

Review Article

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Significant Role of Ornamental Plants as Air Purifiers – A Review

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ABSTRACT

The rapid urbanization and growing industrialization in the world during the last decades led to increasing levels of air pollution dwindling urban air quality. Plants play an important role in monitoring and maintaining the ecological balance by their involvement in the cycling of nutrients and gases like carbon dioxide and oxygen. Public attitudes towards plants usage for air filtration from the environmental pollutants and the evidence of phytoremediation efficacy exhibited by some plants have prompted new investigations into the use of ornamental plants as a green technology in phytoremediation for air contamination. Air pollution caused a problematic health include breathing problems, respiratory illness, changes in the lung's defenses, and worsening respiratory, and cardiovascular disease. Using the ornamental plants, weedy trees and green space as natural filters of air pollution reduces respiratory illness mortality rates and reducing visits to the hospital. Many species of ornamental shrubs and herbaceous landscape plants have been identified as phytoremedator to improve indoor and outdoor air quality. Stomata density can be used as an indicator for the efficiency of plants in the absorption of air pollutants. Based on available literature it could be concluded that ornamental plants have the ability to filtrate the air from the contaminants.

Keywords

Air pollution,
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Introduction

Generally, plants have been labelled as the “lungs of cities” (McPherson, 2005) because they have the ability to remove contaminants from the air that is breathed. Acting as natural filters and reducing air pollution, it has been shown that plants generate health benefits by reducing the mortality rate and reducing visits to the hospital (Powe and Willis, 2004). Air pollution has been becoming a necessary evil with rapid industrialization and urbanization around the world, after it results in kinds of human health problems, such as ophthalmic, respiratory and cardiovascular diseases (Yang and Liu 2011). Naturally everyone likes to

breathe fresh, clean air. But the atmosphere, that invisible yet essential ocean of different gases called air, is as susceptible to pollution from human activities as are water and land environments (Barfield *et al.*, 1992). According to the WHO report, about 10 to 15 % of the total population of India is suffering from common cold, bronchitis, asthma, hay fever etc. These diseases are no doubt airborne and spread the infection from several hundred kilometers under favourable atmospheric conditions. Dust and soot in the air contribute to between 20 and 200 deaths each day in America’s biggest cities. Ill health

from microscopic particulates with tiny specks smaller than the width of a human hair can lodge deep in the lungs and are associated with respiratory diseases, heart attacks and premature deaths. The new research indicates elderly people suffer the most harm. In the United States the Environmental Protection Agency (EPA) currently sets the maximum allowable concentration of microscopic particles at $150 \mu\text{m}^3$ of air. The air is being continuously polluted in urban areas through heavy traffic, industry, domestic fuel combustion, stone quarries, coalmines and various agricultural activities from the adjoining areas. These particulates are no doubt dangerous to human health and environment causing various diseases to plants and animals, damage to properties including our cultural heritage, national monuments, archives etc. Dust concentration varies from place to place and hour to hour, diurnally depending upon traffic, type of industry etc. The highest dust concentration tends to be in summer, reaching maximum during mid-day and late-afternoon. In some large cities where wind and temperature fall more steadily, the concentration of dust also reduces accordingly.

Pollution

Pollution is defined as ‘an undesirable change in physical, chemical and biological characteristics of air, water and land that may be harmful to living organisms, living conditions and cultural assets. The pollution control board defined pollution as unfavourable alteration of our surrounding, largely as a byproduct of human activities (Agarwal and Sharma, 1980). The most necessary thing for the survival of all living beings on this earth is Air. On an average, a person needs atleast 30 lb of air every day to live, but only about 3 lb of water and 1.5 lb of food (Kumar *et al.*, 2013). A person can live about 5 weeks without food and about 5 days without water, but only 5 minutes without air.

(Nahed G. Abd ElAziz *et al.*, 2015) Various types of activity, including agriculture, industry and transportation, produce a large amount of wastes and new types of pollutants in air (Setyorini *et al.*, 2002).

