International Journal of ChemTech Research
CODEN (USA): IJCRGG ISSN: 0974-4290
Vol.8, No.6, pp 468-482, 2015

# Potentiality of Ornamental Plants and Woody Trees as Phytoremidators of Pollutants in the Air: A Review

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**Abstract:** 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 and woody trees as a green technology in phytoremediation for air contamination. Air pollutant can define as any substance emitted into the air from an anthropogenic, biogenic, or gynogenic source, that is either not part of the natural atmosphere or is present in higher concentrations than the natural atmosphere, and may cause a short-term or long-term adverse effect. 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. Non radioactive As, Cd, Cu, Hg, Pb and Zn and radioactive Sr, Cs and U are the most environmentally important metallic pollutants. Metabolism of foreign compounds in plant system is generally considered to be a' detoxification' process that is similar to the metabolism of xenobiotic compounds in humans, which considerd a 'green liver'. Trees and plants have been labeled as the "lungs of cities" because they have the ability to remove contaminants from the air that is breathed. 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. 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. Biowalls were developed due to the evidence of plants as efficient filters of air. One potted plant per 100 square feet of indoor space in an average home or office was sufficient to cleanse the air of pollutants. Based on available literature it could be concluded that ornamental plants and trees have the ability to filtrate the air from the contaminants.
**Keywords**: air pollution, phytoremedation, ornamental plants, woody trees, indoor plant, outdoor plants, human health.

## 1 Introduction

Air is necessary for the survival of all higher forms of life on earth. On an average, aperson needs at least 30 lb of air every day to live, but only about 3 lb of water and 1.5 lb of food. A person can live about 5 weeks without food and about 5 days without water, but only 5 minutes without air[1].

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[2].

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[2].

Various types of activity, including agriculture, industry and transportation, produce a large amount of wastes and new types of pollutants in air[3].

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)[4]. Also, nitrogen dioxide (NO2), Carbon Monoxide (CO), and Hydrocarbons (HC) are considered the main emissions, and higher levels can often be the result of increased airport vehicular traffic [2].

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 [5]. Following agricultural and industrial development, pollutants have formed a huge stereo-network on earth, existing in the water, soil and air.

Phytoremediaton is the process using plants to clean up the environment. 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[6].

Certain species of higher plants can accumulate very high concentrations of metals in their tissues without-showing toxicity [7]. Such plants can be used successfully to clean up heavy metal polluted air if their biomass and metal content are large enough to complete remediation within a reasonable period. Remediative plants must have mechanisms to detoxify and/or tolerate high metal concentrations accumulated in their shoots [8]. In the natural setting, certain plants have been identified which have the potential to uptake heavy metals.

The possibility to clean contaminated air with hyperaccumulator plants has shown great potential. One of the most recently studied species used in phytoremediation applications are woody trees and ornamental plants. These plants can be harvested every 8 to 10 years to generate revenue, along with the added advantage of working as natural air conditioners and greenhouse gas sinks, for ameliorating the highly polluted urban environments[9].

Floriculture farmers produce about 6,000 species of cut flowers, potted flowering plants, houseplants, cut foliage, bedding plants, bulbs, cuttings for propagation, food and medicinal plants in greenhouses and outdoor-grown cut flowers[10,11].

Nursery farmers produce about 9,000 species of annual and perennial plants, woody shrubs, deciduous and coniferous trees, roses, outdoor garden flowers, Christmas trees and sod [11].

Recently, a fern *Pteris vittata* accumulate as much as 14,500 mg $kg^{-1}$ arsenic in fronds without showing symptoms of toxicity[12].

The use of trees and shrubs resistant to environmental pollutants, is one of the important elements in the creation of green spaces that is, preventing dispersion of the noise, the air filtration process and the more beauty of the urban and industrial that this may cause the spirit of happiness in different environments[13].

