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Research Paper

# Air Pollution Tolerance Index of climber plant species to develop Vertical Greenery Systems in a polluted tropical city

Ashutosh Kumar Pandey[a], Mayank Pandey[a], B.D. Tripathi[b,*]

[a] Institute of Environment & Sustainable Development, Banaras Hindu University, Varanasi 221005, India
[b] Department of Botany, Banaras Hindu University, Varanasi 221005, India

## HIGHLIGHTS

- Vertical greenery systems (VGSs) can assist in abating urban air pollution.
- Plants with an air pollution tolerance index (APTI) of 17 or more can be effective in VSGs.
- Suitable plants for VSGs include *Ipomoea plamata*, *Antigon leptopus* and *Thunbergia grandiflora*.
- *Adenocalymma comosum* forms a thick vertical screen with beautiful flowers.

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## ABSTRACT

Urban greenery can provide a cost-effective and eco-friendly technique to help reduce air pollution in compact urban areas. Urbanization generally replaces natural vegetation with concrete structures. Greenery can be reintroduced into such urban areas by development of vertical greenery systems (VGSs) on building walls. Such plants must be selected based on their air pollution tolerance level. Air pollution tolerance index (APTI) is one such index which is based on four properties of plant leaves such as ascorbic acid content, leaf extract pH, relative water content and total chlorophyll content. In this study in Varanasi, India, air pollution was monitored at seven sites to know the air quality status, based on which two sites were selected for evaluating APTI. Twenty eight climber plant species commonly found near a polluted site (site-1) were selected and their APTI was evaluated. APTI of same set of plants were also analyzed at relatively less polluted rural site (site-7) for comparative study. Linear regression analysis has revealed a high positive correlation between APTI a d ascorbic acid content ($R^2 = 0.8676$) and positive correlation between APTI and Chlorophyll content ($R^2 = 0.4957$). On the basis of higher APTI values (greater than 17), eleven climber species i.e. *Ipomoea palmata*, *Antigonon leptopus*, *Thunbergia grandiflora*, *Clerodendrum splendens*, *Aristolochia elegans*, *Quisqualis indica*, *Vernonia elaeagnifolia*, *Petrea volubilis*, *Adenocalymma comosum*, *Cryptolepis buchanani* and *Jacquemontia violacea* have been identified at polluted urban site to develop vertical greenery systems in this compact tropical city.



## 1. Introduction

Air pollution has become a great threat to urban areas of developing countries. The main cause of increase in the level of air pollution are increasing population, urbanization and industrialization (McMichael, 2000; Vailshery, Jaganmohan, & Nagendra, 2013). Urban air often contains high levels of pollutants that are harmful to human health and well being (Lave & Seskin, 2013; Mayer, 1999). The role of green plants in air pollution attenuation is well known (Burton, 2003; Islam et al., 2012; Kapoor & Gupta, 1987), but urban construction is replacing huge areas of vegetation with concrete buildings and low albedo surfaces (Onishi, Cao, Ito, Shi, & Imura, 2010; Sugawara & Takamura, 2014). The resulting changes in the thermal properties of surface materials and the lack of proper evapotranspiration in urban areas lead to the urban heat island (UHI) effect (Sung, 2013; Wong, Kwang Tan, Chen, et al., 2010). Greenery should be reintroduced into such urban landscapes by bringing nature back into the city.

Vertical greenery system (VGS) means growing of plants directly on or with the help of plant guiding constructions alongside the building façade. Green façades generally involve use of woody or

* Corresponding author.
*E-mail addresses:* ashutosh.cest@gmail.com (A.K. Pandey), mayankacademics@gmail.com (M. Pandey), tripathibd@gmail.com (B.D. Tripathi).

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herbaceous climbers, algae, lichens and small shrubs. These can be planted directly into the ground or in pots or planter boxes and some other structures to anchor the plants (Köhler, 2008; Ottelé, van Bohemen, & Fraaij, 2010). Along with green roofs, sky gardens and residential gardens, VGSs can also be used for air pollution attenuation (Rowe, 2011; Speak, Rothwell, Lindley, & Smith, 2012). Green roofs are also known for cooling overlying air masses relative to a conventional roof (Speak, Rothwell, Lindley, & Smith, 2013). Residential gardens are major portion of the urban green space (Gaston, Warren, Thompson, & Smith, 2005; Gill et al., 2008; Goddard, Benton, & Dougill, 2010) and play an important role in the conservation of biodiversity and aesthetic beauty of urban areas (Hunter & Brown, 2012). Sky gardens are of great ecological, economical and social importance (Tian & Jim, 2011; Yang, Yu, & Gong, 2008), but very few studies have been done in India on green roofs, Vertical greenery systems or sky gardens. Choosing appropriate plants for urban landscapes is essential to avoid possible financial and environmental losses (Asgarzadeh et al., 2014) and thus the Air Pollution Tolerance Index (APTI) can be a good tool to select best plant species.