Pollutants are the substances that contaminate air, water and or soil. The most potential toxic elements in the air are the non-radioactive As, Cd, Cu, Hg, Pb and Zn and radioactive Sr, Cs and U (referred to here as toxic metals) (Deveci and Ekmekyapar, 2008). Also, nitrogen dioxide (NO_2), Carbon Monoxide (CO), and Hydrocarbons (HC) are considered the main emissions, and higher levels can often be the result of increased airport vehicular traffic (Yang and Liu, 2011) Pollutants are not necessarily born as pollutants. On the contrary, they may be resources applied in the wrong places. Incorrect uses, accidental releases and/or technical limits make them harmful to our environment (Zhai, 2011).

Primary pollutants are usually produced from a process, such as from volcanic eruptions, CO, SO_2 , NO_2 , Pb, Hg, CFCs and NH_3 . Secondary pollutants are not emitted directly, rather, they form in the air when primary pollutants react or interact such as ground level ozone. Most of sources of air pollution are related to human’s activities as a result of the modern life style. The main pollution sources include chemicals, industries, automobiles, coal-fired power plants, nuclear waste disposal activity, plastic factories etc. Agriculture air pollution comes from spraying of pesticides and herbicides. Harmful effects of pollution have both acute and chronic effects on human health. Health effects range anywhere from minor irritation of eyes and upper respiratory systems, heart disease, lung cancer and death. Ozone depletion is the result of air pollution. The air pollution control is the process of reducing the release of pollutants from industries, wastes of chimneys, fossil-fuel (coal), thermal power

plants etc. It is regulated by various environmental agencies that establish limits for the discharge of pollutants into air (Singh, 2013). The control of emissions can be realized in the number of ways such as collection of pollutants, cooling, emission control in automobile engines (Sharma, 2014). The planting of ornamental plants for the control of pollution and improvement of environment is an effective way. The proper planning and planting scheme depends upon the type of pollution. Tolerant and dust absorbing trees and shrubs should be planted for bioremediation of environment. The aim of the present review is to provide insight into how ornamental plants can be effectively utilized in reducing the air pollution (Table 1).

Method of air pollution control

Process of cleaning the air in environment by using plants is termed as Phytoremediation. The word phytoremediation comes from the Greek word phyto, meaning "plant" and the Latin word remediare, meaning "to remedy". This word is generally used to describe any system where plants are introduced into an environment to remove contaminants from it (Chhotu, *et al.*, 2009). Certain species of higher plants can accumulate very high concentrations of metals in their tissues without showing toxicity (Klassen *et al.*, 2000).

Phytoremediation of air pollutants

Air pollutants may be classified as anthropogenic and natural pollutants according to their sources, or primary and secondary pollutants, which stem from reactions of primary pollutants, when taking production process into account (Unep, 2004). Trees and plants have been labeled as the "lungs of cities" acting as natural filters and reducing air pollution, therefore we can use the ornamental plants as to remediate the air

pollution through absorb and degrade all types of urban air pollutants thereby reducing air pollution levels (Brown, 1997; Yoneyama *et al.*, 2002; Burchett, 2008)

Ornamentals and woody trees can use as eco-friendly alternatives for the removal of the pollutants from the air.

Trees as phytoremediators

Trees are ideal in the remediation of heavy metals as they can withstand and accumulate higher concentration of pollutants owing to their large biomass and size, can reach a huge area and great depths for their extensive rootings and can stabilize an area (Shah and Nongkynrih, 2007)

Fast-growing trees (such as poplar, pine, and eucalyptus) and the hardwood trees, mahogany and rosewood, as well as poplar and eucalyptus, can be used for remediation of contaminated air. The total amount of air pollution removed by urban trees annually within the United States is estimated to be 711,000 metric tons (Nowak *et al.*, 2006)

Concentrations of five metals (cadmium, chromium, copper, nickel and lead) were determined in tree leaves collected from 13 areas of the Attica basin and Athens city, Greece. Geographical distribution patterns were investigated, and factors affecting toxic element accumulation in trees were discussed (Sawidis *et al.*, 2012).