There are over 900 Air Force sites with TCE contamination within 20 feet of land surface that could be reviewed for potential application of phytoremediation by use of poplar trees. Costs may be 10 to 20% of those for mechanical treatments[14]. Phytoremediation is the name given to a set of technologies that use different plants as a containment, destruction, or an extraction technique. Phytoremediation as a remediation technology that has been receiving attention lately as the results from field trials indicate a cost savings compared to conventional treatments[14].

Many studies have calculated the energy savings plants can provide and documented the benefits of these savings in dollar values (as well as reduction in carbon emissions).

Through a series of studies reported [15], an average of $US 0.5782 in energy dollars saved was reported per square meter of tree canopy, per year, when shade trees were planted in urban centre's[15].

Eighty children had been exposed for at least 2 years to air pollution from a refuse-derived fuel incineration plant. All of the patients had increased hair cadmium compared with a control group, but there was a strong seasonal influence on hair cadmium. Exposure to cadmium was ubiquitous[16].

A neurobehavioral toxic effect was found in children who showed evidence of inhibition of pyrimidine-5'-nucleotidase by low hair phosphorus levels and low zinc levels in whom there was enhanced lead absorption. Hair analyses appear to be a useful biological monitor for detecting toxic effects from ambient air cadmium levels in subsets of the population at risk for heavy metal toxicity. Air filter measurements appear worthless for detecting environmental contamination with cadmium in air with low levels of lead. Trees, on the other hand, which are more adversely affected by cadmium than other heavy metals, show evidence of inhibition of pyrimidine-5'-nucleosidase by excess seeding[16].

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 [17].

The health costs incurred by particulate matter (PM10) pollution in the UK have been estimated to range between £9.1 and 21.4 billion per annum as shown in Table (1) [18].

**Table 1. Monetary values of health impacts[18].**

| Health effect | Form of measurement to which the valuations apply | Central value(2004 prices) |
|---|---|---|
| **Acute mortality** | Number of years of life lost due to air pollution, assuming 2-6 months loss of life expectancy for every death brought forward. Life-expectancy losses assumed to be in poor health | £15,000 |
| **Chronic mortality** | Number of years of life lost due to air pollution. Life expectancy losses assumed to be in normal health. | £29,000 |
| **Respiratory hospital admissions** | Case of a hospital admission, of average duration 8 days. | £1,900 – £9,100 |
| **Cardiovascular hospital admissions** | Case of a hospital admission, of average duration 9 days. | £2,000 to £9,800 |

## 2 Air pollution in Egypt

As mentioned in the site of ministry of state environmental affairs (Egyptian Environmental Affairs Agency (EEAA-EIMP) [19] the suspended dust (measured as $PM_{10}$ and TSP) can be seen to be a major air pollution problem in Egypt. $PM_{10}$ concentrations can exceed daily average concentrations during 98% of the measurement period. The Exceedances are highest in industrial areas. On the other hand it seems that the natural background of $PM_{10}$ in Egypt may be close to or around the Air Quality Limit value. These levels can be found also in areas where local anthropogenic sources do not impact the measurements. Further measurements may be used in the future to quantify the relative importance of the different sources relative to a background level that varies dependent upon the area characteristics. In addition to particles, also $SO_2$ in urban areas and in industrial areas, as well as $NO_2$ and CO in the streets may exceed the Air Quality Limit value [19]. Air Quality Limit values are given in the Executive Regulations of the Environmental Law no. 4 of Egypt (1994). These Air Quality Limit values are presented in Table (2) [19].

