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Research Article

Air pollution tolerance index: An approach towards the effective green belt around Kathmandu metropolitan city, Nepal

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Abstract

Road vegetation is an effective way to mitigate road generated particulates. Green belts with high Air Pollution Tolerance Index (APTI) value in the urban centers play an important role in the amelioration of the air quality. The APTI of the trees with higher abundance were examined for bio-chemical parameters such as pH, ascorbic acid, total chlorophyll and relative water content. The APTI value of tree species varied from 5.56 (*Punica granatum*) to 79.99 (*Populous deltoids*). Higher the APTI value, higher is the tolerance towards air pollution. Among the tree species, *Jacaranda mimosifolia, Pinus roxburghi, Ficus benjamin, Celtis australis, Alnus nepalensis, Callistemon lanceolatus, Schima wallichi, Pyrus pyrifolia* and *Punica granatum* were found sensitive, whereas *Prunus persia, Populus deltoides, Thuja sp.* and *Grevillea robusta* were found to be the most tolerant species. The green belts constituting higher number of tolerant to moderately tolerant species of trees results in better air pollution sink and air quality refinement. In order to find plants with good APTI, further extensive studies should be carried out and valley plantation program should give priority of those plants having higher APTI value.

Key words: APTI, Environment management, Green belt, Sensitive

Introduction

Air pollution is a regional and global problem and is one of the major factors deteriorating the quality of life in urban areas, making people more vulnerable to diseases all over the world (Esfahani et al., 2013; Makhelouf , 2009). Cities are responsible for the emission of 71% of energy related to global greenhouse gases worldwide (Hoornweg et al., 2011) and vehicular emission is one of the major contributors for emission of combustion gases, due to increasing dependency on private transportation (Liu & Ding, 2008; Tiwari et al., 2011). Road traffic is the main cause for air pollution in the metropolitan cities resulting in environmental as well as health problems due to harmful emissions (Gidde & Sonawane, 2012). Vegetation is always considered as an indicator for an effective sink for HF, SO_2, Cl_2, NO_2 and O_3 and to a less extent PAN (Peroxyacetyl Nitrate) during the growing season and also for removal of HCl resulting in reduction of concentration of atmospheric pollutants (HILL, 1071).

Plantations on the street canyons can result in reduction of about 40% for NO_2 and 60% for particulate matter (PM) (Pugh et al., 2012). The removal of particulate matter occurs both day and night (as particles are intercepted by leaf and bark surfaces) throughout the year, whereas the effect on ozone (O_3), SO_2 and NO_2 is during the day period (in leaf season), when trees are transpiring water and carbon monoxide removal occurs both day and night of the leaf-in-season (Nowak et al., 2006).

Bio-monitoring of air pollution and its impact on plants biochemical parameters is highly relevant in air pollution science (Rai et al., 2013). The parameters like leaf pH, relative water content, chlorophyll content, and ascorbic acid content combinely suggested as the best index of the susceptibility levels of plants known as the air pollution tolerance index (APTI) (Kuddus et al., 2011), as plant sensitivity and tolerance varies with change in these parameters (Liu & Ding, 2008; Singh & Verma, 2007). Combination of these parameters gives more reliable results than those obtained by individual parameters (Bora & Joshi, 2014). Plantation along the roadside may seem as an easy job, but all the factors that can affect a tree species should be considered beforehand for its sustainability. Air pollutants can affect plants directly through leaves or indirectly through soil acidification (Abida & Harikrishna, 2010). Air pollution can have major effect on photosynthetic system, leaf longevity and on the pattern of carbon allocation within plants (Kuddus et al., 2011) and also can cause increased

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permeability resulting in early senescence of leaves (due to loss of water and dissolved nutrients) (Masuch et al., 1988). Road side vegetations are even more sensitive, as they are in direct contact of the pollutants, which eventually will harm them adversely and make life difficult. Evaluation of the tolerance level of the plants can provide an effective basis for the plantation of trees in air polluted areas, necessary for longevity and sustainable planning of green belts and amelioration of air quality. This study can be a basis for identification of the tolerant trees that can act as a sink as well as screen air pollution and helpful for future plantations, especially for green belt construction in the valley.