The mean heavy metal content in the tree leaves is described in the descending order of copper>lead>nickel>chromium>cadmium. Generally, the most damaged areas have been proved to be those near the city center and in the vicinity of the Attica highway. The geomorphological relief of the area plays an important role in the dispersion of airborne particles from pollution sources to the

surrounding area. Areas on the NE region are also polluted mainly due to wind directions. In *Citrus aurantium* leaves, with relatively impermeable cuticle, high chromium, copper and nickel concentration would be possibly caused only by significant stomatal uptake. The conifer tree *Pinus brutia* providing a rough leaf surface also showed elevated concentrations, especially of cadmium and lead. The thick waxy cuticle of the sclerophyllous broad-leaved *Olea europaea* forms a smooth sheet increasing the barrier properties of the leaf epidermis and causing a reduction in leaf permeability. The dense trichomes of the abaxial epidermis of *O. europaea* also act as a pollution screen keeping away the air particles from the epidermis stomata. The presence of a certain metal within the leaf cells could reduce the uptake or toxicity of some others (Nahed *et al.*, 2015).

Properties of the ornamental plants used as air phytoremediators

The important criteria for the ornamental plants to be phytoremediator for air pollution are plants should be evergreen, large leaved, rough bark, indigenous, ecologically compatible, low water requirement, minimum care, high absorption of pollutants, resistant pollutants, agro-climatic suitability, height and spread, Canopy architecture, Growth rate and habit (straight undivided trunk), Aesthetic effect (foliage, conspicuous and attractive flower colour), Pollution tolerance and dust scavenging capacity (Kumar *et al.*, 2013).

A few ways in which plants reduce air pollution are as follows (Brethour *et al.*, 2007):-

Absorption of gaseous pollutants through their leaves, e.g., ozone, nitrogen oxides, and sulphur dioxide.

Further reducing ozone concentrations at ground level by reducing the temperature via evapotranspiration as mentioned above.

Collection of dust, ash, pollen and other particulate matter on their leaves hence reducing its presence in the air breathed.

Releasing of oxygen, as mentioned above, which increases the quality of the air for human use (McPherson 2005).

The amount of air-borne pollutants removed increases with leaf surface area. Therefore, trees tend to be better filters than shrubs and grasses. Due to their large surface area and year round coverage, conifers (evergreens) are very good pollution filters. However, conifers tend to be sensitive to phytotoxic air pollutants and deciduous trees are more efficient at absorbing gaseous pollutants. It is, therefore, beneficial to have a mixture of species in order to have the greatest effect in reducing air pollution (Bolund and Hunhammar 1999).

The phytoremediation properties of some ornamental plants used in landscape have been investigated (Fusun *et al.*, 2011).

Leaf samples of the plant species belong to leafy, coniferous and shrub were taken from the refuge of main road in the campus area affected heavy metal pollution due to intensive motorized traffic, and from the coastal areas far away from the intensive traffic. Nickel, lead, cadmium, iron, zinc and copper concentrations were determined in leaf samples. There were significant differences among the plant species ($P < 0.01$) according to Fe, Zn, Cu, Ni, Pb and Cd contents of leaves. There were also significant differences among the locations ($P < 0.01$) for Fe, Zn, and Cd contents of leaves. Interactions between locations and plant species were significant ($P < 0.01$) for the heavy metals, except Pb. The highest Fe, Zn, Cu, and Cd concentrations were obtained in species of *Cedrus libani* A. Rich (618 ppm), *Betula Alba* Linn. (106.30 ppm), *Salix Alba* L. (24.54 ppm) and *Eleagnus angustifolia* L. (0.28 ppm),

respectively. The highest Ni (6.36 ppm) and Pb (3.76 ppm) contents were determined in *Pyracantha coccinea* M. Roem (Fusun *et al.*, 2011).

Twenty-eight ornamental species commonly used for interior landscapes were screened for their ability to remove five volatile indoor pollutants: aromatic hydrocarbons (benzene and toluene), aliphatic hydrocarbon (octane), halogenated hydrocarbon [trichloroethylene (TCE)], and terpene (α -pinene). Of the 28 species tested, *Hemigraphis alternata*, *Hedera helix*, *Hoya carnosa*, and *Asparagus densiflorus* had the highest removal efficiencies for all pollutants; *Tradescantia pallida* displayed superior removal efficiency for four of the five VOCs (i.e., benzene, toluene, TCE, and α -pinene). The five species ranged in their removal efficiency from 26.08 to 44.04 $\mu\text{g}\cdot\text{m}^{-3}\cdot\text{m}^{-2}\cdot\text{h}^{-1}$ of the total VOCs.

