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ESTIMATING THE RESPONSE OF SOME PLANT SPECIES TO AMBIENT AIR POLLUTION IN INDUSTRIAL CITY GAJRAULA FOR POTENTIAL GREEN BELT DEVELOPMENT

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ABSTRACT

Present study deals with fifteen road side plant species to find out their ambient air pollution tolerant level with regard to the alleviation of air pollution and for the recommendation of greenbelt development at industrial city Gajraula. The leaf samples were collected during summer season from the plants growing at three different pollution level sites i.e. Town Basti (S1), RACL (S2) and Indra Chowk (S3). The Air Pollution Tolerance Index (APTI) was calculated on the basis of four physio-biochemical parameters. The Anticipated Performance Index (API) of these plants was interpreted by using APTI, morphological, laminar and socio-economic parameters. On the basis of APTI, *Ficus benghalensis* and *Ficus rumphii* showed highest air pollution tolerance at all the three research sites (APTI > 23). On the flipside *Alstonia scholaris* and *Nerium indicum* represented lowest APTI of less than 15 indicating sensitivity to air pollution and can be used as bioindicators for air pollution. The API value interpreted that *Ficus benghalensis, Ficus rumphii, Ficus religiosa, Polyalthia longifolia* and *Mangifera indica* are excellent performer (with API score between 81-90%) and recommended most suitable plants for green belt development. Pearson's correlation coefficient matrices showed a significant strong positive correlation ($p < 0.05$) between APTI and total chlorophyll content (0.755, 0.781 and 0.804) as well as between APTI and ascorbic acid level (0.942, 0.917 and 0.935) at all the three sites S1, S2 and S3, respectively.

Keywords: Air pollution, APTI, API, green belt, total chlorophyll contents, ascorbic acid.

INTRODUCTION

In recent few decades, ambient air pollution has come to be a major challenge in developing countries. Industrial cities encounter environmental stress primarily in the form of bad air quality and motor vehicle congestion on the road side. Studies indicate that road side green plants reduce the pollution level in the air. The researchers, environmentalists and policy makers have long been highlighted the necessity of green belt development along the both sides of road (Chaulya *et al*., 2001; Rao *et al*., 2004). Due to a large surface area, plant leaves come up with a natural way of cleaning the polluted air by trapping and absorption of particulate and gaseous air pollutants (Prajapati and Tripathi, 2008; Pandey *et al*., 2015; Rai, 2016; Yadav and Pandey, 2020). Tree plantation along the roadside is an economical approach for mitigating the air pollution. Green plants function as a sink for air pollution and decline the pollutant level in the atmosphere. Plants respond to these air pollutants by the change in the level of photosynthetic pigments, ascorbic acid, proteins, enzymes, pH and relative water contents. The dust deposited on the surface of the leaves, obstruct the sunlight and change the rate of photosynthesis (Aleadelat and Ksaibati, 2018; Hariram *et al*., 2018; Saini *et al*., 2019). The presence of sunlight in polluted environment, accelerate oxidation, reduction and bleaching reactions inside the chloroplast which cause reactive oxygen species (ROS) formation. These ROS decline the chlorophyll contents in plant leaves under water stress (Tambussi *et al*., 2000; Pathak *et al*., 2011; Bakiyaraj and Ayyappan, 2014). Ascorbic acid found in plant cells, protect the thylakoid membrane from injury caused by ROS under water stress, so its concentration increases (Tambussi *et al*., 2000; Akram *et al*., 2017). The amount of relative water, stabilize the release and uptake of water in stress (Singh and Verma, 2007) and more pH value enhance the plant tolerance against air pollution (Agarwal, 1986). Singh and Rao suggest Air Pollution Tolerance Index (APTI) for estimating the tolerance level of plants (Singh and Rao, 1983). The performance of different plant species can be assessed for mitigation of air pollution by calculating APTI. For APTI calculation biochemical (total chlorophyll pigments and ascorbic acid) and physiological (pH and relative water contents) parameters are taken into consideration. The APTI calculation gives a valid method for screening of plants with regards to their response to air pollutants (Table 1). On the basis of APTI calculation, plants can be considered as either sensitive or tolerant against air pollution. The sensitive plants can act as bioindicators whereas the tolerant as sink for air pollutant.

The APTI categorised the plants on the basis of physio-biochemical parameters only. To mitigate the air pollution and planning of green-belt development, another index called anticipated performance index (API) is taking into consideration. In API, APTI as well as some other morphological, laminar and socio-economic parameters (e.g. habit and type of plants, canopy type, laminar structure and economic importance) are taking into consideration. On the basis of these parameters different grades (+/−) are given to the plants and a plant can obtained maximum 16 positive grades. These grades are further converted into percentage score. In API scoring, plants are categorised into best, excellent, very good, good, moderate, poor, very poor and not recommended on the basis of these percentage scores of 91-100, 81-90, 71-80, 61-70, 51-60, 41-50, 31-40 and up to 30, respectively (Prajapati and Tripathi, 2008; Rai, 2020).

Although, many studies ascertain the effects of ambient air on plant species and evaluation of APTI and API are executed at different pollution sites of the cities of India (Pathak *et al*., 2011; Pandey *et al*., 2015; Patel and Nirmal Kumar, 2018; Gupta *et al*., 2019; Leghari *et al*., 2019; Rai, 2020; Tak and Kakde, 2020; Yadav and Pandey, 2020; Karmakar *et al*., 2021) but there is scarcity of reports with reference to air pollution tolerance of plant species in growing along the road sides (Kumar *et al*., 2015). The aim of the present study had been to select the most competent plant species for air pollution reduction and green belt development on the basis of APTI and API score specially in industrial cities. In this regard by the use of physio-biochemical parameters, the plant responses against air pollution have also been found out.

MATERIALS AND METHODS

Area of Study and Selection of Sampling Sites:

This study has been carried out at Gajraula which is an important industrial city and municipal board present at Amroha district in the state of Uttar Pradesh, India. It is vested on national highway 24, which is a 4-lane highway connecting Lucknow, a state capital to New Delhi, the capital of India. Geographically, it is located at latitude of 28.85 N and longitude 78.23 E at an elevation of 257 metre from mean sea level. The holy river Ganga is just 7 km away from the city. According to 2011 census of India, Gajraula had a population of 55,048 of which 28,896 are males while 26,152 females (Census 2011). Gajraula is at about 105 km distance from New Delhi. It is a hub of many industries like RACL Geartech, Jubliant Life Sciences, Insilco Limited, Navabharath Fertilizers Limited, Israeli Pharma Teva API etc. Present studies have been performed at three different locations of the town i.e. Basti, Indra Chowk and RACL, during the summer (March – June) of 2019. Factors like population density, industries location and traffic movement have been taken into consideration for the selection of the study sites.

Town Basti (S1): This site is thinly populated, likewise the traffic density is quite low. People are mainly involved in agriculture based work. So this site is receiving less pollution as compared to other two sites. Due to above mentioned reasons this site has been taken as control for present study.

RACL (S2): RACL is an automotive industry and this site is located near NH-24. The traffic movement is very frequent near this site.

Indra Chowk (S3): It is a residential area with commercial activities. Many shops and workshops are situated near this site. Throughout the year, more pollution is recorded at this site due to the emissions of the industries like TEVA API Limited, Insilco Limited and Jubilant Life Sciences Limited which are situated near this Site. Traffic movement is slow and highly congested due to traffic jams and encroachment on both sides of the road. More vehicles gather on road near railway line crossing.

