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Review Article

GREEN SOLUTIONS: COMBATING URBAN POLLUTION THROUGH LANDSCAPE GARDENING UNDER GLOBAL CLIMATE CHANGE SCENARIO

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Abstract

The accelerating pace of urbanization and industrialization coupled with escalating human demands, has significantly contributed to rise of greenhouse gases, leading to human-induced global warming. As global warming intensifies, it is driving severe environmental shifts including, melting glaciers at unprecedented rates, elevating sea levels, disturbing weather patterns, increasing the frequency of floods and droughts and endangering countless species across the globe. In urban centers, the absence of sufficient greenery significantly hampers the natural mechanisms of effective cleansing, that would otherwise be crucial for absorption of pollutants from surrounding including soil, water and air through the mechanism of phyto-remediation. Despite spending nearly 80–90% of their time indoors, people are not insulated from the curse of global warming. On the contrary, confined spaces frequently trap harmful indoor pollutants, that becomes a reasonable factor for inhaling indoor pollutants, eventually making the place unsuitable for physical as well as mental health. Addressing this worsening crisis requires prompt, individual actions. Integrating landscape gardening, into day-to-day life can emerge as an effective sustainable measure. Urban landscaping can effectively facilitate in mitigating the situation with proper knowledge of suitable plants which can sequester pollutants or volatile organic compounds from surroundings and can create a sustainable ecosystem even in congested cities. Strategies including, vertical gardening, indoor and outdoor gardening, rooftop gardening etc., offers innovative way out to maximize green space in crowded environments by beautify the space.

Keywords: Climate change, Indoor gardening, Pollutants, Sequestration, Vertical gardening

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Introduction

In the present era, with growing population, the greed and exploitation of natural resource to ease solely human desires is also escalated, there by result into rise in greenhouse gases such as carbon dioxide, carbon monoxide, nitrous oxide, hydro fluorocarbons, perfluoro carbons, Sulphur hexafluoride, nitrogen trifluoride, methane etc. Eventually rise in greenhouse gases has become the prominent reason for shift in climate pattern which ultimately results in global warming. It leads to direct and indirect effects on earth, such as rise in temperature results into melting of glaciers thereby leading to increase in the sea level, shifting weather pattern brings heavy rain falls, storms, floods, drought, and landslides. Forest fires cause habitat loss, wildlife extinction, and mass forest loss. All these changes are interlinked with each other and indirectly increase the chances of water, air or soil borne disease, scarcity of food and water etc. Overall, it is disturbing the balance of nature and ultimately leads to misbalancing the food chain and extinction of life. In the era of technology, where humans are conquering the making of artificial intelligence, climate change is emerging as major crises for survival.

Principally, climate change refers to 'long term shift in temperature and weather pattern.' Anthropogenic activities i.e. deforestation, industrialization, urbanization, transportation are one of the leading reasons for climate change. According to research conducted by the Joint Research Centre in European Commission, global anthropogenic fossil CO_2emissions escalated by 1.2% in 2017 over 2016 (Muntean et al., 2018). As per IPCC assessment report 2022, during the year from 2010-2019, annual average global green house gas emissions were at their upper most peak in human history, but threat of growth has slowed. The most CO_2 emitting countries were USA, China, India, Russia, and Japan (IPCC 2014). The atmospheric CO_2, N_2O and CH_4concentration since industrial revolution risen by 30, 15% and 145% respectively due to anthropogenic activities (IPCC, 2007).

At present, the concentration of CO_2 is exceeding 350 ppm and it is assumed to be 550, 600,650-700ppmin2040, 2060 and 2075 respectively. Doubling of CO_2 concentration can raise temperature approximately 2.3± 1.6°C and it is assumed that about 4°C temperature will be boost up by the year 2080. Moreover, with the rise in temperature, the productivity of Indian farming is predicted to decline by 30-40% (De, 2018). An overall reduction in numbers of rainy days is also predicted in major part of India with the help of climate model (Khurana, 2012). Further, direct and indirect consequences of climate change put adverse effects not only on animals or humans, but also on plant morphology, anatomy and physiology which results into lower germination rate, reduced productivity, change in leaf gas exchange pattern, disturb carbon fixation in dark cycle, enhances respiration rate, high evapo- transpiration, poor grain filling, increment in disease and pest infestation, lower water and fertilizer use efficiency and terminal heat stress etc. (Taiz and Zeiger, 2010). Other indirect impacts of climate change are desertification, heat waves, reduction in soil microbes, soil erosion, soil organic matter transformation and reduction in arable areas etc.(De, 2018)