Fittonia argyroneura effectively removed benzene, toluene, and TCE. *Ficus benjamina* effectively removed octane and α -pinene, whereas *Polyscias fruticosa* effectively removed octane. The variation in removal efficiency among species indicates that for maximum improvement of indoor air quality, multiple species are needed. The number and type of plants should be tailored to the type of VOCs present and their rates of emanation at each specific indoor location (Sawidis *et al.*, 2012).

It is better to arrange some species of plants to achieve the best removal effects taking account of concentrations, fumigation time and pollutants (Yang *et al.*, 2009). On five species of streetscape plants were identified as ornamental shrubs i.e. Ixora Red, Yellow Bush, Masquerade Pine, Tuja Pine and Yellow ficus (Enete and Ogbonna 2012). The Air pollution tolerance index (APTI) values ranged between 10.60 and 14.32 on yellows Bush and Ixora Red respectively. The ornamental shrubs with lower APTI values

(sensitive) were recommended to be utilized as bioindicators of poor urban air quality while shrubs with high APTI values (Tolerant) are to be planted around areas anticipated having high air pollution load (Enete and Ogbonna 2012). Sixteen ornamental plant species commonly used for interior landscapes were screened for their ability to remove three common indoor pollutants of formaldehyde, nitrogen oxides (NO_x) and sulfur oxides (SO_x) (El-Sadek *et al.*, 2012). Also, some components of the selected plants such as, ascorbic acid, chlorophyll, pH, relative water content, leaf osmotic pressure as well as stomatal number, length and width on the lower and upper leaf surfaces were assessed to determine the relationship between these components and plant removal efficiency. Among the tested plants, *Chlorophytum comosum* displayed superior removal efficiency for HCHO and SO_x as 1830 $\mu\text{g day}^{-1}$ and 2120 $\mu\text{g day}^{-1}$ and *Spathiphyllum wallisii* for NO_x as 3200 $\mu\text{g day}^{-1}$. Also, it was found that stomatal density can be used as an indicator for the efficiency of indoor plants in the absorption of air pollutants; especially for HCHO, SO_x or NO_x (Aini *et al.*, 2012).

The responses of plants to pollutants may provide a simple link concerning phytoremediation of air pollutants to admit air pollution abatement. Ten species of landscape plants (*Jatropha pandurifolia*, *Bougainvillea sp.*, *Cordyline terminalis*, *Canna indica*, *Hymenocallis speciosa*, *Mussaenda philippica*, *Codiaeum variegatum*, *Heliconia psittacorum*, *Sansevieria trifasciata* and *Ipooea batatas*) have been identified as ornamental shrubs and herbaceous, and their potential for bioindicators of urban air pollution based on their Air Pollution Tolerance Index (APTI) (Nugrahani *et al.*, 2012). From the literatures, the success of green technology in phytoremediation, in general, is dependent upon several factors (Paz-Alberto and Sigua 2013). Firstly, plants

must produce sufficient biomass while accumulating high concentrations of metal. In some cases, an increased biomass will lower the total concentration of the metal in the plant tissue, but allows for a larger amount of metal to be accumulated overall. Secondly, the metal-accumulating plants need to be responsive to agricultural practices that allow repeated planting and harvesting of the metal-rich tissues. Thus, it is preferable to have the metal accumulated in the shoots as opposed to the roots, for metal in the shoot can be cut from the plant and removed. This is manageable on a small scale, but impractical on a large scale. If the metals are concentrated in the roots, the entire plant needs to be removed. Yet, the necessity of full plant removal not only increases the costs of phytoremediation, due to the need for additional labor and plantings, but also increases the time it takes for the new plants to establish themselves in the environment

and begin accumulation of metals lists some of the common pollutant accumulating plants found by phytoremediation researchers (Paz-Alberto and Sigua, 2013). A list of plants which are effective air purifiers along with the pollutants that they are best at removing was provided (Prescod, 1990; Prescod, 1992). He reported that orchids are very effective at removing numerous pollutants during the daylight hours. They are also effective at removing carbon dioxide and xylene¹⁸ at night, while at the same time releasing oxygen into the air. This is because orchids (and bromeliads) have a unique metabolic process whereby their stomata ²⁰ open at night. This is significant because air can be continuously filtered, day and night (Prescod, 1992). It is important to acknowledge, however, that plants can also contribute to reduce air quality by releasing pollen and spores ⁴² which can cause discomfort in the form of allergies (Prescod, 1990).

