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Assessment of Air Pollution Tolerance Index of some plants to develop vertical gardens near street canyons of a polluted tropical city

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ABSTRACT

The aim of the present study was to examine Air Pollution Tolerance Index (APTI) of some climber plant species to develop vertical gardens in Varanasi city which has characteristics of tall building and narrow roads. This condition results in street canyon like structure and hinders the vertical dispersal of air pollutants. We have selected 24 climber plant species which are commonly found in of Varanasi city. Chosen plants can be easily grown either in planter boxes or directly in the ground, with a vertical support they can climb on walls to form green walls or vertical garden. Air Pollution Tolerance Index (APTI) of the selected plant species was calculated and plants with higher APTI are recommended for the development of Vertical garden. Highest APTI was noted for *Ipomoea palmata* (25.39) followed by *Aristolochia elegans* (23.28), *Thunbergia grandiflora* (23.14), *Quisqualis indica* (22.42), and *Clerodendrum splendens* (22.36). However, lowest APTI value (8.75) was recorded for the species *Hemidesmus indicus.* Moreover, the linear regression analysis has revealed a high positive correlation between APTI and ascorbic acid content (R^2=0.8837) and positive correlation between APTI and Chlorophyll content (R^2=0.6687). On the basis of higher APTI values (greater than 17), nine species of climber plants viz. *I. palmata, T. grandiflora, C. splendens, A. elegans, Q. indica, Petria volubilis, Antigonon leptopus, Cryptolepis buchuanni* and *Tinospora cordifolia* have been recommended to develop vertical greenery systems in a compact tropical city.

1. Introduction

Air pollution in urban areas is gradually becoming a great challenge. Rapid urbanization and industrialization in developing countries like India has resulted in loss of green cover from the earth surface. This condition is causing an imbalance in nature. Cumulative exposure to several pollutants enhances toxicity of the air. Green plants are known for their role in attenuation of certain air pollutants and are widely recommended in the form of green belts and urban green spaces for air pollution mitigation (De Ridder et al., 2004; Lee and Maheswaran, 2011; Rao et al., 2004; Takano et al., 2002). Air Pollution Tolerance Index (APTI) is used to evaluate the susceptibility or resistance level of plants for air pollutants. It uses four parameters, namely ascorbic acid content, total chlorophyll content, relative water content, and leaf-extract pH. These parameters are determined and computed together to obtain the APTI of the plant (Singh et al., 1991). Various studies on the APTI of plants for development of green belt has been conducted by many workers (Govindaraju et al., 2012; Krishnaveni, 2013; Prajapati and Tripathi, 2008; Rai and Panda, 2014a; Rai et al., 2013) but investigations on the APTI of climber plants for development of Vertical Greenery Systems (VGSs) is still unexplored.

Varanasi is characterised by tall buildings and narrow lanes, along with that a substantial vehicular traffic exists here. This condition results in street canyon like structure which creates hindrance in dispersal of air pollutants (So et al., 2005). Rapid urbanization and industrialization are the main culprits of replacing natural vegetation with concrete structures and low albedo surfaces. Such changes in urban area are resulting in a phenomenon known as 'urban heat island' (UHI) effect. Thus, it is need of the day that the natures should again be reintroduced in such urban areas in the form of VGSs, green roofs, vertical garden, green façade or living walls. This is one of the areas of environmental management which is still unexplored in many aspects in India such as classification of plants (in this case climber species) on the basis of their sensitivity or tolerance for air pollutants.

VGSs are developed by growing plants on building walls with some support; generally climber plants are used for this purpose.

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Various studies are reported on conservation of energy using VGSs (Euán et al., 2013; Pérez et al., 2014; Wong et al., 2010). Along with higher green plants, VGSs can also be utilized in the attenuation of air pollution (Pugh et al., 2012). In this study we have explored various climber plant species found in Varanasi and calculated their APTI to recommend tolerant plants for the development of VGSs around street canyons of Varanasi city.