During the pandemic of Covid 19, the world got imprisoned in their respective dwellings, which somehow ceased the anthropogenic emissions of pollutants. According to a report by Pillai in India, 2021, it was revealed that, during lockdown in Delhi, the total Carbon monoxide emissions depict declining trend by 86.39% compared to without lockdown days. However, Carbon monoxide emissions from transportation vehicles fell from 31.01 giga gram/month (Gg/month) on regular days to just 3.1Gg/month during the lockdown (Pillai, 2021). Surprisingly, from past many decades, it was the first time when annual Carbon monoxide emission had recorded negative trend. These kinds of findings support the arguments as anthropogenic activities to meet the greed are the primary reason for emission

of pollutants which escalate the threat of climate change (Rout, 2021).Change in climate pattern and insufficiency of natural resources majorly caused by anthropogenic activities forcing researchers and policy makers to search for an alternative approach for sustainability. Deforestation, Industrialization, transportation, power house production, agriculture sector etc., are not the only reason for emission of greenhouse gases however pollutants are emitted on individual bases from own dwellings and workplaces, especially in urban areas, where vehicles in masses and industries contribute maximum. Due to congested areas, it is very difficult for sufficient plantation to absorb the sources of pollutants by plants.

Hence, before fixing the problem of pollutants at mass scale, one should try to fix it on their individual levels from their own respective houses by adopting and practicing different approaches of landscape gardening such as indoor gardening, roof gardening, vertical gardening, gardening of highways, rivers, railways, hotels, hospitals, schools, private buildings etc. Wherever, especially in urban areas places are vacant they should be turn into green. Moreover, several studies have confirmed that a number of plants can proficiently eliminate detrimental gases and compounds, contributing to healthier living environments.

Fig. 1 Different methods of landscape gardening

Also, it will not only sequester pollutants but will also provide aesthetic peace that would assists in reducing anxiety and depression and help one to overcome "Sick Building Syndrome." In recent years, due to increasing environmental challenges and global changes, ornamental plants have gained attention not only for their aesthetic appeal but also for their ability to enhance the environment and improve the quality of human life (Save, 2009). Thus, landscape gardening is one of the alternatives that can restore degraded landscapes, control erosion, reduce energy and water consumption, combat different types of pollution and improve the aesthetic quality of indoor and outdoor environments where people live (Tascano, 2019). Therefore, this review aims to elucidate the role of landscape gardening to amend Urban Pollution in the era of Climate change.

Importance of Landscape Gardening

- Reducing pollution of the environment and purifies air.
- Minimizes some of the effects of heat, sound, wind, etc.,
- Prevents soil erosion and minimizes noise pollution.
- Plants with thick foliage also trap pollutants.
- Increases the privacy and property value**.**
- Controls pedestrian and vehicular traffics.
- Contributes to the improvement rather than the destruction of environment
- Modifies the microclimate of an area.
- Acts as a shelter for wildlife especially birds.

Indoor Gardening

Nowadays, the lifestyle pattern has shifted due to variety of reasons. People have started start spending about 80-90% of the time indoor (Raymond et al., 2017) however, staying indoor is not shielding them from the curse of global warming, instead it has become a reasonable factor for inhaling indoor pollutants, which ultimately makes the place unsuitable for staying. Indoor pollution is considered as a chemical, biological and physical contamination of indoor atmosphere which can cause "sick building syndrome" or 'building-related' disorder with acute symptoms like headache, nausea, dizziness, sore throat, eyes and concentration disturbance.

According to research conducted in UAE, the indoor atmosphere of the apartments is causing building- related disorders quicker than in any other country (Amoatey et al., 2020; Jung et al., 2021). Whereas, in USA, about 27 million office workers are at risk of sick building syndrome (Lu et al., 2016). However, exposure to natural scenery or greenery can be considered as better alternative to cope up with mental, social, and physical health and can surely reduce the concentration of pollutants (Irga et al., 2013).

On the other hand, increasing population and their desires, leads to fragmentation of land and most of it is occupied by industrial, public and private sectors in urban areas. As result, people do not have enough space to view up on greenery. Indoor gardening refers to the act of “growing plants inside the building” or “growing of houseplants within a residence or building, in a conservatory, or in a greenhouse.”It is not only restricted to residential dwellings, but can be practiced at any closed shelter, for instance, inside any office building, hotels, restaurants, hospitals, schools, universities, shopping malls, airports etc. Hence, they need to adopt indoor gardening to add up greenery in their daily life in order to uplift the social, physical and mental well-being of an individual inside surroundings and workplaces. It also improves their work efficiency.