Fig.1 Installation of vertical gardens on metro pillars in Bengaluru for pollution control



Fig.2 Arrangement of different indoor plants for pollution control



Table.1 Major air pollutants in the environment, pollutant sources and their effect on public health

Outdoor pollutant	Pollutant sources	Health problem
Carbon Monoxide	Burning diesel, petroleum and wood	Increases confusion, sleepiness, low blood oxygen level, slow reflexes
Carbon dioxide	Burning oil, coal and natural gases	Lowers oxygen levels, vision defects, reduces respiratory and brain functions,
Nitrogen dioxide (NO ₂)	Burning fuels, electricity generation plus vehicle engines,	defect in lung function and causes bronchitis in asthmatic children, toxic
Sulphur dioxide (SO ₂)	industrial processes, and Burning fossil fuels	eye irritation and respiratory inflammation, asthma attacks,, mucus secretion, decreases pulmonary function.
Ozone (O ₃)	photochemical smog produced by the interaction of sunlight and air pollutants	breathing difficulties and asthma, colds, pneumonia
Suspended particulate matter (PM ₁₀ , PM _{2.5} , SPM)	Mixture of solid and liquid organic plus inorganic materials including nitrates, sulphate, carbon, sodium chloride, ammonia, mineral dust and water	Disrupts lung's gas exchange function and respiratory illness

(Kapoor, 2017)

Table.2 Indoor plants suitable for air pollution control

Name of the plant	Family	Growth habit
<i>Dyopsis lutescens</i>	Araceae	Erect, small,
<i>Dendrobium</i> (orchid)	Orchidaceae	Small plant
<i>Dracaena</i>	Liliaceae	Small plant
<i>Hedera helix</i>	Araliaceae	Vigorous climber
<i>Dieffenbachia</i>	Arecaceae	Small plant
<i>Nephrolepis obliterated</i>	Lomariopsidaceae	Small plant
<i>Rhapis excelsa</i>	Areceae	Small palm
<i>Chlorophytum comosum</i>	Liliaceae	Medium plant
<i>Spathiophyllum</i>	Areceae	Small palm
<i>Aloe vera</i>	Xanthorrhoeaceae	Small plant

(Kapoor, 2017, Cristiano *et al.*, 2016, Orwell *et al.*, 2006; Lohr *et al.*, 1994 and Wood *et al.*, 2006)

Table.3 Outdoor plants suitable for air pollution control

Name of the plant	Family	Growth habit	Environmental importance
<i>Pongamia Pinnata</i>	Leguminosae	Small tree	Suitable for avenues
<i>Pithecellobium dulce</i>	Fabaceae	Large tree	Suitable for road planting
<i>Holoptelea integrifolia</i>	Ulmaceae	Large tree	Suitable for road planting