**Table 2. Ambient Air Quality Limit values as given by Law no.4 for Egypt (1994) compared to the World Health Organization (WHO) air quality guideline values [19].**

| Pollutant | Averaging | Maximum Limit Value | |
|---|---|---|---|
| | time | WHO | Egypt |
| **Sulphur Dioxide ($SO_2$)** | 1 hour | 500 (10 min) | 350 |
| | 24 hours | 125 | 150 |
| | Year | 50 | 60 |
| **Nitrogen Dioxide ($NO_2$)** | 1 hour | 200 | 400 |
| | 24 hours | - | 150 |
| | Year | 40-50 | |
| **Ozone (O3)** | 1 hour | 150-200 | 200 |
| | 8 hours | 120 | 120 |
| **Carbon Monoxide (CO)** | 1 hour | 30 000 | 30 000 |
| | 8 hours | 10 000 | 10 000 |
| **Black Smoke (BS)** | 24 hours | 50 * | 150 |
| | Year | - | 60 |
| **Total Suspended Particles (TSP)** | 24 hours | - | 230 |
| | Year | - | 90 |
| **Particles <10 µm (PM10)** | 24 hours | 70 ** | 70 |
| **Lead (Pb)** | Year | 0.5-1,0 | 1 |

*Together with $SO_2$ ** Norwegian Air Quality Limit value

The Egyptian Demographic and Health Survey indicated that 10% of children under the age of 5 years complained of acute respiratory tract infection, and 19% suffered from diarrhea. The mortality rate for the under-five years old was 46 deaths per 1000 births and the results showed a strong negative association between household wealth and early childhood morbidity and mortality rates. Another study assessed home environment and its relation to child health in rural area in Alexandria revealed that 99% of the study subjects complained of cough, 40.9% had pneumonia 10.5% had bronchitis, and 6.2% complained of dyspnea. Generally, this complains were related to environmental factors [20].

The traffic related air pollutants were assessed in homes located on streets with different traffic density in Damietta, Egypt. Paired indoor and outdoor concentrations of particulate matter (PM 10), nitrogen dioxide ($NO_2$) and sulfur dioxide ($SO_2$) were determined at 22 homes during winter and summer Seasons 2010 [21]**.** The influence of the traffic on the indoor concentration was apparent in the high traffic areas. There was a general pattern of increasing summer I/O ratios. The most I/O ratios of PM10, $NO_2$ and $SO_2$ were less than one indicating that the outdoor traffic-related sources contributed more to indoor air quality. The concentrations of all pollutants varied significantly ($P<0.05$) in both seasons. The PM10 had higher values in winter while both $NO_2$ and $SO_2$ were slightly higher in summer for the all traffic density areas[21].

The correlations observed between outdoor and indoor concentrations in winter were relatively low than those observed in summer. Results showed poor correlation between indoor and outdoor $PM_{10}$ and relatively strong correlation of $NO_2$ and $SO_2$ at both summer and winter [21]**.**

## 2. Contaminate metabolism during phytoremediation in plants

The ‘green liver ’model is often used to describe the fate and disposition of organic contaminants (xenobiotic compounds) within plants. Metabolism of foreign compounds in plant system is generally considered to be a’ detoxification’ process that is similar to the metabolism of xenobiotic compounds in humans, hence the name ‘green liver” [22].

## 3. Air Pollution

Defining “air pollution” is not simple. One could claim that air pollution started when humans began burning fuels. In other words, all man-made (anthropogenic) emissions into the air can be called air pollution, because they alter the chemical composition of the natural atmosphere. So we can define an “air pollutant” as any substance emitted into the air from an anthropogenic, biogenic, or gynogenic source, that is either not part of the natural atmosphere or is present in higher concentrations than the natural atmosphere, and may cause a short-term or long-term adverse effect [23].

Air pollution is broad term, which actually covers lots of different types of problems. They are acid rain, domestic and industrial smoke, smog, greenhouse effect, particulates, radionuclides and ozone layer depletion [1, 24].

In ambient air, metals, metalloids and their compounds are mainly encountered as part of particulate matter. They may be present in the non soluble, non stoichiometric mixture phase (for example as spinels) or as soluble ionic compounds (salts). Cadmium and arsenic compounds are enriched in the fine particle mode about or below 1 μm and, consequently, can penetrate deeply into the respiratory system and have long residence times in the atmosphere. In contrast, up to 30 % of the total nickel compounds may be found in the coarse mode [25].