Average summer (March-June 2019) values for major air pollutants recorded from all the three sites at Gajraula city have been presented in Table 2, which clearly indicate the pollution level in the order of site S1 < site S2 < site S3. The values of $PM_{2.5}$, PM_{10}, SO_2 and NO_2 were measured by Respirable Dust Sampler APM-460 NL (Envirotech, New Delhi), Fine Particulate Sampler (Envirotech, New Delhi, Model: APM-550), West-Geake method (1956) and modified Jacob and Hochheischer method (1958), respectively.

Selection of Plant species:

Fifteen most common plant species have been selected, namely- *Alstonia scholaris* (Satparni), *Azadirachta indica* (Neem), *Cassia fistula* (Amaltas), *Cassia siamea* (Kassod), *Dalbergia sissoo* (Shisham), *Delonix regia* (Gulmohar), *Ficus benghalensis* (Banyan), *Ficus religiosa* (Pipal), *Ficus rumphii* (Pilakhan), *Mangifera indica* (Aam), *Melia azedarach* (Bakain), *Nerium indicum* (Kaner), *Polyalthia longifolia* (False ashok), *Ricinus communis* (Arandi) and *Terminalia arjuna* (Arjuna) from the study sites. These are abundantly available all over the Gajraula city.

The leaf samples were plucked from the selected plant species near the study sites in the morning between 7:30-9:30 AM for avoiding any alteration in biochemical parameters. After collection, samples were enclosed in polyethylene packets and sent to the laboratory for analysis. The collected samples were processed immediately within the 3-4 hours of plucking.

Biochemical analysis of plants:

Total Chlorophyll Contents-

The amount of chlorophyll-a and chlorophyll-b was estimated by the formula given by Maclachlan and Zalic (1963). The amount of total chlorophyll was calculated by summation of chlorophyll-a and chlorophyll-b. The amount of chlorophyll contents was expressed in unit of '*mg pigment per gm of fresh leaves*'.

$$\text{Chlorophyll-a} = \frac{12.3\ \text{O.D.}_{663} - 0.86\ \text{O.D.}_{645}}{d \times 1000 \times W} \times V$$

$$\text{Chlorophyll-b} = \frac{19.3\ \text{O.D.}_{645} - 3.6\ \text{O.D.}_{663}}{d \times 1000 \times W} \times V$$

$$\text{Total Chlorophyll} = \text{Chlorophyll-a} + \text{chlorophyll-b}$$

Where, V is the volume of the chlorophyll supernatant solution, d is the length of light path in centimetres, W is the fresh weight of leaves and O.D. is the absorbance at respective wavelengths.

Ascorbic acid-

The ascorbic acid content of leaf sample was calculated by the formula given by Keller and Schwager (1977) with the help of a spectrophotometer.

Ascorbic acid was estimated by the following formula:

$$\text{Ascorbic acid (mg/g fresh weight)} = \frac{(Eo - Es - Et)\ V}{W \times 100} \times 100$$

Where, V is the volume of the extract, W is the weight of the leaf sample (g) and Eo, Es and Et are optical densities of blank, plant sample and sample with one drop of 1% ascorbic acid respectively.

Leaf extract pH

The leaf extract pH was measured by digital pH meter (Systronics MK6). Before measurement, pH meter was calibrated with buffer solutions of pH 4 and pH 9.

For measuring leaf extract pH, 0.5 grams of the fresh leaves were homogenized in 50 ml deionized water with the help of mortar and pestle. The homogenized solution then filtered and the pH of leaf filtrate was determined by calibrated digital pH meter.

Relative water content (RWC)

RWC in percentage was calculated by the method given by Liu and Ding (2008).

$$RWC = \frac{\text{Fresh weight} - \text{Dry weight}}{\text{Turgid weight} - \text{Dry weight}} \times 100$$

Evaluation of APTI -

For APTI calculation total chlorophyll content, ascorbic acid, leaves extract pH and relative water content were taken into consideration by using the formula suggested by Singh and Rao (1983).

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

Where, A is ascorbic acid content (mg/gm dry weight of leaves), T is total chlorophyll content (mg/gm dry weight), P is pH of leaf extract and R is the percent relative water contents of the leaf tissue.

Evaluation of Anticipated Performance Index (API)

To find out most promising plant species for the development of green belts, the API had been calculated for all 15 plants selected for green belt development. For API calculation, APTI as well as some other morphological and socio-economic parameters (e.g. habit and type of plants, canopy type, laminar structure and economic importance) were taken into consideration for each plant species (Table 3). On the basis of these parameters different grades (+/–) had been given to the plants which were further converted into percentage score. The maximum grade that can be assigned to a plant species was 16. Based on grading pattern given to fifteen studied plants, most suitable plant species were proposed for green belt development.

The percentage API score had been calculated by following formula:

$$\%\ \text{API score} = \frac{\text{Grades obtained by plant species}}{\text{Maximum possible grades of any species}} \times 100$$

Percentage API scores have been used to categorize each plant species into different level of performance which is described in Table 4 (Prajapati and Tripathi, 2008).

Statistical analysis

For statistical analysis we used Analysis ToolPak in Microsoft Office Excel 2007. Pearson's correlation coefficient (r) was calculated between dependent variable (APTI) and independent variables (total chlorophyll content, ascorbic acid, pH and RWC) of each site to determine the degree of correlation at 5% level ($p \leq 0.05$) of significance.

RESULTS AND DISCUSSION

Total chlorophyll contents:

The chlorophyll contents of fifteen selected plant species from S1, S2 and S3 sites has been summarized in Figure 1 and Table 5. The level of total chlorophyll in plant leaves had been varied significantly from 9.35 to 3.35, 8.63 to 2.89 and 8.31 to 2.71 mg/ gm at site S1, S2 and S3, respectively. Among fifteen studied plant species maximum chlorophyll contents (9.35 mg/g) have been found in *Polyalthia longifolia* at S1 site followed by 8.63 at site S2. At S3, maximum total chlorophyll contents have been reported in *Cassia fistula* (8.31 mg/ gm). There was observed a decrease in the mean value of chlorophyll contents from site S1 (6.91) to S2 (6.2) and S3 (5.93 mg/ gm). The highest effect of air pollution on the amount of total chlorophyll had been observed in *Dalbergia sissoo* whereas 57% reduction in chlorophyll was recorded from site S1 to Site S3. There had been an increase in the total chlorophyll contents from site S1 to S3 in plant species *Cassia fistula*, *C. siamea* and *Melia azedarach*.

Total chlorophyll content in plant leaves is a main biochemical parameter which determines the photosynthetic process and finally the plant growth (Karmakar *et al.*, 2021). It is used frequently to estimate the impact of air pollution on plant. Many studies have documented the reduction in total chlorophyll contents in plants which had been exposed to air pollution (Rai, 2019; Gupta *et al.*, 2020). Present studies record reduction in total chlorophyll contents with dust deposition on the leaves in polluted environment (Bharti *et al.*, 2017).