<i>Saraca indica</i>	Leguminosae	Small tree	Suitable for avenues
<i>Sorbus aria</i>	Rosaceae	Medium tree	Suitable for industrial area
<i>Acer campestre</i>	Sapindaceae	Medium tree	Suitable for industrial area
<i>Pinus nigra</i> var. <i>maritima</i>	Pinaceae	Large tree	Suitable for hilly areas
<i>Ficus nitida</i>	Moraceae	Small tree	High dust capture capacity
<i>Eucalyptus globules</i>	Myrtaceae	Large tree	High dust capture capacity
<i>Ficus infectoria</i>	Moraceae	Medium tree	Suitable for avenues
<i>Psidium guajava</i>	Myrtaceae	Small tree	Suitable for avenues
<i>Ficus rumphii</i>	Moraceae	Large tree	Suitable for road side
<i>Azadirachta indica</i>	Meliaceae	Large tree	Suitable for road side
<i>Grevillea robusta</i>	Proteaceae	Large tree	Suitable for road side
<i>Ficus benghalensis</i>	Moraceae	Large tree	Suitable for road side
<i>Ficus religiosa</i>	Moraceae	Large tree	Suitable for road planting
<i>Ziziphus jujuba</i>	Rahmnaceae	Large tree	Suitable for road planting
<i>Phyllanthus emblica</i>	Euphorbiaceae	Large tree	Suitable for road planting
<i>Cassia fistula</i>	Leguminosae	Medium tree	Suitable for avenues
<i>Alstonia scholaris</i>	Apocynaceae	Large tree	Suitable for road side
<i>Cassia siamea</i>	Leguminosae	Low growing	Suitable for road side
<i>Bauhinia variegata</i>	Leguminosae	Small tree	Suitable for avenues
<i>Caesalpinia pulcherrima</i>	Leguminosae	Large tree	Suitable for road side
<i>Delonix regia</i>	Leguminosae	Large tree	Suitable for road side
<i>Michelia champaca</i>	Magnoliaceae	Medium tree	Suitable for industrial area
<i>Populus spp.</i>	Salicaceae	Large tree	Suitable for industrial area
<i>Psidium cattleianum</i>	Myrtaceae	Medium tree	Suitable for industrial area
<i>Tradescantia</i>	Commelinaceae	Small plant	Suitable for industrial area
<i>Petunia</i>	Solanaceae	Small plant	Suitable for industrial area
<i>Madhuca latifolia</i>	Sapotaceae	Small plant	Suitable for avenues
<i>Clerodendron infortunatum</i>	Verbenaceae	Small plant	Outdoor condition of a house
<i>Eupatorium odoratum</i>	Asteraceae	Small plant	Suitable for road side
<i>Hyptis suaveolens</i>	Lamiaceae	Small plant	Outdoor condition of a house
<i>Polyalthia longifolia</i>	Annonaceae	Medium tree	Suitable for avenues

(Kapoor, 2017; Beckett *et al.*, 2000; Freer-Smith *et al.*, 2004; Rzepka *et al.*, 2005; Pandey, *et al.*, 2005; Lakshmi *et al.*, 2008; Tripathi *et al.*, 2009 and Jyothi and Jaya, 2010)

However, there is a substantial amount of research that indicates having indoor plants has the net effect of improving indoor air quality (Lohr *et al.*, 1996) (Fig. 2).

Control of indoor air pollution

Indoor air pollution from solid fuel use and urban outdoor air pollution are estimated to be responsible for 3.1 million premature deaths worldwide every year and 3.2% of the global burden of disease (WHO, 2009).

More than half of the global burden of disease from air pollution is borne by people in developing countries. Air pollutants have been linked to a range of adverse health effects, including respiratory infections, heart disease and lung cancer. Reduction of air pollution levels will decrease the global health burden related to these illnesses. Efforts to significantly reduce concentrations of air pollutants will also help to decrease greenhouse gas emissions and mitigate the effects of global warming (WHO, 2008). Indoor concentrations of some cancerous chemicals are between 5 and even up to 70 times higher than outdoors, although the indoor concentration of pollutants is still lower than in industrial factories and heating power stations or next to busy roads (Brody, 2001, Wood, 2003 and Gawrońska *et al.*, 2015.)

A number of air pollutants have been recognized to exist indoors, including NO_x, SO₂, O₃, CO, volatile and semi-volatile organic Compounds (VOCs), PM, radon, and microorganism. Some of these pollutants (e.g., NO_x, SO₂, O₃, and PM) are common to both indoor and outdoor environments, and some of them maybe originated from outdoors (Leung, 2015).

