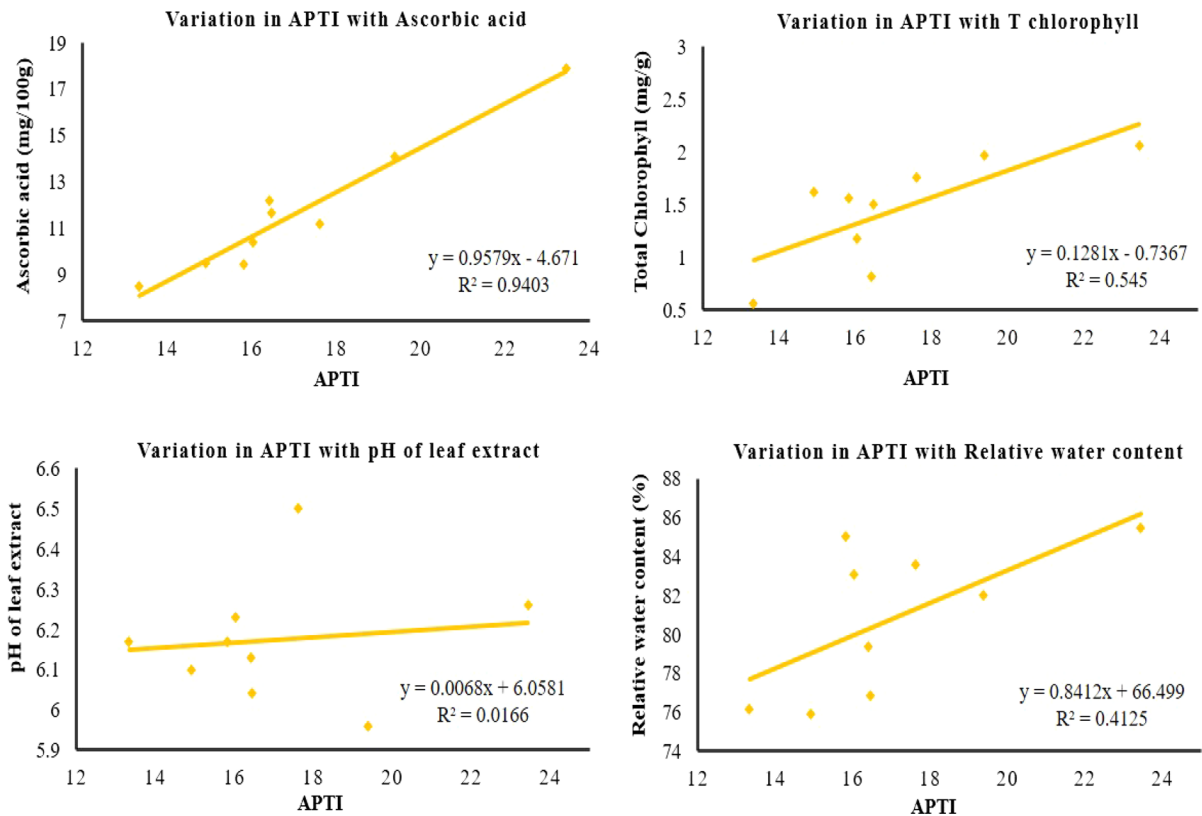


Fig. 2 Regression analysis of various biochemical parameters and the APTI

between drought tolerance indices (chl-a, chl-b, T-chl), pH, ascorbic acid, RWC, APTI, and dust capturing capacity (Fig. 4). The scatterplot indicated considerable differences between *F. benghalensis* and the other nine plant species, with over 70% variance in two PCA regions. Tables 5 and 6 further support the results of the principal component analysis, as they demonstrate that *F. benghalensis* has the highest stress parameter values compared to other plant species.

Dust capturing capacity and dust load

Due to its rough leaf surface, large size, and phyllotaxy, *F. benghalensis* exhibited the highest dust deposition rate among the chosen plant species (Fig. 2). Sett (2017) demonstrated that evergreen plants with horizontally oriented leaves are more effective at absorbing dust than deciduous or evergreen plants with vertically oriented leaves. In comparison with the other plants, *F. benghalensis* had the most dust

on its leaves and a moderate ability to capture dust, possibly due to its large, horizontally placed leaves. The smooth surface and pendulous orientation of *D. strictus* and *B. nutans* leave cause dust to easily fall from the leaf due to gravity or wind. The rate of dust accumulation was lower for *T. oliveri*, likely due to its vertical positioning and thin lamina. The wavy margins of *M. elengi* leaves may contribute to dust accumulation. According to Adhikari et al. (2021), evergreen trees with simple and rough leaf surfaces are better dust collectors than deciduous trees with smooth and compound leaf surfaces.

Conclusion

This study demonstrates that planting certain tree species in and around thermal power plants can effectively mitigate air pollution and restore degraded sites. These plants can act as barriers

against airborne fine particulate matter and heavy metals, contributing to environmental management. However, excessive exposure to air pollution can have negative impacts on tree health, underscoring the need for ongoing monitoring and analysis of the foliage of trees. By identifying plant species that exhibit pollution tolerance and adaptability, this study provides important insights into nature-based solutions for controlling air pollution and promoting human and environmental health. These findings have broad implications for sustainable urban development and environmental policy and can help inform the design of effective green infrastructure in smart green cities.