Research studies reveal that the total chlorophyll contents vary with the tolerance level as well as the sensitivity of plant species (Chauhan *et al.*, 2019), that is, higher the sensitivity of the plant species against pollution, lower is the total chlorophyll content (Rai and Panda, 2014). The chlorophyll content varies with air pollution level, from one plant species to another plant species, leaf age and different climatic conditions along with some biotic and abiotic factors of the plant habitat (Begum and Harikrishna, 2010). The air pollution tolerance level varies from one plant species to another, depending upon their capacity to withstand the pollutants effect without displaying any morphological symptoms (Rai, 2019; Gupta *et al.*, 2020). Present studies represent a decline in the total chlorophyll contents from site S1 to S3 is due increase in pollution level, which may be due to chloroplast damage or chlorophyll degradation or inhibition in chlorophyll biosynthesis (Lakshmi *et al.*, 2009).

Ascorbic Acid:

The ascorbic acid contents of fifteen selected plant species from S1, S2 and S3 sites are summarized in Figure 2 and Table 5. The amount of ascorbic acid varied significantly from 3.89 to 9.84, 5.11 to 10.88 and 5.42 to 11.89 mg/g at site S1, S2 and S3, respectively. The amount of ascorbic acid level in *Ficus benghalensis* had been reported 9.84 mg/g at site S1 which was further increased at site S2 up to the level of 10.88 mg/g and at the highest level at site S3 (11.89 mg/gm). The lowest ascorbic acid value was found in *Ricinus* *communis* at site S1 (3.89 mg/gm) and S2 (5.11 mg/gm), while at site S3 it was lowest in *Alstonia scholaris* (5.42 mg/ gm). There has been found an increase in the mean value of ascorbic acid contents from site S1 (7.37) to S2 (8.33) and S3 (8.64 mg/ gm). The highest effect of air pollutants was reported on the value of ascorbic acid in *Ricinus communis* (85% increase), followed by *Ficus benghalensis* (20% increase) from site S1 to Site S3. There had been a decrease (18%) in ascorbic acid from site S1 to S3 in *Cassia siamea*. Present studies represent that the plant species responded differently against air pollution. The highest ascorbic acid level was recorded at most polluted S3 site as compared to S1 (control). Our results are similar to the findings of Rai, 2019, Gupta *et al*., 2020 and Yadav and Pandey, 2020 who worked on different plant species. However, the reports of Rai and Panda, 2014 show contradictory trends they reported elevated ascorbic acid at the control site while, lower amount at polluted sites.

Ascorbic acid is an essential antioxidant compound which is found in sufficient amount in all parts of the plant. It provides resistance to the plants against all kinds of environmental stresses, including air pollution, by neutralizing the reactive oxygen species produced in cytoplasm (Lima *et al*., 2000). Reducing power of ascorbic acid is directly equivalent to its amount present in plant cell and depends on the pH of the cell. At higher pH, the conversion of hexose sugar to ascorbic acid is increased. It provides more tolerance against environmental stresses. It also helps in cell division and cell wall formation (Krishnaveni *et al*., 2017).

Leaf extracts pH:

The variation in pH level from studied plants has been briefly explained in Figure 3 and Table 5. The level of pH increased significantly from less polluted site (S1) to more polluted site (S3). Highest pH level (in the range of slightly alkaline) was found in *Ficus benghalensis* at all the sites as compared to other studied plant species. The lowest pH level was observed in *Dalbergia sissoo* at site S1 and S2, and in *Nerium indicum* at site S3. Present studies report elevated level of leaf extract pH during winter (more pollution) as compared to summer (less pollution). These values are important to find out plant tolerance against air pollutants (Yadav and Pandey, 2020). Higher pH increases the conversion of hexose sugar to ascorbic acid and provide tolerance against air pollution (Bharti *et al*., 2017). The pH play a crucial role in plant's physiological and metabolic processes. Many enzymes used in metabolic activity of plants, require higher pH for their proper functioning. Plants having low leaf extract pH are more sensitive while plants having pH round about 7 are relatively tolerant against environmental stresses (Pathak *et al.,* 2011). Areas having high level of SO_2 gaseous pollutants are responsible for more H^+ formation due to generation of sulphuric acid which results into a decline in leaf extract pH. Low leaf extract pH causes decline in the photosynthetic process and increase in the sensitivity against air pollution (Patel *et al*., 2018).

Relative Water Content (RWC):

Water is the most important requirement for all kinds of life on the earth. RWC indicates status of water in plant tissues and its sufficient quantity helps in maintaining physiological balance under environmental stress (Seyyednejad *et al*., 2017). Plants grown in polluted areas show a decline in the rate of transpiration and RWC which results into less movement of water and nutrients from roots to leaves. Apart from this, pollution stress increases the cell membrane permeability which motivates loss of water and dissolved nutrients from cytoplasm and causes early senescence in plants. High RWC in plants under environmental stress escalate their tolerance while low RWC induce sensitivity (Bakiyaraj and Ayyappan, 2014). The brief description in RWC variation from fifteen plants studied is depicted in Figure 4 and Table 5. There was a minor increase (4.5%) in mean RWC from site S1 to S3. *Dalbergia sissoo* showed 18% increase in RWC, followed by *Ficus benghalensis* (9%) and *Polyalthia longifolia* (8.8%). On the other side, *Ricinus communis* and *Cassia siamea* represented 10.3% and 3.4 % decline in RWC, respectively from site S1 to S3.

Air pollution tolerance index (APTI):

APTI is a measure to determine the tolerance as well as the sensitivity of the plant against changing environmental pollution level (Singh *et al*., 1991). APTI of fifteen plant species studied from site S1, S2 and S3 has been summarized in Fig. 5 and Table 5. The mean APTI of studied plants has been reported in an increasing trend from 12.44 to 23.82, 13.27 to 24.93 and 13.26 to 26.05 at S1, S2 and S3 sites, respectively. Increased values of APTI suggest greater tolerance level of the experimental plant species against air pollution. Present studies record increased APTI in *Ficus benghalensis* which is followed by *Ficus rumphii* and *Ficus religiosa* at all the three sites. *Alstonia scholaris* represent decreased value of APTI at all the sites (12.44, 13.27 and 13.26) suggesting it a sensitive plant against air pollution. The decreasing order of APTI value from all the sites is as *Ficus benghalensis > Ficus rumphii > Cassia fistula > Ficus religiosa > Melia azedarach > Polyalthia longifolia > Delonix regia >Terminalia arjuna > Mangifera indica > Cassia siamea > Azadirachta indica > Dalbergia sissoo > Ricinus communis > Nerium indicum > Alstonia scholaris*. On the basis of APTI value (Table 1), Lakshmi et al. (2009) has classified the plants into tolerant, intermediate, sensitive and very sensitive in response to the environmental pollution. Out of the fifteen plants studied in present studies, eight plants are intermediate while seven are as sensitive in response to the air pollution.

Pearson's correlation matrix analysis for physio-biochemical parameters with APTI:

Pearson's correlation coefficient matrices showed a significant strong positive correlation ($p < 0.05$) between APTI and total chlorophyll contents (0.755, 0.781, 0.804), APTI and ascorbic acid contents (0.942, 0.917, 0.935), and moderate positive correlation between ascorbic acid and total chlorophyll contents (0.545, 0.527, 0.603) at all the three sites S1, S2 and S3, respectively. It indicates that total chlorophyll content and ascorbic acid level affect the APTI value in plants species. A study from urban area of Lucknow also reported similar findings of positive correlation of APTI with ascorbic acid level in plants (Bharti *et al*., 2017).