The major sources of indoor air pollution worldwide include indoor combustion of solid fuels, tobacco smoking, outdoor air

pollutants, emissions from construction materials and furnishings, and improper maintenance of ventilation and air conditioning systems (WHO, 2010.). While outdoor sources of air pollutants include vehicles, combustion of fossil fuels in stationary sources, such as power generating stations, and a variety of industries. Forest fires and deliberate biomass burning, although intermittent sources of air pollution, represent major sources of combustion pollution globally (WHO, 2010.) Many studies have confirmed that indoor air quality is highly affected by outdoor air quality (Leung, 2015). As our population continues to urbanize, the number of people spending 80-90% of their time indoors is also increasing (Orwell, 2004). Many studies have reported that the concentrations of volatile organic compounds are higher indoors than outdoors (Sakai *et al.*, 2004).

Plants continue to function as atmospheric filters indoors as they do outdoors and enhance the air quality of confined environments. Recent studies show that indoor plants are effective at removing VOCs (Orwell, 2004). The best indoor plants that could be used to improve indoor air quality in a small office space was studied (Aini *et al.*, 2012). They found that, the concentration of Volatile Oil Compound (VOC) inside a room was monitored before and after the test, using Aeroquol Model S500 VOC Gas Detector and by using oil-based paint painted on a panel measuring 0.05 x 0.05 m in order to create a minimum of 3ppm of (VOC) (Aini *et al.*, 2012). Three types of tropical indoor plants were used in this study; *Nephrolepis exaltata*, *Rhapis excels* and *Dracaena fragrans*. Data were monitored for eight hours at 10 minutes interval. The results showed no significant differences between the number of pots and the type of plants used in reducing VOC content in the real room environment. This was probably due to several factors, such as the interference of outside air and the

condition of the experimental room. This experiment suggests that further experiments should be carried out in a controlled environment to improve our knowledge of how indoor plants can improve indoor air quality, and thus improve human health and well-being (Aini *et al.*, 2012).

The most important step to reduce exposure to the selected pollutants HCHO, NO_x and SO_x, is to increase indoor air quality through reducing levels of these pollutants, while at the same time reducing indoor CO₂. The most promising method to achieve this aim is by using suitable indoor plant species (Burchett *et al.*, 2008).

During the 1980's NASA investigated the use of plants as air purifiers. The results of their investigation suggested that one potted plant per 100 square feet of indoor space in an average home or office was sufficient to cleanse the air of pollutants (Nugrahani *et al.*, 2012)

Ten species of ornamental plants that are effective at removing benzene from the air and are, therefore, considered as hyperaccumulators at removing other gaseous pollutants were identified (Liu, 2007). The green dragon tree (*Dracaena deremensis*) was found to be the species with the largest capacity to remove benzene from indoor air. Houses with six or more potted-plants showed reductions of over one third in NO₂ levels (Coward *et al.*, 1996). In another study found that if an office containing 2.5 ppm of each of B benzene, toluene, xylene and ethylbenzene (TEX) and had an approximate volume of 30 m³, it contains 16, 8, 22 and 22 mg/m³ benzene, toluene, xylene and ethylbenzene, respectively. Using ten *Opuntia microdasy* pots with the same size (10 cm diameter), can remove benzene, toluene, xylene and ethylbenzene totally after 36, 40, 30 and 39 hours (Kim *et al.*, 2011). In the presence of plants, CO₂ levels were reduced by about

10% in offices in the air-conditioned building, and by about 25% in the naturally ventilated building (Tarran *et al.*, 2007). Potted-plants can provide an efficient, self-regulating, low-cost, sustainable, bioremediation system for indoor air pollution, which can effectively complement engineering measures to reduce indoor air pollution, and hence improve human wellbeing and productivity (Wood *et al.*, 2006). They added that when mean of the total volatile organic compounds (TVOC) loads in the air of reference offices exceeded 100 ppb, concentrations were greatly reduced in the presence of any of the three potted-plant (*Racaena deremensis*) regimes trialled, by from 50–75% (Wood *et al.*, 2006) (Table 2).