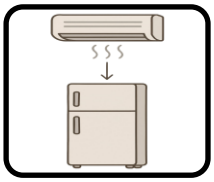
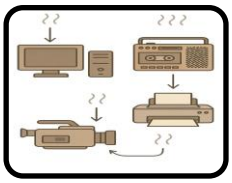
According to a report by Environmental Protection Agency (EPA) of USA, it was witnessed that, due to high concentration of indoor pollutants, the exposure to indoor contamination is hundred times greater than the exposure to outdoor pollutants. Contamination of indoor air can be ten times more dreadful as compared to outside atmosphere contamination and due to indoor activities (Kankaria et al., 2014). As per the studies of World Health Organization, it was reported that, worldwide nine out of ten of people inhale contaminated air and because of unclean fuels for cooking about 3 billion people inside their home are at risk of household air pollution (WHO, 2018). Major sources of indoor pollution inside the house is enlisted in table no 1.

As per the scientific investigation from past few years, it has been witnessed that, indoor gardening can appreciably decline the concentration of different types of pollutants (Wolverton et al., 1989; Orwell et al., 2004; Kim et al., 2008; Deng and Deng, 2018). However, some plants can tolerate whereas some are highly sensitive to pollution. The early recognition damage due to pollutants in plants can be characterized by foliar symptoms which gives alarm for toxic risk to humans and their environment (Upadhyay and Kobayashi, 2007).

In addition, numbers of research findings have demonstrated that, indoor potted plants have the optimistic potential to amend the indoor air quality, by dropping the air-borne pollutants viz. Nitrogen oxides, VOCs, and dust particles (Han, 2009). Also, as per findings of Seughal et al, 2016broadleaf or foliage plants are efficient for indoor purification. Moreover, indoor plants can be utilized as natural water-filtration that can filter VOCs such as, benzene, formaldehyde, and trichloroethylene (Seughal et al, 2016). Indeed, certain indoor plants possess the potential to absorb and metabolize various pollutants that are present in the

indoor atmosphere, ultimately resulting into purification of the indoor air quality.

Table 1. Source of Pollutants inside house

	**Kitchen (fuel-burning combustion appliances for cooking):** Carbon dioxide, carbon monoxide, sulphur oxides, nitrogen oxides, nitrogen dioxides methane, aldehydes, asbestos, acrolein, etc.
	**Living room or bed rooms (damaged or deteriorating ceiling, wall, cented paraffin candles, foam, furniture polish, paints, glues, air fresheners, mosquito repellents, carpets, cleaning agents, etc.):** Volatile organic compounds, fine dust, CO, C02, radon gas, formaldehyde, particulate matter, methyl chloroform, tetrachloroethylene, n-undecane, benzene, trichloroethane, aldehydes, asbestos, suspended particulate matter, toluene, etc.
	**Air conditioning and refrigerators**: Chlorofluorocarbons, hydrochlorofluorocarbons , hydrofluorocarbons , carbon dioxide, nitrous oxides, mercury, sulfur dioxide, particulate matter, volatile organic compounds (vocs), ozone (O_3), mold and bacteria, noise pollutionre, etc.
	**Bathrooms and laundry rooms (soaps, detergents, pipe insulation):** Respirable suspended particulates (RSP), ammonia fumes, chlorine, benzene, asbestos, aldehydes, lead, fatty acids, polyphospha tes, glycerol, sulphonated hydrocarbon, asbestos, suspended particulate matter, etc.
	**Electrical equipment (computer, cassette tape recorder, video cameras, printers, videotapes, etc.):** Ethyl benzene, chloroform, polybrominated diphenyl ethers carbon dioxide, trichloroethylene, xylene, lead, mercury, ozone etc.
	**Personal care products (eyeliner pencil, deodorant, skin lotion, perfumes, hairspray and nail polish removers, etc.):** Methylchloroform, styrene, tetrachloroethylene, trichloroethylene, benzene, lisopene, volatile organic compounds, formaldehyde, etc.

Most of the selected indoor plants are foliage with broadleaf which are partial to shady in nature. However, the broadleaf plants have process of adaptation to the environment. One effect of adaptation is the reduction of stomata pores on the leaves therefore, instead of absorption of pollutants; it gets attached to the leaves surface (Brilli et al., 2018).

Plants have been manifested that during gaseous exchange, stomata pores absorb air pollutant (Smits, 2005). Moreover, evapo-transpiration by indoor greenery aids in cooling down the inner temperature, control humidity and lower the sound levels. Living wall

systems in grouping with bio-filtration can be utilized as an emerging technology for a better alternative to get better of indoor comfort (Moya et al., 2019).