Although, all the plant species show significant ($p<0.05$) correlation of APTI with total chlorophyll contents and ascorbic acid level, but the extent up to which the experimental plant species responded against air pollution varied from site to site and species to species. The change in the biochemical parameters in plant leaves can be used as an early diagnostic indicator of environmental pollution stress (Joshi and Swami, 2007; Anake *et al.* 2019).

Anticipated performance index (API):

API is an indicator to evaluate the most capable plant species for mitigation of ambient air pollutants and their use in green belt development. For its gradation and assessment, APTI score, some morphological, laminar and socioeconomic characters were used from fifteen selected plant species (Table 3 and 4). Among all the fifteen plant species under study, *Ficus benghalensis* ranked first. A study from Nandesari industrial area, Vadodara, Gujarat also reported *Ficus benghalensis* as best performer and keystone species indicator (Patel and Kumar, 2018). We recorded maximum API grade of 6 and *Ficus benghalensis, Ficus rumphii, Ficus religiosa, Mangifera indica* and *Polyalthia longifolia* were assessed as 'excellent' for Green belt development at all the three sites (Table 7, 8 and 9). *Nerium indicum* with API grade of 1 was assessed as 'very poor' and not recommended for plantation along road sides due to its poor pollution tolerance indices. *Dalbergia sissoo, Terminalia arjuna, Alstonia scholaris and Cassia fistula* with the API grade of 4 were considered as 'good' while *Azadirachta indica, Cassia siamea, Melia azedarach, Delonix regia* and *Ricinus communis* with the API grade of 3 were considered as 'moderate' for the green belt development.

CONCLUSION AND RECOMMENDATION

For the mitigation of ambient air pollutants and potential green belt development in the industrial city, we found out that estimation of API might be useful for the selection of most appropriate plant species. Some plant species have been categorised with respect to their extent of tolerance and sensitivity against ambient air pollutants. In the present study, among all the fifteen experimental plants, *Ficus benghalensis, Ficus rumphii, Ficus religiosa, Mangifera indica* and *Polyalthia longifolia* are the tree species with maximum APTI grade, dense canopy of evergreen foliage along with high socio-economic values. Therefore, these tree species may be recommended for the plantation along the road sided and also for green belt development in polluted cities.

Table 1: Classification of plants on the basis of APTI value (Lakshmi *et al*., 2009)

Sr. No.	APTI value	Response
1	<1	Very sensitive
2	16 – 01	Sensitive
3	29 – 17	Intermediate
4	30 – 100	Tolerant

Table 2: Average summer (March-June 2019) values for major air pollutants at site S1, S2 and S3.

Study Site	$PM_{2.5}$ (µg/m^3)	PM_{10} (µg/m^3)	SO_2 (µg/m^3)	NO_2 (µg/m^3)
S1	45.25	178.25	18.75	29.5
S2	78.5	193.75	21.25	33.75
S3	95.25	240	26.5	39

Table 3: Gradation of plant species on the basis of air pollution tolerance index and other biological and socioeconomic characters for assessment of the anticipated performance index (API) of selected plants (Pathak *et al*., 2011)

Sr. No.	Grading	Characters	Pattern of assessment	Grade allotted
1	**Tolerance**	APTI	9.0-12.0	+
			12.1-15.0	++
			15.1-18.0	+++
			18.1-20.0	++++
			20.1-24.0	+++++
2	**Morphological**	Plant height	Small	–
			Medium	+
			Large	++
		Canopy structure	Sparse/ Irregular/ Globular	–
			Spreading/ Crown/ Open/ Semi-dense	+
			Spreading dense	++
		Type of plant	Deciduous	–
			Evergreen	+
3	**Laminar structure**	Size	Small	–
			Medium	+
			Large	++
		Texture	Smooth	–
			Coriaceous	+
		Hardness	Delineate	–
			Hardy	+
4	**Socio-economic**	Economic value	Less than three uses	–
			Three or four uses	+
			Five or more uses	++

Table 4: Assessment of plants on the basis of API score (Prajapati and Tripathi, 2008).

Grade	Score (%)	Assessment category
0	Up to 30	Not recommended for plantation
1	31-40	Very poor
2	41-50	Poor
3	51-60	Moderate
4	61-70	Good
5	71-80	Very good
6	81-90	Excellent
7	91-100	Best

Table 5: Calculation of APTI value of 15 selected plant species from site S1, S2 and S3.

Name of Plant species	Total chlorophyll (mg/ gm)			Ascorbic acid (mg/ gm)			pH			% Relative water content			APTI		
	S1	S2	S3	S1	S2	S3	S1	S2	S3	S1	S2	S3	S1	S2	S3
Alstonia scholaris (Satparni)	5.24	4.69	4.38	4.35	5.36	5.42	7.30	6.67	6.53	69.93	71.80	73.48	12.45	13.27	13.26
Azadirachta indica (Neem)	3.64	3.07	3.17	6.65	7.59	7.88	7.30	6.67	6.51	72.92	75.37	78.60	14.57	14.93	15.49
Cassia fistula (Amaltas)	7.88	7.30	8.31	9.55	9.89	10.52	7.44	6.81	5.81	77.82	77.23	78.21	22.41	21.68	22.68
Cassia siamea (Kassod)	3.84	2.89	6.78	7.51	8.67	6.12	6.18	5.55	6.82	75.82	77.53	73.23	15.11	15.07	15.65
Dalbergia sissoo (Shisham)	6.37	5.69	2.71	6.14	7.18	8.69	6.07	5.44	5.29	67.11	68.98	79.20	14.35	14.89	14.87
Delonix regia (Gulmohar)	7.93	6.53	5.93	8.21	8.93	9.23	6.71	6.17	6.10	78.21	79.73	81.60	19.84	19.31	19.26
Ficus benghalensis (Banyan)	8.45	8.10	7.60	9.84	10.88	11.89	7.67	7.04	7.01	79.61	84.60	86.83	23.82	24.93	26.05
Ficus religiosa (Pipal)	9.23	8.45	7.01	8.75	9.72	10.01	6.58	5.95	6.60	74.44	76.31	79.84	21.28	21.63	21.61
Ficus rumphii (Pilkhan)	8.31	7.68	7.52	9.71	10.72	11.16	7.58	6.95	6.80	78.61	81.32	83.45	23.29	23.82	24.33
Mangifera indica (Aam)	6.08	5.45	5.34	5.65	6.62	6.78	7.30	6.67	6.58	76.99	78.79	79.10	15.26	15.90	15.99
Melia azedarach (Bakain)	8.02	7.39	8.19	8.83	9.59	9.51	7.26	6.63	5.71	76.82	78.71	78.38	21.17	21.32	21.06
Nerium indicum (Kaner)	3.35	2.91	2.87	5.25	6.87	6.95	6.30	5.67	5.23	80.71	82.11	86.10	13.14	14.11	14.24
Polyalthia longifolia (False ashok)	9.35	8.63	6.80	8.51	9.11	9.43	6.57	5.94	6.57	72.82	74.69	79.23	20.83	20.74	20.53
Ricinus communis (Arandi)	8.17	7.12	5.37	3.89	5.11	7.23	7.10	6.91	5.32	78.12	71.23	70.02	13.75	14.29	14.73
Terminalia arjuna (Arjuna)	7.82	7.19	7.03	7.84	8.78	8.91	7.57	6.94	6.84	65.15	67.82	69.00	18.58	19.19	19.26
Mean	6.91	6.21	5.93	7.38	8.33	8.65	7.00	6.40	6.25	75.01	76.41	78.42	17.99	18.34	18.60
Minimum	3.35	2.89	2.71	3.89	5.11	5.42	6.07	5.44	5.23	65.15	67.82	69.00	12.45	13.27	13.26
Maximum	9.35	8.63	8.31	9.84	10.88	11.89	7.67	7.04	7.01	80.71	84.60	86.83	23.82	24.93	26.05

S1 = Town Basti (control), S = 2 RACL, and S3 = Indra Chowk

Table 6: Pearson's correlation coefficient (r) matrices between physio-biochemical parameters and APTI of plants species collected from site S1, S2 and S3.