Control of outdoor air pollution

Outdoor air pollution is believed to cause an estimated 1.3 million annual deaths worldwide, as well as an increased risk of respiratory and cardiovascular diseases (WHO, 2012). Outdoor air pollutants mainly consist of NO_x, SO₂, O₃, CO, HC, and particulate matters (PM) of different particle sizes. In urban areas, these pollutants are mainly emitted from on-road and off-road vehicles, but there are also contributions from power plants, industrial boilers, incinerators, petrochemical plants, aircrafts, ships and soon, depending on the location and prevailing winds (Leung, 2015). As with the outdoor environment, particulate matter such as dust, ash, pollen and smoke are also irritants and pollutants of indoor air. The levels of particulate matter accumulation in a room were lower when plants were present than when they were not. In addition to finding a reduction in particulate matter it was also found that relative humidity was slightly higher when plants were present (Prescod, 1990). An increase in relative humidity, particularly in heated environments, increases the comfort level. Another means by which indoor plants improve enclosed

environments is by removing offensive odours from the air (Oyabu *et al.*, 2003) (Table 3).

Advanced technique of air pollution control

Earlier times, vertical garden (biowalls) are meant for indoor biological air purification which are composed of a variety of plant species and microorganisms that live on their roots (Hum and Lai 2007).

Vertical gardens are a new technology that can add appealing green space, while actively enhancing the air quality in the environment (Curtis and Stuart 2010).

Through microbial activity, airborne contaminants such as volatile organic compounds (VOCs), benzene, toluene and other toxic fumes are degraded into end products that are harmless to humans and the environment.

In addition, biowalls reduce noise pollution, as their plants and planting medium are effective sound barriers. Another benefit of the biowall will be educating those who pass through the building regarding the importance of air quality, and workplace health (Curtis and Stuart 2010).

But now a day, vertical gardens are used to purify the outdoor pollution especially in cosmopolitan cities like Bengaluru, Delhi, Mumbai and Culcatta (Kidiyoor, 2017) (Fig. 1). Biowalls can also effectively improve the environmental conditions by reducing greenhouse gas emissions (Loh, 2000).

Mechanism of air pollution control by ornamental plants

There are four main ways by which plants reduce air pollution (Kapoor, 2017). These are:

Temperature reduction

There is a direct relationship exists between the emission of many pollutant and/or ozone forming chemicals with atmospheric temperature. Ozone forming chemicals are also reported to decrease with reduction in air temperature. Plant has a direct effect on temperature, incident radiation, radiation absorption, surface roughness, wind velocity, relative humidity and surface albedo. Trees contribute towards cooler summer temperature. These changes help to create a microclimate in surrounding areas which has the ability to alter the pollutant concentrations in urban and industrial areas (Nowak *et al.*, 1998).

Removal of air pollutant

The principle process by which plants removed gaseous air pollution is through the stomata, though some gases are also removed by other plant organs. Absorbed gases diffuse into intercellular space react with inner surface of leaves, may be absorbed by water to form acid. Suspended air particle intercepts with the leaf surface, adsorbed on the leaf and dropped to the ground during leaf or twig fall or rain fall (Smith, 1990). It is reported that a large healthy tree (> 77cm diameter) remove approximately 70 times more air pollution annually than small healthy trees which having diameter less than 8 cm (Nowak, 1994).

Emission of Volatile Organic Compounds (VOCs)

Each and every plant emits certain amount of volatileorganic compounds (VOCs) in the atmosphere. These VOCs are mainly responsible for the formation of ozone and carbon monoxide. However, in the presence of low nitrogen dioxide VOCs actually remove ozone (Crutzen *et al.*, 1985). VOCs emission rates dependent upon the species

and nine genera have been reported to have very high VOCs emission rate; among them *Eucalyptus*, *Salix*, *Casuarina* are important.

Energy effects on building

Tress reduces the building energy by lowering temperatures through shading during the summer and blocking winds during winter (Heisler, 1986); however, shading effect may lead to increase energy use during winter while during summer energy use may increase or decrease in the buildings situated near the sea shore. Therefore, proper knowledge of tree placement near the vicinity of the buildings is required to achieve maximum benefit.

As we consider the current scenario of the air pollution in the world, there is a growing need for planting ornamental plants which have the maximum capacity to reduce air pollution. Inclusion of the ornamental plants having pollution mitigating ability in the landscape plan will serve the dual purpose of making the cities green and pollution free in the long run. And a technique like vertical garden (biowalls) helps in reducing the pollution in big cities where the space is big lacuna. By growing more and more ornamental plants we can keep our environment healthy as well as recreational.

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