Site description:
Kathmandu Valley lies at 1300 m asl, located between latitudes 27°32'13" & 27°49'10" north and longitudes 85°11'31" & 85°31'38" east. The valley is bowl shaped being surrounded by Mahabharat range on all sides. South and south westerly wind dominate the valley (Pradhan et al., 2012). The calm and low wind speeds in the valley causes poor dispersion conditions and the bowl-shaped topography makes the area more prone to air pollution (Pradhan et al., 2012, Shrestha, 2001). Kathmandu city is amongst one of the world's most polluted cities (Chattopadhyay et al., 2010), particulate matter being one of the major pollutant (Shrestha, 2001). The number of vehicles has increased tremendously with the rate of 4.3% in the valley (Department of Transport Management, 2014).

Materials and Methods

The abundant trees along the 27 km Ring Road side of the valley was observed and least abundant tree species were used as sample for analysis in the study. UN Park and forest patch within the premises of Buddhanilkantha School were selected as control sites and studied according to tolerant trees. Leaves were collected from the selected plant species in early morning. Plants were randomly selected and three replicates of fully matured leaves were used. Leaf samples were kept in polythene bag, in ice box and brought to the laboratory for biochemical analysis. The laboratory work was conducted from August to October. APTI value was calculated using the formula (Eq. 1) (Chouhan et al., 2012; Thambavani et al., 2011).

$$\text{APTI: } \frac{[A(T+P)+(R)]}{10} \quad \ldots 1$$

Where,
A= Ascorbic acid content (mg/gm) (dry weight)
T= Total chlorophyll content (mg/gm)
P= pH of leaf extract and
R= Relative water content (%).
APTI values were categorized into three groups (Table 1) (Thambavani & Kumar, 2011).

Table 1 Category of tree species based on APTI

APTI value	Response
30-100	Tolerant
29-17	Intermediate
16-1	Sensitive

Total chlorophyll (TCh) was determined according to (Arnon, 1949) 1.0 gm of fresh leaves blended and then extracted with 20.0 ml of 80% acetone and left for 15 min. The liquid portion was decanted into another test tube and was centrifuged at 2,500 rpm for 3 min. The supernatant was then collected and the absorbance was measured at 645 nm and 663 nm using a spectrophotometer. Calculations were done using the Eq. 2 and 3.

$$\text{Chlorophylla} = (12.7\ \text{Dx}\ 663\ 2.69\ \text{DX}\ 645 * \text{V})/\ 1000\text{W mg/gm} \ldots 2$$

$$\text{Chlorophyllb} = (22.9\ \text{Dx}\ 645\ 4.68\ \text{DX}\ 663 * \text{V})/\ 1000\text{W mg/gm} \ldots 3$$

$$\text{TCH} = \text{chlorophyll a+b (mg/gm)} \quad \ldots 4$$

Where,
Dx = Absorbance of the extract at the wavelength Xnm
V = Total volume of the chlorophyll solution (ml)
W = Weight of the tissue extracted (gm)

Relative water content (RWC) was determined according to Sadeghian and Mortazaienezhad (2012) and calculated using Eq. 5.

$$\text{RWC} = (\text{FW - DW/TW - DW}) \times 100 \quad \ldots 5$$

Fresh weight (FW) was obtained by weighing the leaves. The leaf samples were then immersed in water overnight and then blotted dry and then weighed to obtain the turgid weight (TW). The leaves were then blotted to dryness and placed in oven at 105°C for 2 hours to obtain the dry weight (DW).

Ascorbic acid (AA) content was calculated using the spectrophotometric method according to Bajaj and Kaur (1981). In which, about 1.0 gm of the fresh foliage was put in a test-tube, 4.0 ml oxalic acid - EDTA extracting solution was added; then 1.0 ml of orthophosphoric acid and then 1.0 ml of 5% sulphuric acid was added to this mixture, 2.0 ml of ammonium molybdate was added and then 3.0 ml of water. The solution was then allowed to stand for 15 minutes. After which the absorbance at 760 nm was measured with a spectrophotometer. The concentration of ascorbic acid in samples was calculated from standard ascorbic acid curve. Leaf extract pH was determined following the method of Chauhan et al. (2012). For that, about 1.0 gm of the fresh leaves was homogenized in 10 ml de-ionised water. This mixture was filtered and the pH of the leaf extract was determined after calibrating pH-meter with buffer solution of pH 4 and pH 9.