## 4. Phytoremedation of air contaminants

Air pollutants can be divided into 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 [26].

Trees and plants have been labeled as the "lungs of cities" [27] 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 [11, 28].

Therefore we could used the ornamentals and woody trees as a green plants to remediate the air pollution through absorb and degrade all types of urban air pollutants thereby reducing air pollution levels [29,30,31]. Ornamentals and woody trees can use as eco-friendly alternatives for the removal of the pollutants from the air.

## 5. Trees as phytoremedators

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 [32]. 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 [33]. The ability of plants to remove specific polluting compounds from the research is presented in the Table (3) below [33].

**Table 3. Average air pollution removal and value for all urban trees in the United States [11, 33].**

| Pollutant | Removal (metric tons) | Values (million US$) |
|---|---|---|
| **Ozone ($O_3$)** | 305,100 | 2,060 |
| **Particulate matter ($PM_{10}$)** | 214,900 | 969 |
| **Nitrogen dioxide ($NO_2$)** | 97,800 | 660 |
| **Sulphur dioxide ($SO_2$)** | 70,90 | 117 |
| **Carbon Monoxide (CO)** | 22,600 | 22 |
| **Total** | 711,300 | 3,828 |

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 [34]. 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 [34].

## 6. Properties of the ornamental plants and woody trees used as air phytoremedators

The important criteria for the ornamental and woody trees to be phytoremetioter 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 [1].

A few ways in which plants reduce air pollution are as follows [11]:-

- 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 [27].

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 [17].

The phytoremediation properties of some ornamental plants used in landscape have been investigated [35]. 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 [35].

Twenty-eight ornamental species commonly used for interior plantscapes 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 ($\alpha$-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 $\alpha$-pinene). The five species ranged in their removal efficiency from 26.08 to 44.04 $\mu g \cdot m^{-3} \cdot m^{-2} \cdot h^{-1}$ of the total VOCs. *Fittonia argyroneura* effectively removed benzene, toluene, and TCE. *Ficus benjamina* effectively removed octane and $\alpha$-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[34]. It is better to arrange some species of plants to achieve the best removal effects taking account of concentrations, fumigation time and pollutants[36].

On five species of streetscape plants were identified as ornamental shrubs i.*e.* Ixora Red, Yellow Bush, Masquerade Pine, Tuja Pine and Yellow ficus [37]. 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 bioindictors of poor urban air quality while shrubs with high APTI values (Tolerant) are to be planted around areas anticipated having high air pollution load [37].

Sixteen ornamental plant species commonly used for interior plantscapes were screened for their ability to remove three common indoor pollutants of formaldehyde, nitrogen oxides ($NO_x$) and sulfur oxides ($SO_x$) [38]. 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 µg day$^{-1}$ and 2120 µg day$^{-1}$ and *Spathiphyllum wallisii* for $NO_x$ as 3200 µg 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 $NO_x$ [39].

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) [40].

From the literatures, the success of green technology in phytoremediation, in general, is dependent upon several factors [41]. 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 ac-cumulated 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 en-tire 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 [41].

A list of plants which are effective air purifiers along with the pollutants that they are best at removing was provided [42, 43]. 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 [43].

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. However, there is a substantial amount of research that indicates having indoor plants has the net effect of improving indoor air quality [44].

## 7. Indoor Air Quality Improvement

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 [45]. 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 [46].

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 [47,48,49].

A number of air pollutants have been recognized to exist indoors, including NOx, $SO_2$, $O_3$, CO, volatile and semi-volatile organic Compounds (VOCs), PM, radon, and microorganism. Some of these pollutants (e.g., $NO_x$, $SO_2$, $O_3$, and PM) are common to both indoor and outdoor environments, and some of them maybe originated from outdoors [50].

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 [51]. 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 [51].

Many studies have confirmed that indoor air quality is highly affected by outdoor air quality [50].