		TCh	AA	pH	RWC
S1	AA	0.55	1.00		
	pH	0.30	0.26	1.00	
	RWC	0.03	0.19	0.08	1.00
	APTI	0.76	0.94	0.40	0.28
S2	AA	0.53	1.00		
	pH	0.37	0.13	1.00	
	RWC	0.00	0.50	0.07	1.00
	APTI	0.78	0.92	0.37	0.46
S3	AA	0.60	1.00		
	pH	0.43	0.20	1.00	
	RWC	-0.04	0.49	-0.02	1.00
	APTI	0.80	0.93	0.41	0.44

TCh is total chlorophyll contents, AA is ascorbic acid, RWC is percentage relative water contents and APTI is air pollution tolerance index

Table 7: Calculation of API score and assessment of 15 selected plant species from site S1

S1 (Town Basti)												
Plant name	**APTI**	**Plant height (small, medium, large)**	**Canopy structure**	**Type of plant (deciduous, evergreen)**	**Laminar**		**Economic importance**	**Hardiness**	**Grade alloted**		**API grade**	**API Assessment**
					Size (small, medium, large)	**Texture (smooth, Coriaceous)**			**Total plus (+)**	**% scoring**		
Ficus benghalensis (Banyan)	+++++	++	+	+	++	+	+	+	14	87.5	6	Excellent
Ficus religiosa (Pipal)	+++++	++	+	+	++	+	+	+	14	87.5	6	Excellent
Ficus rumphii (Pilkhan)	+++++	++	+	+	++	+	+	+	14	87.5	6	Excellent
Mangifera indica (Aam)	+++	++	++	+	+	+	++	+	13	81.25	6	Excellent
Polyalthia longifolia (False ashok)	+++++	++	++	+	+	+	+	+	13	81.25	6	Excellent
Dalbergia sissoo (Shisham)	++	++	++	+	+	+	+	+	11	68.75	4	Good
Terminalia arjuna (Arjuna)	++++	++	++	-	+	-	+	+	11	68.75	4	Good
Alstonia scholaris (Satparni)	++	++	++	+	+	+	+	+	10	62.5	4	Good
Cassia fistula (Amaltas)	+++++	+	+	-	+	-	+	+	10	62.5	4	Good
Azadirachta indica (Neem)	++	++	++	+	-	-	++	+	9	56.25	3	Moderate
Cassia siamea (Kassod)	++	+	+	+	+	+	+	+	9	56.25	3	Moderate
Melia azedarach(Bakain)	+++++	++	+	+	-	-	++	+	9	56.25	3	Moderate
Delonix regia (Gulmohar)	++++	+	+	+	-	-	+	-	8	50	3	Moderate
Ricinus communis (Arandi)	++	+	-	+	++	-	+	+	8	50	3	Moderate
Nerium indicum (Kaner)	++	+	+	+	-	+	-	-	6	37.5	1	Very poor

Table 8: Calculation of API score and assessment of 15 selected plant species from site S2

S2 (RACL)												
Plant name	**APTI**	**Plant height (small, medium, large)**	**Canopy structure**	**Type of plant (deciduous, evergreen)**	**Laminar**		**Economic importance**	**Hardiness**	**Grade alloted**		**API grade**	**API Assessment**
					Size (small, medium, large)	**Texture (smooth, Coriaceous)**			**Total plus (+)**	**% scoring**		
Ficus benghalensis (Banyan)	+++++	++	+	+	++	+	+	+	14	87.5	6	Excellent
Ficus religiosa (Pipal)	+++++	++	+	+	++	+	+	+	14	87.5	6	Excellent
Ficus rumphii (Pilkhan)	+++++	++	+	+	++	+	+	+	14	87.5	6	Excellent
Mangifera indica (Aam)	+++++	++	++	+	+	+	+	+	13	81.25	6	Excellent
Polyalthia longifolia (False ashok)	+++	++	++	+	+	+	++	+	13	81.25	6	Excellent
Dalbergia sissoo (Shisham)	++++	++	++	-	+	-	+	+	11	68.75	4	Good
Terminalia arjuna (Arjuna)	++	++	++	+	+	+	+	+	11	68.75	4	Good
Alstonia scholaris (Satparni)	+++++	+	+	-	+	-	+	+	10	62.5	4	Good
Cassia fistula (Amaltas)	+++	++	++	+	-	-	++	+	10	62.5	4	Good
Azadirachta indica (Neem)	++	++	++	+	+	+	+	+	10	62.5	4	Good
Cassia siamea (Kassod)	+++++	++	+	+	-	-	++	+	9	56.25	3	Moderate
Melia azedarach(Bakain)	+++	+	-	+	++	-	+	+	9	56.25	3	Moderate
Delonix regia (Gulmohar)	++	+	+	+	+	+	+	+	9	56.25	3	Moderate
Ricinus communis (Arandi)	++++	+	+	+	-	-	+	-	8	50	3	Moderate
Nerium indicum (Kaner)	++	+	+	+	-	+	-	-	6	37.5	1	Very poor

Table 9: Calculation of API score and assessment of 15 selected plant species from site S3

S3 (Indra Chowk)												
Plant name	APTI	Plant height (small, medium, large)	Canopy structure	Type of plant (deciduous, evergreen)	Laminar: Size (small, medium, large)	Laminar: Texture (smooth, Coriaceous)	Economic importance	Hardiness	Grade alloted: Total plus (+)	Grade alloted: % scoring	API grade	API Assessment
Ficus benghalensis (Banyan)	+++++	++	+	+	++	+	+	+	14	87.5	6	Excellent
Ficus religiosa (Pipal)	+++++	++	+	+	++	+	+	+	14	87.5	6	Excellent
Ficus rumphii (Pilkhan)	+++++	++	+	+	++	+	+	+	14	87.5	6	Excellent
Mangifera indica (Aam)	+++++	++	++	+	+	+	+	+	13	81.25	6	Excellent
Polyalthia longifolia (False ashok)	+++	++	++	+	+	+	++	+	13	81.25	6	Excellent
Dalbergia sissoo (Shisham)	++++	++	++	-	+	-	+	+	11	68.75	4	Good
Terminalia arjuna (Arjuna)	++	++	++	+	+	+	+	+	11	68.75	4	Good
Alstonia scholaris (Satparni)	+++++	+	+	-	+	-	+	+	10	62.5	4	Good
Cassia fistula (Amaltas)	+++	++	++	+	-	-	++	+	10	62.5	4	Good
Azadirachta indica (Neem)	++	++	++	+	+	+	+	+	10	62.5	4	Good
Cassia siamea (Kassod)	+++++	++	+	+	-	-	++	+	9	56.25	3	Moderate
Melia azedarach(Bakain)	+++	+	-	+	++	-	+	+	9	56.25	3	Moderate
Delonix regia (Gulmohar)	++	+	+	+	+	+	+	+	9	56.25	3	Moderate
Ricinus communis (Arandi)	++++	+	+	+	-	-	+	-	8	50	3	Moderate
Nerium indicum (Kaner)	++	+	+	+	-	+	-	-	6	37.5	1	Very poor