According to the report of Wolverton *et al.,* 1989plants having low-light-requirement with activated carbon filters possess the capacity for recovering indoor air quality and the plant root zone is considered as a potential area for absorbing volatile organic compounds (VOCs) i.e. benzene, ammonia and formaldehyde etc. In fact, rhizosphere area was recommended for best filtration, further, it aids unbalancing the sick building syndrome (Wolverton et al., 1984). Similar kind of report was also presented by Torpy et al., 2013 that concludes, potted-plants can considerably lower down the concentration of VOCs levels in indoor atmosphere and the root-zone bacteria of the potting mix also assists biodegradation of VOCs and carbon dioxide (Torpy et al., 2013). Likewise, it is recommended to plant at least two indoor plants in aroomof100 squarefeet (9.3 m^2) to keep the indoor atmosphere healthy (Klepeis et al., 2001).

In Japan a study was conducted on 40 students in a high school, where students were asked to look at artificial and real pansies, and later, they found that, the visual stimulation of real flower shown noteworthy decline in the ratio of low- to high-frequency heart rate variability component as compare to artificial one, which depicts sympathetic nerve activity. In case of psychological indices, looking at real flowers resulted in natural, comfortable, and relaxed feelings (Igarash et al., 2015). Hence plants play significant role in inducing positive impact both on psychology and physiology of students.

In an experiment conducted by Teiri et al., in 2018, it was found out that the *N. obliterate* plant can effectively remove 90–100% concentration of formaldehyde from the polluted air during long time exposure where roots and soil contribute 26% for formaldehyde elimination.

On the other hand, according to Aydogan et al, 2011 *Hedera helix*(English ivy), *Dieffenbachia compacta* (dump cane), *Epipremnumaureum* (golden pathos), *Chrysanthemum morifolium* (pot mum)gave similar sort of capacity to remove formaldehyde concentration up to 90% within 24 hours. Additionally, according to findings of Hongetal, 2017, 75% of ethyl benzene, 9% of benzene, 72% of xylene, 50% of formaldehyde, 75% of styrene, 36% of acetaldehyde, 35% of acrolein with acetone, and 85% of toluene were reduced with the use of indoor plants. Contaminated air with VOCs has also been efficiently removed by plants. Even though there are no specific criteria to set out the best indoor plants, however during1989, National Aeronautics and Space Administration (NASA) in collaboration with Associated Landscape Contractors of America (ALCA) accomplished Clean Air Study and published results with the list of plants that are highly effective for purifying indoor air, and the list is given in table no.2.

Table 2. List of Air purifying plants according to NASA

S. No.	Plant	Controlling pollutants
1.	Aloevera (*Aloevera*)	Benzene, Formaldehyde
2.	Arecapalm (*Dypsislutescens*)	Formaldehydes, Xylene, Toluene,
3.	Bamboo Palm(*Chamaedorea Seifritzii*)	Benzene, Formaldehyde, Tricholoroethylene

4.	Banana(*Musa Oriana*)	Formaldehyde
5.	Bostonfern (*Nephrolepisexaltata*	Formaldehyde, Xylene, Toluene,
6.	Broadleaf lady palm (*Rhapis excelsa)*	Formaldehyde, Xylene, Toluene, Ammonia
7.	Chinese evergreen (*Aglaonema modestum)*	Benzene, Formaldehyde
8.	Corn Plant (*Dracaena deremensis*)	Benzene, Formaldehyde
9.	Dendrobium orchids (*Dendrobium spp.)*	Xylene, Toluene
10.	Dumbcanes (*Dieffenbachia spp.)*	Xylene, Toluene,
11.	Dwarf date palm (*Phoenix roebelenii)*	Formaldehyde, Xylene, Toluene,
12.	Englishivy (*Hederahelix*)	Benzene, Formaldehyde, Xylene, Tricholoroethylene toluene,
13.	Flamingo lily (*Anthurium andraeanum*)	Formaldehyde, Xylene, Toluene, Ammonia
14.	Florist's chrysanthemum (*Chrysanthemum morifolium*)	Benzene, Formaldehyde, Xylene, Ammonia, Tricholoroethylene Toluene,
15.	Heartleaf philodendron (*Philodendron cordatum)*	Formaldehyde
16.	Kimberly queen fern (*Nephrolepisobliterata*)	Formaldehyde, Xylene, Toluene,
17.	Money plant (*Epipremnum aureum*)	Benzene, Formaldehyde, Xylene, Toluene
18.	Spider plant (*Chlorophytum comosum*)	Formaldehyde, Xylene, Toluene,
19.	Variegated snake plant, (*Sansevieriatrifasciata' Laurentii'*)	Benzene, Formaldehyde, Xylene, Toluene
20.	Weepingfig (*Ficus benjamina*)	Formaldehyde, Xylene, Toluene
21.	Peacelily (*Spathiphyllum 'Mauna Loa*)	Benzene, Formaldehyde, Trichloroethylene, Ammonia, Xylene, Toluene