Results and Discussion

The most abundant tree species along the Ring-road side were *Gravellia robusta* (1057), *Jacaranda mimosifolia* (903), *Populas deltoids* (707), *Callistemon lanceolatus* (241), *Thuja sp.* (193), *Cinnamomum camphora* (154) and *Ficus elastica* (112), whereas the least obtained species were Tudi (5), *Ficus benjamin* (4) and *Punica granatum* (2). Similarly, from the controlled sampling site; the forest of Buddhanilkantha School premises and UN-Park, *Alnus nepalensis* (56), *Cinnamomum camphora* (20) were found to be the most common tree and *Schima wallichi* (1), *Quercus spp.* (1) and *Pyrus communis* (1) were obtained as the species of least occurrence within the premises of Buddhanilkantha School and in the UN-Park *Callistemon lanceolatus* (21), *Grevillea robusta* (14) were obtained as the most abundant and *Melia azedarach* (1) and *Jacaranda mimosifolia* (1) as the least abundant in the park.

The abundant trees species from the polluted site (Ring Road) along with two least abundant trees were taken as sample species for the evaluation of the air pollution tolerance index (Table 2).

Relative water content (RWC) is the total water content in a given leaf relative to its fully tur gid or hydrated state (Bora & Joshi, 2014). High amount of water content in plants mak es the plant species drought resistance (Chouhan et al., 2012; Sadeghian & Mortazaienezhad, 2012). Plants with high RWC are more tolerant to air pollutants (Chouhan et al., 2012; Ghar ge & Menon, 2012; Kuddus et al., 2011). The RWC in the sampled species ranged from 34.14% to 92.30%, with highest value in *Thuja sp.* (92.30%) followed by *Prunus persia* (90.29%) and *Cinnamomum camphora* (87.25%) (Fig.1). Lower values were reported *Callistemon lanceolatus* (44.58%) and *Punica granatum* (34.15%) (Table 2). This results reveal that *Prunus persia, Thuja sp.* and *Cinnamomum camphora* are more drought resistance as well as more air pollutants stress resistance (among the studied samples). Relative water content of plants near polluted sites was found higher than those present in the non-polluted sites and also plants retain more water at polluted sites to become more tolerant (Bora & Joshi, 2014). The samples of the controlled site represent lower RWC, ranging from 47.32% to 56.74% which is comparatively less than the majority of samples from polluted site.

Plants with high amount of water content is favorable to combat the adverse effects (Kuddus et al., 2011) and maintain the ecological balance, whereas plants with lower tolerance may lead to reduction in the transpiration rate resulting in damage to the leaf engine that pulls water up from the roots (Chouhan et al., 2012; Seyyednjad et al., 2011) and then the plants neither can uptake the minerals nor cool the leaf (Seyyednjad et al., 2011) destroying the whole plant system.

The chlorophyll content in the studied tree leaves ranged from 0.03 mg/gm to 0.60 mg/gm in the roadside trees along the Ring-road. This value exhibited greater in controlled site, i.e. 0.79 mg/gm (Fig. 2). Among the tree species, *Punica granatum* exhibited the highest chlorophyll content followed by *Celtis australis, Pinus roxburghii* and *Cinnamomum camphora* , whereas *Jacaranda mimosifolia* (0.04 mg/gm) and *Ficus elastica* (0.03 mg/gm) exhibited the lowest chlorophyll content among the studied tree leaves (Fig. 2, Table 2).

The chloroplast is the primar y site of attack by air pollutants, affecting the leaf chlorophyll content (loss in the chlorophyll content) (Tripathi & Gautam, 2007). Chlorophyll undergoes several photochemical reactions such as oxidation, reduction, reversible bleaching under stress conditions (Sharma et al., 2013) influenced by pollution level as well as other biotic and abiotic stresses. Depletion in chlorophyll content causes a decrease in productivity of plant due to decrease in photosynthetic activity (Seyyednjad et al., 2011) and subsequently plant exhibit poor vigor, affecting the tolerance of plants towards air pollution (Chinthala & Khare, 2012; Singh & Verma, 2007). *Schima wallichi* exhibited the highest chlorophyll content being far from the pollution (less polluted-controlled site) and representing high productivity of plant and functioning.