Figure 1: Effect of air pollution on total chlorophyll content (mg/ g fresh wt) of different plant species at three sites

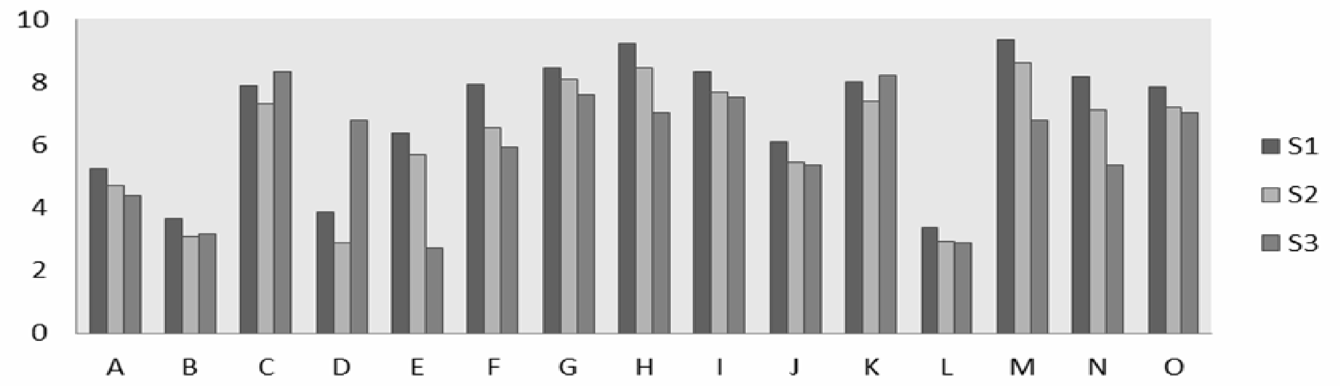
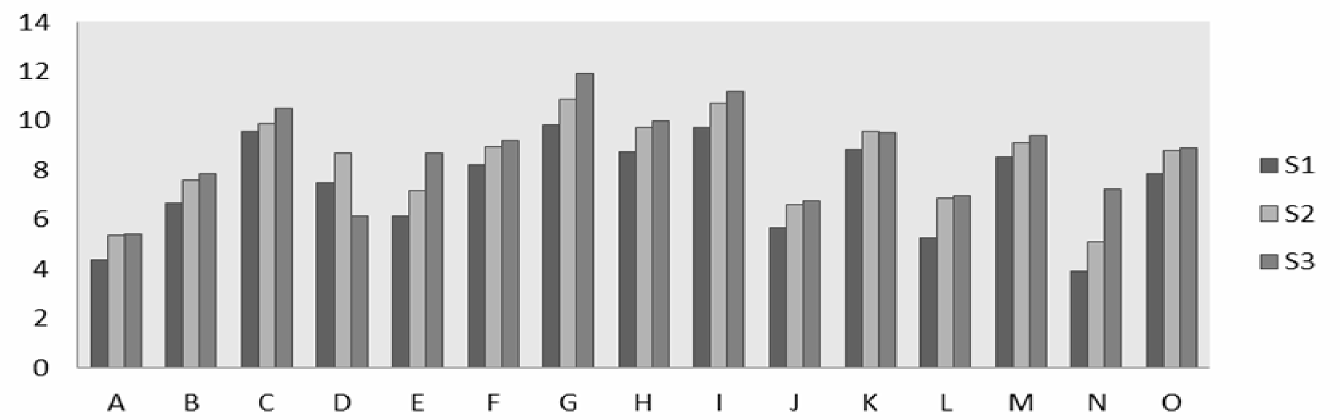
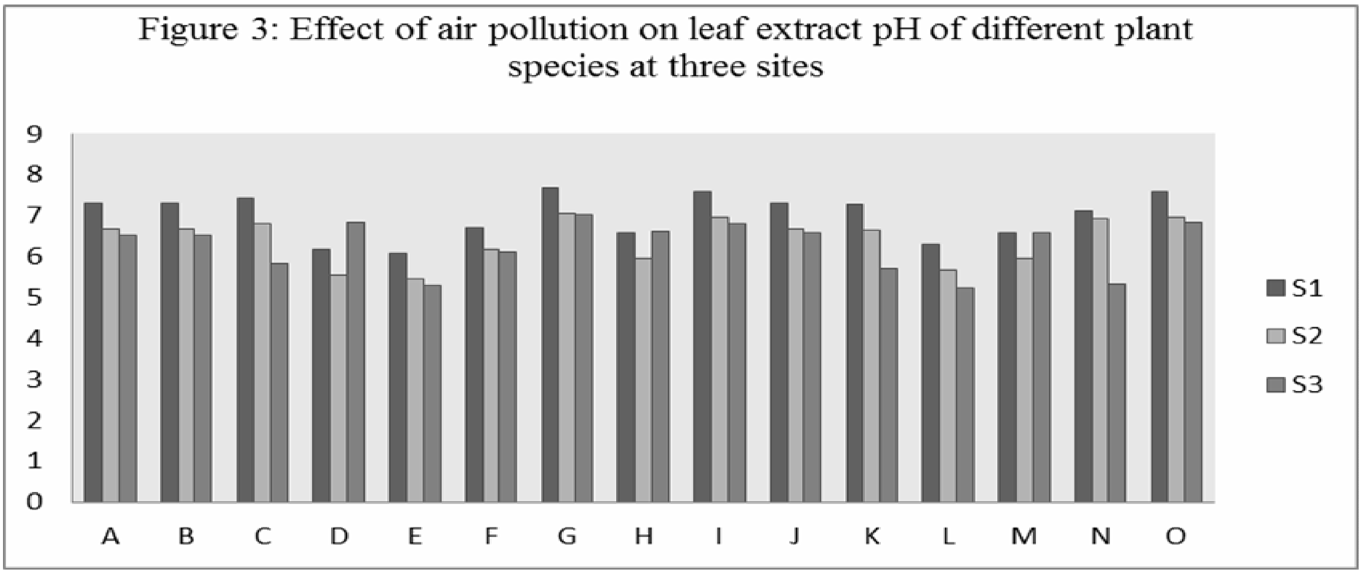
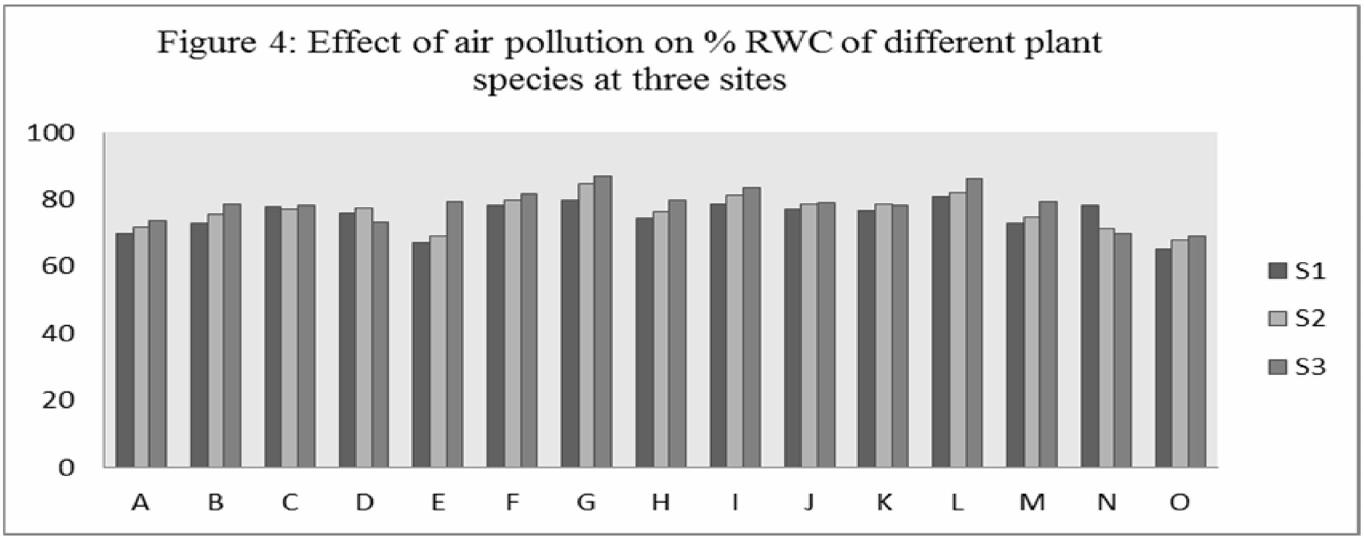