As our population continues to urbanize, the number of people spending 80-90% of their time indoors [52] is also increasing.

Many studies have reported that the concentrations of volatile organic compounds are higher indoors than outdoors [53]. 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 [52].

The best indoor plants that could be used to improve indoor air quality in a small office space was studied [39]**.** 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) [39]**.** 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 [39].

The most important step to reduce exposure to the selected pollutants HCHO, $NO_x$ and SOx, is to increase indoor air quality through reducing levels of these pollutants, while at the same time reducing indoor $CO_2$. The most promising method to achieve this aim is by using suitable indoor plant species [31].

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 [40].

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Ten species of ornamental plants that are effective at removing benzene from the air and are, therefore, considered as hyperacumulators at removing other gaseous pollutants were identified [54]. 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 $NO_2$ levels [55]. 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 $m^3$, it contains 16, 8, 22 and 22 $mg/m^3$ 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 [56].

In the presence of plants, $CO_2$ levels were reduced by about 10% in offices in the air-conditioned building, and by about 25% in the naturally ventilated building [57].

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 [58]. 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% [58].

## 8. Outdoor

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 [59].

Outdoor air pollutants mainly consist of $NO_x$, $SO_2$, $O_3$, 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 sand prevailing winds [50].

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 [42]. 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 outdours from the air [60].

## 9. Biowalls

Biowalls are indoor biological air purification systems are composed of a variety of plant species and microorganisms that live on their roots [61].

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 [62].

Biowalls can also effectively improve the thermal performance of a building, thus resulting in less energy consumption and greenhouse gas emissions [63].

Biowalls are a new technology that can add appealing green space, while actively enhancing the air quality in a building [62]. The Biowall does not contain soil and relies on a pumping system with water and nutrients to sustain the plants as shown in Fig. (1) [64].

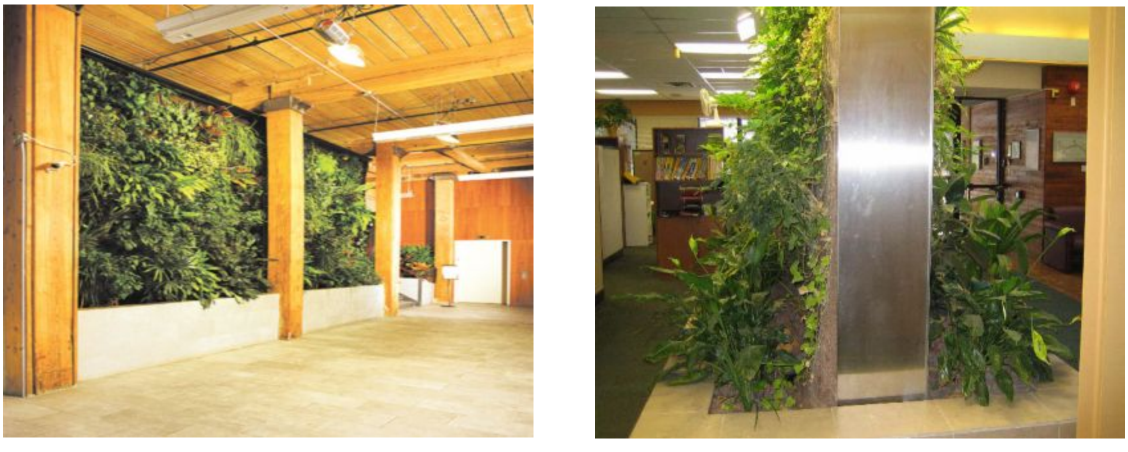

**Figure 1. Biowall for air pollutants filtration[64].**

In street-canyon, the team estimated that vegetation may reduce concentrations of two of the most harmful urban air pollutants, nitrogen dioxide ($NO_2$) and coarse particulate matter ($PM_{10}$), by as much as 40% and 60% respectively, although average reductions over a year were in the range of 7–30% [65].