Table 2 Air pollution tolerance index (APTI) of tree species

S.No.	Scientific Name	Common name	Relative water content (%)	pH (mg/gm)	Total Chlorophyll (mg/gm)	Ascorbic acid	APTI
1.	*Populus deltoides*	Laharepipal	80.59	6.1	0.36	111.35	79.99
2.	*Prunus persia*	Aaru	90.29	5.8	0.23	111.97	77.44
3.	*Grevillea robusta*	Kalki	67.55	6.0	0.43	41.01	33.24
4.	*Thuja* sp.	Dhupi	92.30	5.9	0.18	37.85	32.55
5.	*Cinnamomum camphora*	Kapur	87.25	6.1	0.47	29.45	28.16
6.	*Ficus elastica*	Rubber plant	71.63	6.2	0.03	29.49	25.67
7.	*Mussaenda grandiflora*	Asharephool	77.25	5.6	0.27	22.47	21.10
8.	*Eucalyptus alba*	Masala	69.71	5.1	0.54	20.46	18.55
9.	*Jacaranda mimosifolia*	Siris	79.38	4.6	0.04	15.27	15.09
10.	*Callistemon lanceolatus*	Bottle brush	44.58	6.1	0.42	8.82	10.25
11.	*Pinus roxburghii*	Pine	58.85	3.6	0.49	5.46	8.14
12.	*Ficus benjamina*	Ficus	58.55	4.6	0.29	3.51	7.57
13.	*Celtis australis*	Khari	41.52	6.7	0.54	1.99	5.59
14.	*Punica granatum*	Anar	34.15	4.9	0.60	3.86	5.56