Figure 2: Effect of air pollution on Ascorbic Acid content (mg/ g fresh wt) of different plant species at three sites







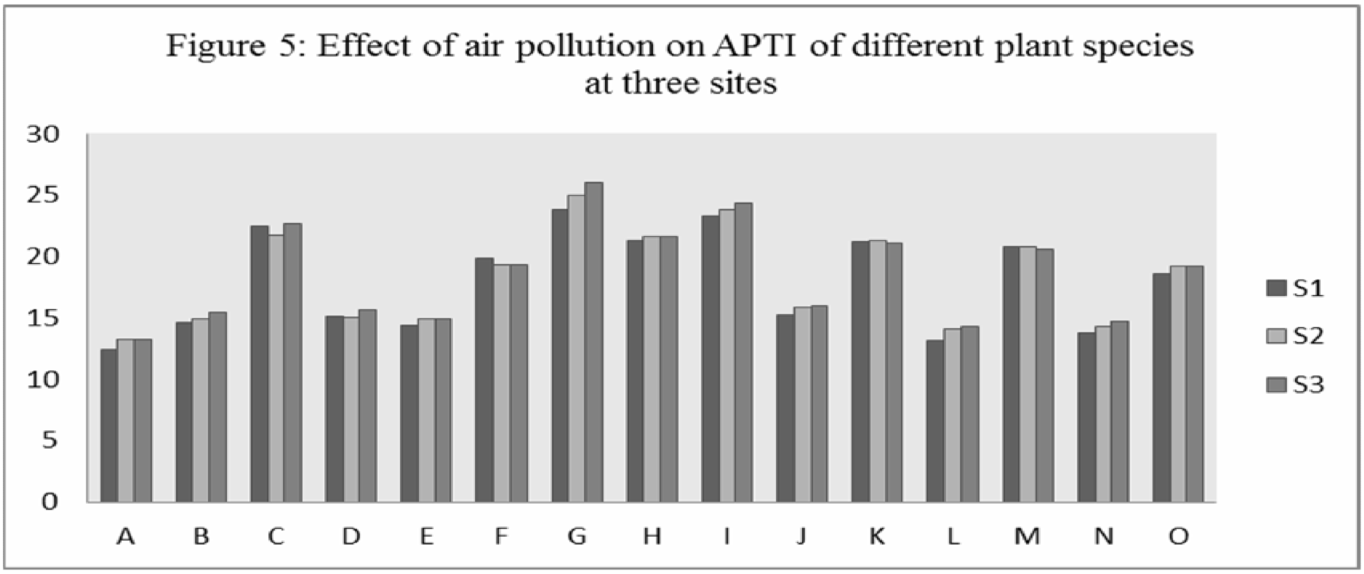


Figure 1 to 5

(S1, S2 and S3 are study sites) S1 = Town Basti (control), S2 = RACL, S3 = Indra Chowk; and (A to O are plant species) A = *Alstonia scholaris* (Satparni), B = *Azadirachta indica* (Neem), C = *Cassia fistula* (Amaltas), D = *Cassia siamea* (Kassod), E = *Dalbergia sissoo* (Shisham), F = *Delonix regia* (Gulmohar), G = *Ficus benghalensis* (Banyan), H = *Ficus religiosa* (Pipal), I = *Ficus rumphii* (Pilkhan), J = *Mangifera indica* (Aam), K = *Melia azedarach* (Bakain), L = *Nerium indicum* (Kaner), M = *Polyalthia longifolia* (False ashok), N = *Ricinus communis* (Arandi), O = *Terminalia arjuna* (Arjuna)

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REFERENCES

Agarwal, S.K. (1986). A new distributional function of foliar phenol concentration in the evaluation of plants for their air pollution tolerance index. *Acta Ecol.* 8 (2) : 29-36.

Akram, N.A.; Shafiq, F. and Ashraf, M. (2017). Ascorbic acid - A potential oxidant scavenger and its role in plant development and abiotic stress tolerance. *Front Plant Sci.* 8 : 613.

Aleadelat, W. and Ksaibati, K. (2018). A comprehensive approach for quantifying environmental costs associated with unpaved roads dust. *J Environ Econ Pol.* 7 (2) : 130-144.

Anake, W.U.; Eimanehi, J.E. and Omonhinmin, C.A. (2019). Evaluation of air pollution tolerance index and anticipated performance index of selected plant species. *Indones J Chem.* 19 (1): 239-244.

Bakiyaraj, R. and Ayyappan, D. (2014). Air pollution tolerance index of some terrestrial plants around an industrial area. *Int J Mod Res Rev*. 2 (1) : 1-7.

Begum, A. and Harikrishna, S. (2010). Evaluation of some tree species to absorb air pollutants in three industrial locations of South Bengaluru, India. *E - J Chem*. 7(1) : 151-156.

Bharti, S.K.; Kumar, D.; Anand, S.; Barman, S.C. and Kumar, N. (2017). Characterization and morphological analysis of individual aerosol of PM_{10} in urban area of Lucknow, India. *Micron.* 103 : 90-98.

Census of India (2011) Office of the Registrar General & Census Commissioner, Ministry of home affairs, Govt. of India. Available at: http://censusindia.gov.in/2011-provresults/data_files/up/Census2011Data%20Sheet-UP.pdf.

Gangwar, C.; Choudhari, R.; Chauhan, A.; Kumar, A.; Singh, A. and Tripathi, A. (2019). Assessment of air pollution caused by illegal e-waste burning to evaluate the human health risk. *Environ Int.* 125 : 191-199.