Biowalls were developed due to the evidence of plants as efficient filters of air. The biowall system, known as Naturaire®, is adaptable to a variety of spaces including condominiums, homes, office buildings and public buildings and may be used during space exploration in the future [66, 67]. Researchers at the University of Guelph developed an air filtration system that has a wall of living plants which cleans the air of a building and incorporates it back in to the air distribution system. In the most complex systems, water to irrigate and fertilize the plants comes from integral waterfalls and vertical drip systems sourced from ponds which support fish, plants and other organisms that cleanse the water while adding nutrients for the plants. The biowall system, known as Naturaire®, is adaptable to a variety of spaces including condominiums, homes, office buildings and public buildings, and may be used during space exploration in the future [66, 67].

Toluene is a common volatile organic compound (VOC) found in homes and offices that represents a serious health hazard. Toluene is not considered a carcinogen, exposure to high levels is known to affect the kidneys, nervous system, liver, brain, and heart. Changes in phytoremediation efficiency after repeated exposures (three) totoluene (1.3 ppm) were assessed in 26 species and two additional cultivars of indoor plants [56].

There was a rapid increase in toluene removal efficiency in 27 of the 28 crops with the greatest increase between the first and second exposure (i.e., after 3 days). The increase in efficiency between the first and third exposure ranged from 378 $mg\_m^{-3}\_h^{-1}\_m^{-2}$ leaf area in *Pinus densiflora* to –16.6 in *Salvia elegans* with a mean of 156 for all crops. Percent change ranged from 614 (*Pittosporum tobira*) to –8 (*Salvia elegans*) but was not necessarily indicative of phytoremediation value of a species. Rapid changes in phytoremediation efficiency in response to exposure to toluene appear to be widespread in plants and may be the result of an effect on gene expression in the plant and/or certain soil microbes or changes in the population density of toluene metabolizing microbes. Increasing toluene removal efficiency is advantageous and as a consequence, a better understanding of the mechanism(s) operative may improve use of the response for practical applications [56]. Comparing the increase in toluene removal efficiency based on the general plant type (Table 4), woody foliage plants had the greatest mean increase in removal rate (159 $mg\_m^{-3}\_h^{-1}\_m^{-2}$ leaf area) and herbaceous foliage plants the least (71 $mg\_m^{-3}\_h^{-1}\_m^{-2}$ leaf area); herbs were intermediate between the two (118 $mg\_m^{-3}\_h^{-1}\_m^{-2}$ leaf area) [56].

**Table 4. Effect of plant type on the change in rate of toluene removal with previous exposure to the gas (Δ rate = third exposure – first exposure) and the mean rate of toluene removal from the air [57].**

| | Rate of toluene removal ($mg\_m^{-3}\_h^{-1}\_m^{-2}$ leaf area) | | | |
|---|---|---|---|---|
| | Δ rate | | Third exposure | |
| **Type of plants** | Mean | Range | Mean | Range |
| **Woody foliage plants** | 158.7 | 378.2–26.4 | 351.5 | 929.3–22.1 |
| **Herbs** | 117.5 | 303.7 –16.6 | 376.9 | 733.7–108.6 |
| **Herbaceous foliage plants** | 71.1 | 133.0–8.2 | 254.4 | 449.8–55.9 |

## 10. The difference between plant species for removing the air pollutants

*Opuntia microdasys* was able to remove 2 ppm of toluene from air in the test chambers completely after 55 hours. However, *D. dermensis* could remove toluene from air in the test chambers completely after 120 hours. The removal rates of toluene in test chambers were 1.47 and 0.67 $mg/m^3\ d^1$ for *Opuntia microdasys* and *D. dermensis*, respectively [68]. Spider plants can remove formaldehyde up to 50% [69].

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 a-pinene) [70]. They added that the five species ranged in their removal efficiency from 26.08 to 44.04 $mg\_m^{-3}\_m^{-2}\_h^{-1}$ of the total VOCs. *Fittonia argyroneura* effectively removed benzene, toluene, and TCE. *Ficus benjamina* effectively removed octane and a-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 [70].