The findings of the research are as follows:

- Bioconcentration was studied in this research our finding, suggesting that the highest concentration factor and translocation factor were observed in *M. elengi* and *A. indica*.
- The accumulation of air-suspended dust particles and dust deposition on plant leaves is influenced by their morphological and anatomical features.
- The accumulation of dust particles on leaves can cause changes in the physiological and microscopic morphological traits of plants, and these changes vary depending on the plant's tolerance to dust.
- To ensure the environmental sustainability of residential and industrial areas, it is essential to select tolerant plant species. Species such as *F. benghalensis*, *M. elengi*, *F. religiosa*, *A. indica*, and *F. racemosa* are highly recommended for sustainable urban plantations due to their greater capacity to retain dust and the least susceptibility to air pollution.
- Additionally, the dense and tall nature of bamboo can act as a barrier to block dust and particulate matter from entering residential or industrial areas. Furthermore, the roots of bamboo plants (woody grass) can help to stabilize soil, preventing erosion and reducing the amount of dust that is kicked up into the air. Therefore, including woody grasses such as bamboos along with the recommended plant species can be an effective way to enhance the green infrastructure in smart green cities and improve air quality.
- One way to protect against pollution is to develop a green belt in and around thermal power station

Fig. 3 Principle component analysis of different biochemical parameter of plant species, APTI = Air pollution tolerance index; DCC = Dust capturing capacity; WC = Relative water content; pH = pH of leaf extract; AA = Ascorbic acid; Chl-a = Chlorophyll a; Chl-b = Chlorophyll b; T chl = Total chlorophyll

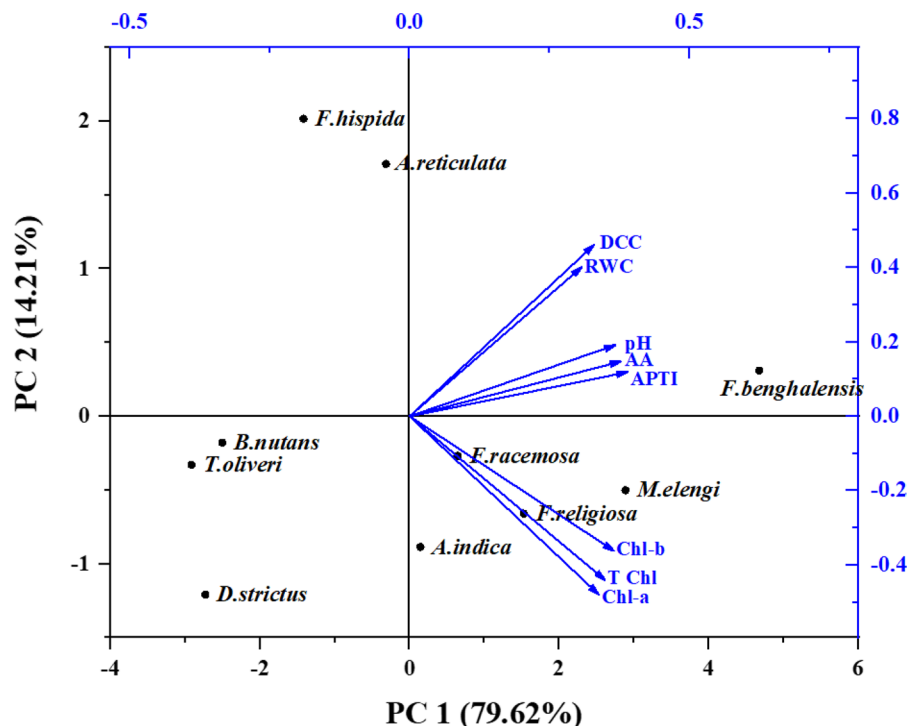
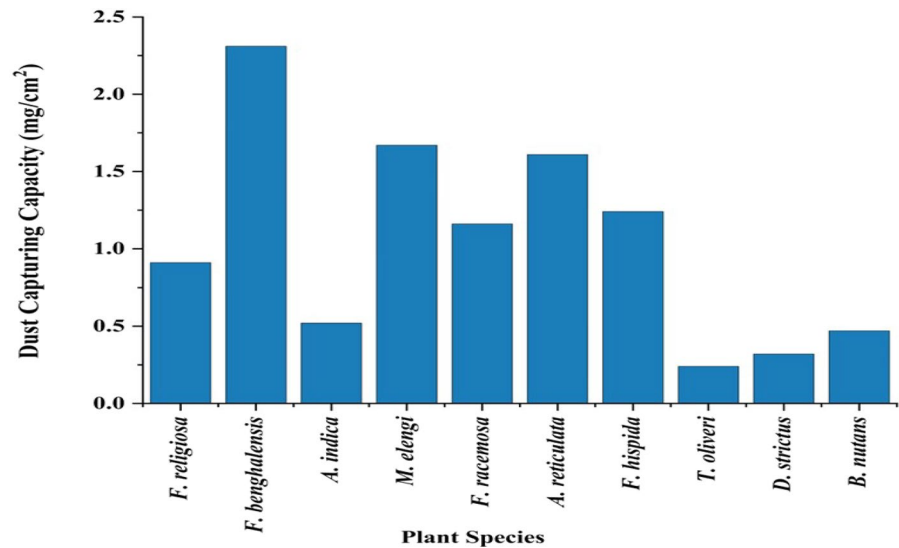


Fig. 4 Dust capturing ability of some plant species at industrial environments



areas and fly ash dumpsites, using the suggested plant species adjacent to pollution sources.

- This will create a protective layer between pollutant sources and living areas, reducing the health risks of humans and animals. Ultimately, the use of appropriate plant species is an affordable and effective method for promoting environmental sustainability and improving the quality of life in urban areas.

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Declarations

Conflicts of interest The authors declare no conflict of interest.

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