Chaulya, S.K.; Chakraborty, M.K. and Singh, R.S. (2001). Air pollution modelling for a proposed limestone quarry. *Water Air Soil Poll*. 126(1): 171-191.

Gupta, A.; Kumar, M.; Chauhan, A.; Kumar, A. and Tripathi, A. (2020). Assessment of air pollution tolerance index and evaluation of air pollution anticipated performance index of various plants and their application in planning of Moradabad city, India. *Poll Res*. 39(4) : 463-473.

Gupta, M.; Anita, G.; Gupta, R.; Neeraj, D. and Sarita, N. (2019). Pollution controlling ability of indigenous plant species growing around drain in Delhi. *Poll Res.* 38 : 29–35.

Hariram, M.; Sahu, R. and Elumalai, S.P. (2018). Impact assessment of atmospheric dust on foliage pigments and pollution resistances of plants grown nearby coal based thermal power plants. *Arch Environ Contam Toxicol.,* 74(1) : 56-70.

Jacobs, M.B. and Hochheiser, S. (1958). Continuous sampling and ultramicro determination of nitrogen dioxide in air. *Anal Chem*. 30(3): 426-428.

Joshi, P.C. and Swami, A. (2007). Physiological responses of some tree species under roadside automobile pollution stress around city of Haridwar, India. *The Environmentalist*. 27(3): 365-374.

Karmakar, D.; Deb, K. and Padhy, P.K. (2021). Ecophysiological responses of tree species due to air pollution for biomonitoring of environmental health in urban area. *Urban Clim*. 35 : 100741.

Keller, T. and Schwager, H. (1977). Air pollution and ascorbic acid. *Eur J Plant Pathol.* 7(6) : 338-350.

Krishnaveni, G. (2018). Air pollution tolerance index of selected plants in Vijayawada city, Andhra Pradesh. *Int J Green Pharm.* 11(04) : S877

Kumar, A.; Gupta, A.; Shyam, S. and Tripathi, A. (2015). Estimation of air pollution tolerance index in various plant species in industrial area, Gajraula, India. *Pollut Res*., 34(2) : 271-276.

Lakshmi, P.S.; Sravanti, K.L. and Srinivas, N. (2009). Air pollution tolerance index of various plant species growing in industrial areas. *Int J of Environ Sci.* 2 : 203-206.

Leghari, S.K.; Akbar, A.; Qasim, S.; Ullah, S.; Asrar, M.; Rohail, H.; Ahmed, S.; Mehmood, K. and Ali, I. (2019). Estimating anticipated performance index and air pollution tolerance index of some trees and ornamental plant species for the construction of green belts. *Pol J Environ Stud*. 28 : 1759-1769.

Lima, J.S.; Fernandes, E.B. and Fawcett, W.N. (2000). *Mangifera indica* and *Phaseolus vulgaris* in the bioindication of air pollution in Bahia, Brazil. *Ecotoxicol Environ Safety*. 46(3) : 275-278.

Liu, Y.J. and Ding, H.U.I. (2008). Variation in air pollution tolerance index of plants near a steel factory: Implication for landscape-plant species selection for industrial areas. *WSEAS Transactions on Environment and Development.* 4(1): 24-32.

Maclachlan, S. and Zalik, S. (1963). Plastid structure, chlorophyll concentration, and free amino acid composition of a chlorophyll mutant of barley. *Canadian Journal of Botany*, 41(7): 1053-1062.

Pandey, A.K.; Pandey, M.; Mishra, A.; Tiwary, S.M. and Tripathi, B.D. (2015). Air pollution tolerance index and anticipated performance index of some plant species for development of urban forest. *Urban Forestry & Urban Greening*. 14(4): 866-871.

Patel, D. and Kumar, J.I.N. (2018). An evaluation of air pollution tolerance index and anticipated performance index of some tree species considered for green belt development: A case study of Nandesari industrial area, Vadodara, Gujarat, India. *Open J Air Poll*., 7(1): 1-13.

Pathak, V.; Tripathi, B.D. and Mishra, V.K. (2011). Evaluation of anticipated performance index of some tree species for green belt development to mitigate traffic generated noise. *Urban Forestry & Urban Greening*. 10(1): 61-66.

Rai, P.K. (2020). Particulate matter tolerance of plants (APTI and API) in a biodiversity hotspot located in a tropical region: Implications for eco-control. *Part Sci Tech*. 38(2): 193-202.

Prajapati, S.K. and Tripathi, B.D. (2008). Anticipated Performance Index of some tree species considered for green belt development in and around an urban area: A case study of Varanasi city, India. *J Environ Manage.* 88(4): 1343-1349.

Rai, P.K. (2016). Impacts of particulate matter pollution on plants: Implications for environmental biomonitoring. *Ecotoxicol Environ Saf.* 129: 120-136.

Rai, P.K. (2019). Particulate matter tolerance of plants (APTI and API) in a biodiversity hotspot located in a tropical region: Implications for eco-control. *Part Sci Technol.,* 38(2) : 193-202.

Rai, P.K. and Panda, L.L. (2014). Dust capturing potential and air pollution tolerance index (APTI) of some road side tree vegetation in Aizawl, Mizoram, India: an Indo-Burma hot spot region. *Air Qual Atmos Health*. 7(1) : 93-101.

Rao, P.S.; Gavane, A.G.; Ankam, S.S.; Ansari, M.F.; Pandit, V.I. and Nema, P. (2004). Performance evaluation of a green belt in a petroleum refinery: a case study. *Eco Eng*. 23(2): 77-84.

Saini, D.K.; Garg, S.K. and Kumar, M. (2019). Major air pollutants and their effects on plant and human health: A review. *Plant Archives*. 19(2) : 3273-3278.

Seyyednejad, S.M.; Motamedi, H. and Lordifard, P. (2017). Biochemical changes of *Conocarpus erectus* (combretaceae) in response to gas refinery air pollution as an air pollution indicator. *Pollut*. 3(2): 185-190.

Singh, S.K. and Rao, D.N. (1983). Evaluation of plants for their tolerance to air pollution. *In proceedings of symposium on air pollution control,* 1(1): 218-224.

Singh, S.N. and Verma, A. (2007). Phytoremediation of air pollutants: A review. *Environ Bioremed Technol.* 293-314.

Tak, A.A. and Kakde, U.B. (2020). Evaluation of air pollution tolerance and performance index of plants growing in industrial areas. *Int J Eco Environ Sci*. 2(1): 1-5.

Tambussi, E.A.; Bartoli, C.G.; Beltrano, J.; Guiamet, J.J. and Araus, J.L. (2000). Oxidative damage to thylakoid proteins in water□stressed leaves of wheat (*Triticum aestivum*). *Physiologia Plantarum.* 108(4): 398-404.

West, P.W. and Gaeke, G.C. (1956). Fixation of sulphur dioxide as sulfitomercurate (II) and subsequent colorimetric determination. *Anal Chem.*, 28: 1916-1819.

Yadav, R. and Pandey, P. (2020). Assessment of Air Pollution Tolerance Index (APTI) and Anticipated Performance Index (API) of Roadside Plants for the Development of Greenbelt in Urban Area of Bathinda City, Punjab, India. *Bulletin Environ Contam Toxicol*. 105(6): 906-914.