Sometimes, the level of air pollution indoors can be more than ten times higher than the outdoors, and in the case of some harmful substances, their concentrations can even exceed permissible norms by up to 100 times [71].

Spider plants accumulate particulate matter (PM) of both categories (water washable and trapped in waxes) and in all three size fractions determined and that the amount differed depending on the type of activity taking place in the particular rooms ranging from 13.62 to 19.79 μg/cm$^2$. The amount of wax deposited on the leaves of plants grown in these rooms also differed (34.46–72.97 μg/cm$^2$) [49].

For gaseous pollutants it was primarily done through the stomata. After the absorption, the aromatic ring of benzene and toluene molecules is converted into non-volatile organic acids. The ability of a hypostomatous leaf to take up benzene and toluene from air by its adaxial side and transform them into non-volatile components indicates that the leaf cuticle is permeable to the aromatic hydrocarbons. The amount of absorption of contaminants is dependent on the number of stomata and the structure of the cuticle [62, 72].

Many other studies have shown that the roots take up most of the VOCs out of the air. Once the VOCs are degraded, the products can be used to food for the plant. It seems to be dependent on the species of the plant and the origin and type of the contaminant [62].

## 11. Economic and social aspects of phytoremediation acceptability

The cost to the U.S. economy from the lowered productivity as a result of poor indoor air quality could be as high as $125 billion per year [73]. Biowall system has the potential to reduce the energy consumption in residential and commercial buildings, which jointly represents more than 60% of the electric energy consumption in the United States [74].

Phytoremediation is an environmentally friendly, safe, cheap way to clean up contaminants. Early estimates on the costs have shown that plants could do that same job as a group of engineers for one tenth of the cost. Plants can be planted, watered, and then harvested with less manpower. If need be, the storage of the harvested plants as hazardous waste would be a far smaller amount. The main drawback on the use of this technology is that it isn't good for all sites. If the contamination runs too deep or the contaminant concentration is too great, the plants alone can't efficiently remediate the contaminated site [75].

Researchers in the United Kingdom quantified the benefits of air pollution absorption in terms of mortality and morbidity. The woodlands in Britain saved 5-7 lives and reduced hospital admissions by approximately 4-6 annually. This had an estimated economic value of at least £900,000 [28]. Their argument was that by absorbing pollution such as particulate matter (PM: consists of airborne particles in solid or liquid form) and sulphur dioxide [28].

Phytoremediation does not require expensive equipment or highly-specialized personnel, and it is relatively easy to implement. It is capable of permanently treating a wide range of contaminants in a wide range of environments. However, the greatest advantage of phytoremediation is its low cost compared to conventional clean-up technologies [76, 77].

For example, the cost of cleaning up one acre of sandy loam soil with a contamination depth of 50 cm with plants was estimated at $60,000-$100,000 compared to $400,000 for the conventional excavation and disposal method [19].

Remediation decision making is a social process informed by scientific and technical information, rather than a science- or technology-driven process [75].

A cost-benefit analysis for the use of indoor plants which clearly indicates the savings will more than cover costs, thus achieving a win-win situation for IEQ and human wellbeing, and an essential contribution to 'enabling sustainable communities' [31]. They added that urban air pollution in the Sydney metropolitan area alone is estimated to cause some 1,400 deaths per year. On average, indoor air can have 5 to 100 times the concentration of air contaminants as outdoor air, since we stay indoors 90% of the time, that is where we breathe the contaminated air [29,77, 78].

One of the advantages of phytoremedation is a cost-effective technology, as cost involved in phytoremediation technology is 60-80% less than the conventional physico-chemical or mechanical technologies [79]. The conventional methods of remediation may cost from 10$ to 1000$ per cubic meter while Phytoextraction costs are estimated to be as low as 0.05$ per cubic meter [80].

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