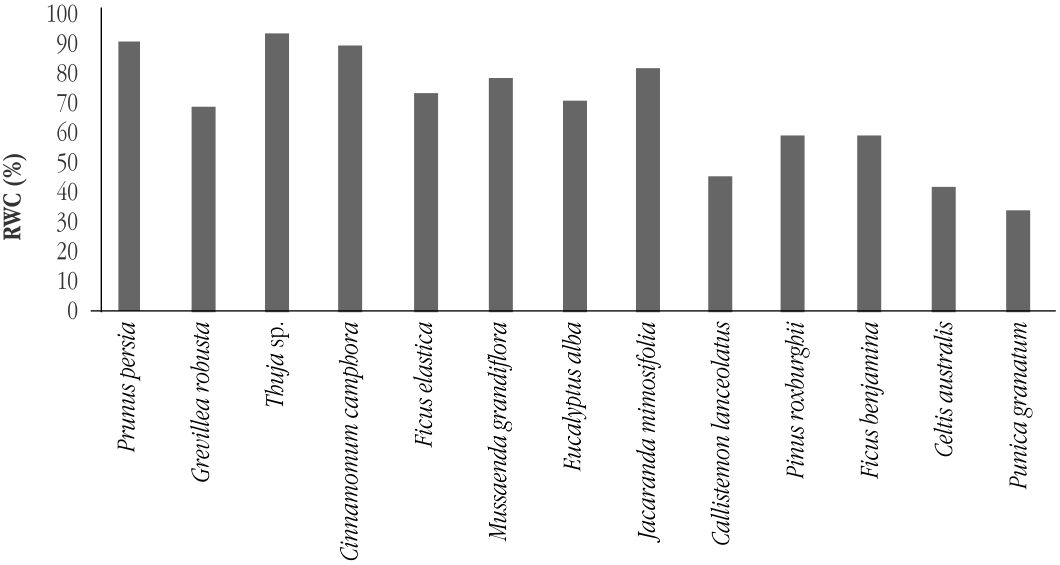

Figure 1 Variation in relative water content in the selected tree species

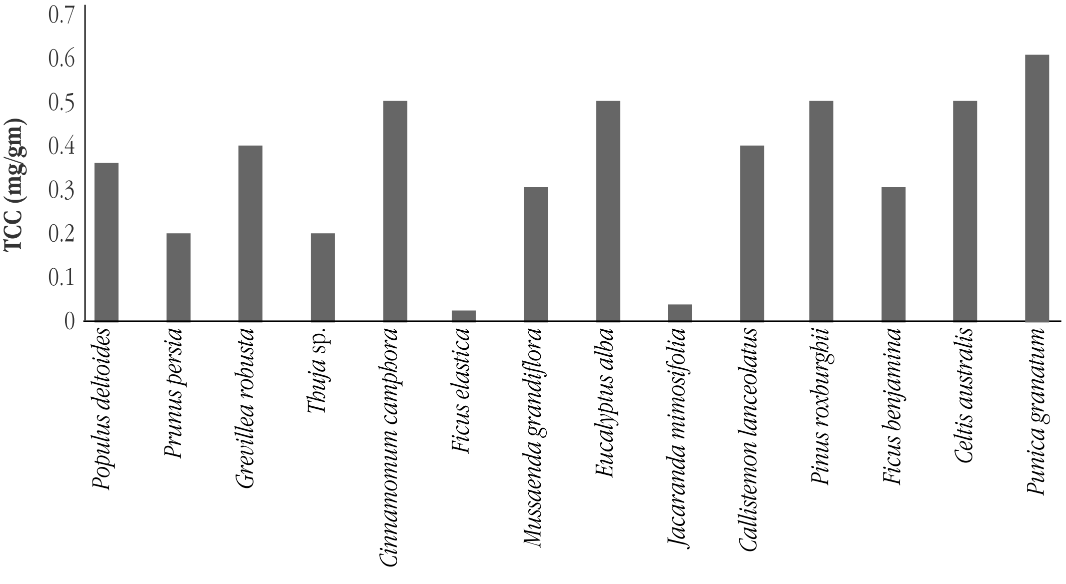

Figure 2 Variation in total chlorophyll content in the selected tree species

Ascorbic acid is an important antioxidant that is found in all plant parts (Keller & Schwager, 1977; Singh et al., 1991). It plays a significant role in cell-wall synthesis, defense and cell division (Seyyednjad et al., 2011) and also protects chloroplasts and chlorophyll functions through its pH dependent reducing power (Singh et al., 1991). It influences resistance to adverse environmental conditions in plants against air pollution (Lima et al., 2000) to prevent the damaging effect in plant tissues (K apoor & Bansal, 2013). High pollution load causes an increase in ascorbic acid content in plants, due to the increased rate of production of reactive oxygen species (ROS) during photo-oxidation process (Lima et al., 2000; Tripathi & Gautam, 2007) and also plays an important role in protection of chlorophyll from H_2O_2 induced damages (Singh & Verma, 2007) .

The ascorbic acid content in the leaf extracts ranged from 1.99 mg/gm to 111.97 mg/gm. Most of the plants exhibited low ascorbic acid content in the leaves, which ranged from 20.0 mg/gm to 42.0 mg/gm (Fig. 3). The decrease in the ascorbic acid content can be due to pollution exposure (Keller & Schwager , 1977). *Prunus persia* showed the highest ascorbic acid content followed by *Populus deltoides* and *Grevillea robusta*, whereas *Ficus benjamin* and *Celtis australis* showed low ascorbic acid content. High pollution level in the air increases the phytotoxicity of plants (Singh & Verma, 2007) by impinging a decrease in the ascorbic acid content which eventually results in increased susceptibility of plants to pollution. High ascorbic acid content in leaf represents a higher tolerance against air pollution load and higher resistance (Singh & Verma, 2007). Higher the level of ascorbic acid content, more will be the tolerance toward air pollutants (Kousar et al., 2014; Kuddus et al., 2011).

pH is an important parameter of plant physiology to measure the air pollution tolerance index. Photosynthesis is strongly associated with the leaf pH, the low leaf pH in the same species indicates reduced photosynthetic rate (Chouhan et al., 2012). More acidic pH is more susceptible, whereas neutral (pH 7) and more basic pH are considered to be more tolerant (Singh & Verma, 2007). The pH level of the studied plant leaves ranged from 3.6 to 6.7, with highest pH values in *Celtis australis* followed by *Ficus elastica* and lowest in *Pinus roxburghii* (Fig. 4). The lower leaf pH, i.e. towards the acidic side, can be due to the presence of SO_2 and NO_x in the air as the result of vehicular emissions (Choudhury & Banerjee, 2009), showing this type of air pollution (Thambavani & MA, 2011). According to Larcher (1995) plants sensitive towards SO_2 and NO_x close the stomata faster when exposed to the pollutants. Higher level of pH in leaf extract indicates higher or increased tolerance level to air pollutants (Kuddus et al., 2011). In the present study, 50% of the trees fall in the range 5.8 - 6.0, which is nearer to 7 and indicates pH level nearer to tolerant level (Fig. 4).