The air pollution tolerance index (APTI) is based on four major biochemical properties of leaves which are ascorbic acid, relative water content, total chlorophyll and leaf extract pH (Singh & Rao, 1983). A plant's tolerance to air pollutants varies with these parameters. Chlorophyll content decreases due to production of Reactive Oxygen Species (ROS) in the chloroplast under water stress (Prajapati & Tripathi, 2008). Presence of higher ascorbic acid content in leaves might be a strategy to protect thylakoid membranes from oxidative damage under such water stress conditions (Tambussi, Bartoli, Beltrano, Guiamet, & Araus, 2000), as ascorbic acid is involved in the defence against ROS produced by the photosynthetic apparatus (Mittler, 2002; Sharma, Jha, Dubey, & Pessarakli, 2012; Smirnoff, 1996). Few works have been done on the APTI of various tree species in Varanasi (Singh, Rao, Agrawal, Pandey, & Naryan, 1991), Anticipated performance index based on APTI for green belt development was also analyzed (Pathak, Tripathi, & Mishra, 2011; Prajapati & Tripathi, 2008). Deposition of particulate matter on climber vegetation on living walls have been quantified (Ottelé, van Bohemen, & Fraaij, 2010). The APTI of some climbers were also estimated in India (Karthiyayini, Ponnammal, & Joseph, 2005), but systematic study is rather lacking for the development of vertical gardens and green roofs by using particular climber plants based on their APTI. Increasing motor vehicle emissions and decreasing green space have created an imbalance in the air quality (Heidt & Neef, 2008). Thus, it is necessary to develop VGSs on buildings to compensate for the loss of natural vegetation in the process of urbanization (Safikhani, Abdullah, Ossen, & Baharvand, 2014). Climbers can be grown directly in the ground with a support to develop green façade or they can also be grown in pots or planter boxes (Johnston & Newton, 2004). Loamy soil with good drainage is considered good for most of the climbers. Climbers can be grown according to different situations. *Quisqualis indica*, *Antigonon leptopus* and *Adenocalymma comosum* can be grown in sunny conditions. Similarly, *Clerodendrum splendens* can be grown in partial shade. Heavy climbers like *A. leptopus*, *Bignonia magnifica*, *Beaumontia grandiflora*, *Hiptage benghalensis*, *Quisqualis magnifica* and *Clerodendron splendens* grow vigorously and cover large area and thus they are suitable choice for development of VGS. Some of these plants such as, *C. splendens*, *Q. indica* and *Adenocalymna calycina* can also be grown on pergola. Climbers can add to air pollution attenuation along with higher plants, along with that, they can also increase the aesthetic value of a building (Perini & Magliocco, 2012). Factors such as soil type, availability of sunlight, and adequate nutrients to plants, proper irrigation, and proper support for plants to grow should also be considered for development of VGSs. Annual maintenance will promote plant survival and proper growth of plants. Unplanned urban expansion and urban sprawl in Varanasi has resulted in dense settlements with little green space in the core areas of the city (Kumar, Mukherjee, Sharma, & Raghubanshi, 2010). Varanasi is a compact sub-tropical city which is characterized by tall buildings and narrow roads which results in the city canyon-like structure (Prajapati, Tripathi, & Pathak, 2009; Salmond et al., 2013). Thus, air pollutants are not dispersed properly and remain in surrounding ambient air for longer durations (Gu, Zhang, Cheng, & Lee, 2011). Removal of such pollutants can be easily achieved with the help of vertical greenery system on building walls (Baik, Kwak, Park, & Ryu, 2012). Much building wall and rooftop surface area can be used to develop roof top gardens and vertical greenery systems in the city. Therefore it is necessary to evaluate the APTI of selected climber plants that could be used to develop VGSs.

Thus in this work, the aim is to evaluate APTI of commonly available climber species of plants so that those with a higher tolerance can be recommended for use in VGSs in the city to attenuate air pollution and bring other ecosystem services. Air quality was monitored at different sites to assess the status of pollution. Common climber plant species growing on polluted site and at relatively less polluted site were selected to analyze for their air pollution tolerance index.

## 2. Materials and methods

### 2.1. Study region

The present study was performed in 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), one of the oldest surviving cites cities in the world and regarded as religious and cultural capital of India. Varanasi city has various socio-economic residential, commercial areas and traffic intersections. But mostly these areas are not well defined and thus they overlap with each other i.e. at some places residential area also has commercial activities and traffic is common in most of the residential areas. Tall buildings and narrow lanes are important characteristics of this city. We randomly selected seven sites for air quality monitoring out of which six sites were located in the urban area and fairly away (4–7 km) from each other while one site was located in rural area (site-7) as reference site (Fig. 1, Table 1).

#### 2.1.1. Climate

Varanasi has a sub-tropical climate. The average annual relative humidity during the study period was found to be 75.72%. The rainy season (June–September) accounted for 90–97% of the annual rainfall, during which relative humidity ranged from 58% to 89%. In dry months, the relative humidity ranged from 37% to 57% in summer (March–May) and 86% to 96% in winter (November–February) respectively. The meteorological data collected from the office of the Indian meteorological department at Banaras Hindu University shows that the highest monthly average temperature was recorded in summer during the month of May (42 °C) and June (40 °C). On the other hand the minimum temperature was recorded in winter during January (7 °C) and December (10 °C). The average rainfall in the area was 1100.3 mm, out of which 1064.3 mm were recorded in the rainy season. The predominant wind direction for the study area is to towards west (Fig. 2).

### 2.2. Air quality monitoring

We investigated the air quality at seven study sites of Varanasi city for the major pollutants sulphur dioxide ($SO_2$), nitrogen dioxide ($NO_2$), $PM_{10}$ (respirable suspended particulate matter or RSPM) and ozone ($O_3$). Regular monitoring of all the parameters was done at all the seven sampling sites for three years (January 2011 to