2. Materials and method

2.1. Description of study sites

The city of Varanasi (82°15′E to 83°30′E and 24°35′N to 25°30′N, area 79.79 km^2, India) is the oldest living city of India. Varanasi is often regarded as religious and cultural capital of India. The meteorological data for Varanasi has been collected from the office of the Indian meteorological department at Banaras Hindu University. Varanasi city has mosaic of various residential colonies, commercial areas and traffic intersections. As Varanasi is not a well planned city so these areas are not well defined, thus they overlap with each other i.e. at some places residential area has commercial activities too and vehicular traffic is a common feature also in most of the residential areas. Tall buildings and narrow roads are important characteristics of this city which results in street canyons like conditions. With the increasing pace of development and urbanization these features are also spreading throughout the city. The compact built fabric and narrow lanes in the city lead to limited air circulations, in this manner, acting as an obstruction to the dispersal of pollution load. Urban sprawl is aggravating this phenomenon. In the present study we have arbitrarily selected seven sites for air quality monitoring. These sites were fairly away from each other and had different land use patterns. Sites 1–6 were located in city while site-7 was located in rural area (Table 1). Rural site (site-7) has been used as reference site in this study. Air quality monitoring was done at all seven sites to identify most and least polluted sites among them. Based on the findings of air quality monitoring, estimation of the APTI was done at site-3 and at site-7 only as they were found to be most and least polluted sites respectively.

2.2. Air quality monitoring

This study investigates the air quality at seven sampling sites in Varanasi city for criteria pollutants viz. sulfur dioxide (SO_2), nitrogen dioxide (NO_2), PM_{10} (Respirable suspended particulate matter or RSPM having aerodynamic diameter $\leq 10\ \mu m$), suspended particulate matter (SPM, having aerodynamic diameter $\geq 10\ \mu m$) and ozone (O_3) for a period of one year (January 2013–December 2013). Respirable dust sampler (Envirotech APM 460-NL) was used for monitoring of gaseous and particulate pollutants. The concentration of NO_2 was determined using the modified Jacob and Hochheiser method (Jacobs and Hochheiser, 1958) while that of SO_2 by improved West and Gaeke method (West and Gaeke, 1956). Ozone was analyzed by the chemical method. Sampling and analysis was done by following standard monitoring and analysis procedures (CPCB, 2011). All quality assurance and quality control measures were strictly followed.

2.3. Air Pollution Tolerance Index (APTI)

Twenty four climber plants were identified and collected from various gardens situated near site-3. These plants were planted in triplicate in earthen pots of 30 cm diameter at site-3 and site-7 which were observed to be worst and least polluted sites respectively. To ensure similar conditions of soil and nutrients these pots were filled with soil and farmyard manure in 3:1 ratio. For determining the APTI values, at least three individual plants were identified and samples in triplicate were taken from each plant. Sampling was done thrice in a year i.e. in winter, summer and rainy season and the seasonal mean values of all parameters were used to calculate the final APTI. Sampling of leaves at both sites (site-3 and site-7) was done on the same day between 08:00 am and 10:00 am. Proper care was taken to ensure that all plant species tend to have the similar ecological conditions with respect to soil, water, light and exposure to the pollutants.

The APTI of various plant species was calculated by the following mathematical expression by substituting values of ascorbic acid content, leaf extract pH, total chlorophyll content and relative water content (Singh and Rao, 1983).

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

where A is the ascorbic acid content in mg g^{-1} of fresh weight; T is the total chlorophyll in mg g^{-1} of fresh weight; P is the pH of leaf extract and R is the relative content of water in percentage.

Ascorbic acid content of leaf samples was determined using spectrophotometer (Keller and Schwager, 1977). Chlorophylls 'a' and 'b' content (Bell and Mudd, 1976) and relative water content (Sen and Bhandari, 1978) were also determined. To obtain leaf extract pH, 0.5 g of leaf sample was crushed and homogenized in 50 ml de-ionized water, after that the mixture was centrifuged and supernatant was collected for evaluation of pH by using a digital pH meter.

3. Results and discussion

3.1. Climate

Varanasi has a tropical climate. The average annual relative humidity was found to be around 76% during investigation period. Rainy season (June–September) accounted for almost 95% of the annual rainfall. During rainy season, the relative humidity ranged from 60% to 90%. In dry summer months (March–May), the relative humidity was low and ranged between 30% and 55%. While in winter (November–February) it ranged from 80% to 95%. Highest values of monthly average of maximum temperature were

Table 1
Description of study sites.

S. No.	Site	Site	Latitude (N)	Longitude (E)	Classification
1	Chandpur	Site-1	25°17'58.24"	82°57'16.80"	Predominantly industrial area
2	Sigra	Site-2	25°18'59.3"	82°59'24.07"	Co-dominantly commercial and traffic zone
3	Lanka	Site-3	25°16'42.79"	83°0'7.89"	Mosaic of commercial, residential, traffic zone
4	Pandeypur	Site-4	25°20'57.51"	82°59'37.93"	Predominantly traffic zone
5	DLW	Site-5	25°17'6.24"	82°57'35.80"	Residential and industrial zone
6	Padao	Site-6	25°19'4"	82°52'26"	Traffic zone
7	Jakkhini	Site-7	25°11'6.39"	82°47'7.14"	Rural area (Reference site)

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