The APTI exhibited by the studied plants ranged from 79.99 *(Populus deltoids)* to 5.56 *(Prunus persia)* representing the highest tolerance, whereas *Celtis australis* and *Punica granatum* with the least tolerance (Fig. 5).

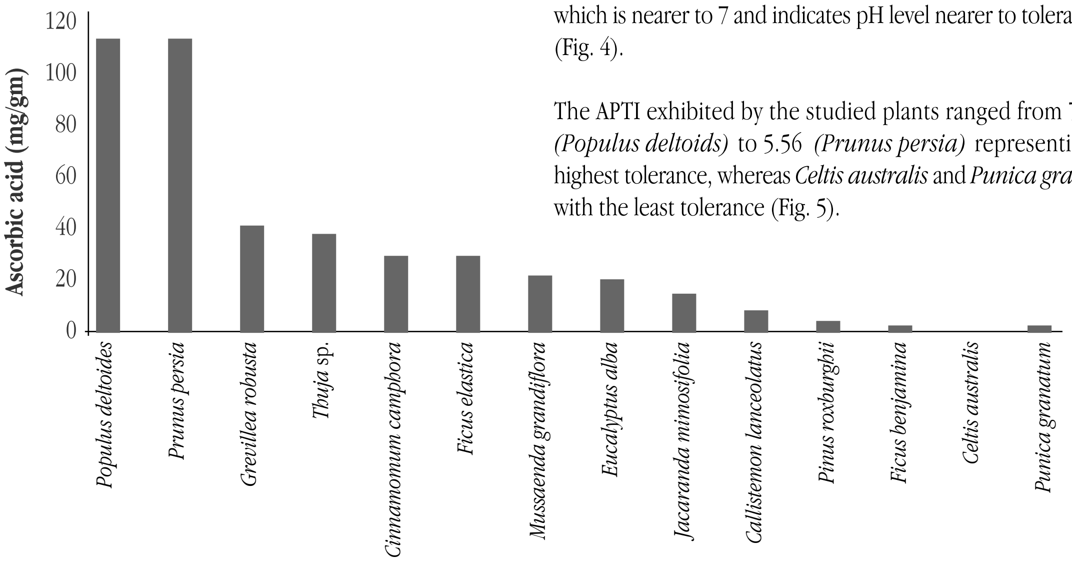

Figure 3 Variation in ascorbic acid content in the selected tree species

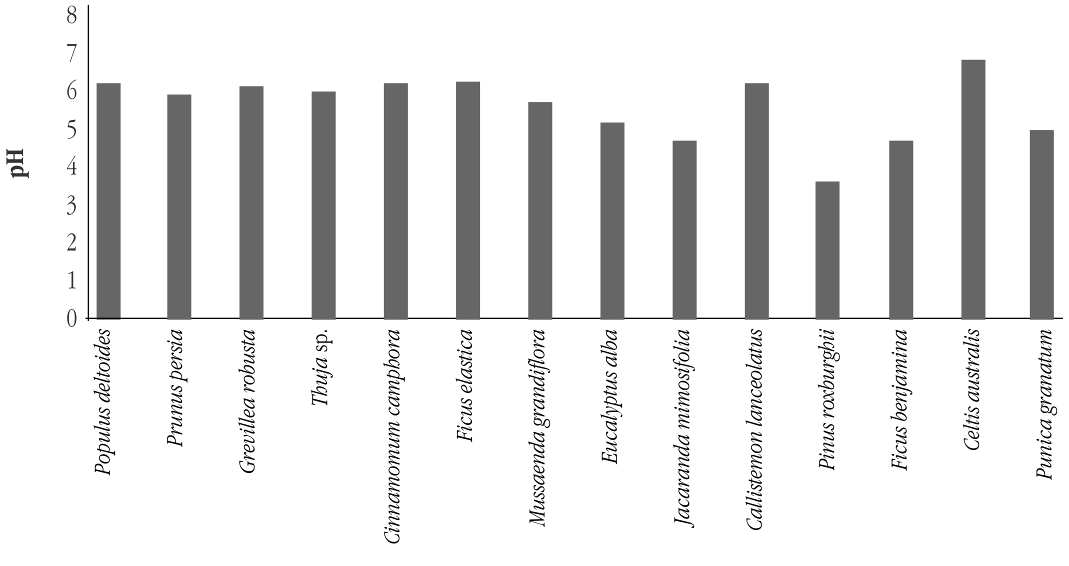

Figure 4 Variation in pH value in the selected tree species

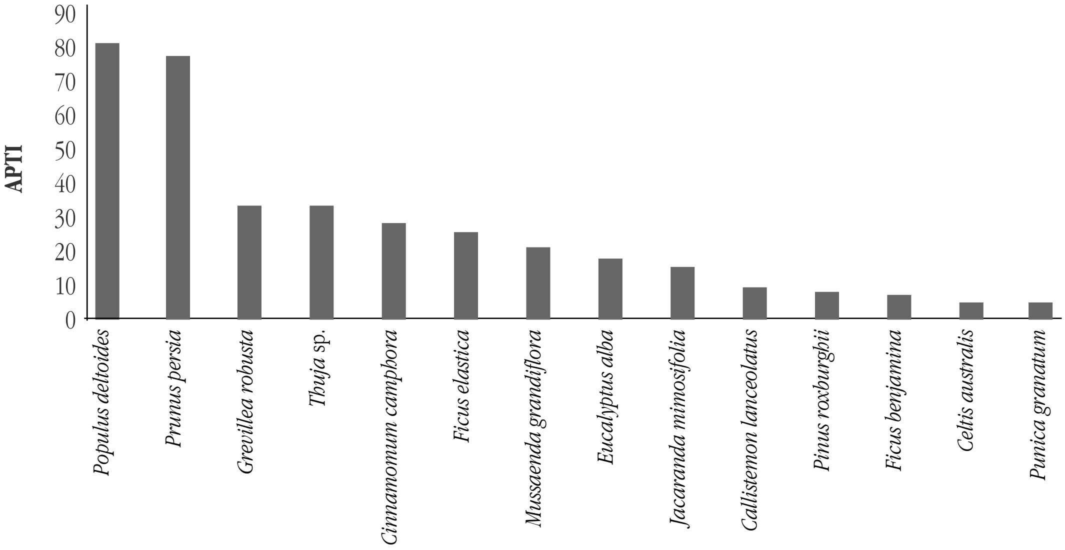

Figure 5 Variation in APTI value in the selected tree species

According to the categorization as in Table 1, the tree species: *Jacaranda mimosifolia, Pinus roxburghi, Ficus benjamin, Celtis australis, Alnus nepalensis, Callistemon lanceolatus, Schima wallichi, Pyrus pyrifolia, Celtis australis* and *Punica granatum* fall in the sensitive species to air pollution, whereas *Mussaenda grandiflora, Ficus elastica, Cinnamomum camphora* and *Eucalyptus alba* fall in the intermediately tolerant species. *Prunus persia, Populus deltoides, Thuja sp.* and *Grevillea robusta* fall in the tolerant category and can effectively be used as sink to air pollution in the polluted sites and the nearby roads for the green belt to enhance air quality and for the abatement of air pollution. On the basis of the tolerance, both the green areas, i.e. Buddhanilkantha controlled site (APTI ranged from 6.78 to 28.19) and UN Park (availability of higher sensitive species *(Callistemon lanceolatus)* and intermediately tolerant species *(Jacaranda mimosifolia and Cinnamomum camphora)* both fall in the sensitive category.

Conclusions

Tolerant tree species such as *Prunus persia, Populus deltoides* and *Grevillea robusta* with the highest APTI values as observed can be effective roadside vegetation for better absorption and screening of the air pollutants, whereas the sensitive species such as *Pyrus pyrifolia, Celtis australis* and *Punica granatum* can act as bio-indicators of air pollutants. The role of the tolerant tree species can be more important near the polluted sites not only to act as an effective sink but also for screening the pollutants. Considering the green belts with more tolerant trees can yield a better result for maintaining air quality. Future studies must focus with relationship with ambient pollutants concentration.

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