Indoor gardening is not only limited to purification of air but also offers mental peace, and provides opportunity for nutritional gardening. The plants like *Murrayakoenigii*, *Moringa oleifera*, *Ocimum tenuiflorum*, *Peppermint*, Lemon grass, Rosemary, Aloevera, Coriander, Oregano etc., are rich sources of phyto-chemicals such as antioxidants, vitamins, flavonoids, and other secondary metabolites.

The growth and nutritional requirement of every plant is different as some requires direct amount of sunlight, some partial, whereas, some can even grow in dark corners. Therefore, selection of plant must be done carefully. Few suitable plants for different Indoor Gardening location are listed in table no. 3.

Table 3. Plants suitable for different Indoor Gardening location

S. N.	Dark corner plants	South Window plants	West Window plants	East Window plants	North Window plants
1	*Ficus benjamina* 	*Crassula portulacea* 	*Aloe spp.* 	*Asparagus setaceus* 	*Aspidistra elatior* 
2	*Sansevieria trifasciata* 	*Crassula argentea* 	*Hedera helix* 	*Epipremnumaureum* 	*Pandanus veitchii* 
3	*Schefflera variegated* 	*Kalanchoe spp* 	*Codiaeum variegatum* 	*Araucaria heterophylla* 	*Aglaonema modestum* 
4	*Chlorophytum Comosum* 	*Aloe variegate* 	*Cordyline terminalis* 	*Spathiphyllumwallisii* 	*Fittoniaverschaffeltii* 
5	*Zamioculcaszamifolia* 	*Sedum morganianum* 	*Crassula argentea* 	*Diffenbachiamaculate* 	*Dracaena fragrans* 

6	*Philodendron Hederaceum* 	*Rebutia spp.* 	*Euphorbia pulcherrima* 	*Pilea cadierei* 	*Syngonium podophyllum* 
7	*Dracaena marginata* 	*Lithops spp* 	*Dracaena reflexa* 	*Calathea makoyana* 	*Sansevieria trifasciata* 
8	*Aspidistra elatior* 	*Rhiphsalisspp* 	*Hippeastrum hybrids* 	*Schefflera arboricola* 	*Spathiphyllumfloribundum* 
9	*Dieffenbachia spp.* 	*Senecio rowleyanus* 	*Ficus lyrata* 	*Saintpauliaionantha* 	*Peperomia obtusfolia* 
10	*Syngonium Podophyllum* 	*Echeveria elegans* 	*Primula spp.* 	*Chrysalidocarpuslutescens* 	*Dieffenbachia amoena* 

Vertical gardening

The concept of vertical gardening dates to 600 BC, during the civilization of Babylonian and the Hanging Gardens of Babylon is the current evidence (Wang et al., 2016). In ancient time, green walls were usually utilized for the cultivation of fruits, vegetables, herbs or for ornamental purposes**.** The initial green wall system was built by the Professor of Landscape Architecture at the University of Illinois "Stanley Hart White" in 1930s,and patented this invention under the name 'Botanical Bricks' however, 'Patrick Blanc' a French botanist and art designer is considered as the founder of Vertical Gardens.

Green walls, living walls, plant walls or vertical gardens a real most synonyms (Bakar et al., 2013) and defined as "planting plants on upright structures to make use of the vertical space". Nowadays, in urban or especially in industrial areas where land is not enough for plantation, it is noticed that the temperature is about 6ºC higher than countryside areas(Loh,2008) which results in the "Urban Heat Island Effect". An Urban Heat Island occurs when a city experiences much warmer temperatures than nearby countryside areas due to urbanization or industrialization or it is the result of sunlight reflected off concrete and other reflective materials, which rises the temperature. Hence, it is the necessity of place to accumulate ore greenery. Therefore, to maintain the greenery, vertical gardening can be considered as one of the best approaches. Moreover, it can construct outdoor as well as indoor. Even, fact-fully the vertical space of a house, industries or any building scan accommodate more area for planting as contrast to roof or indoor sites.

For setting up a perfect vertical gardens, it important to select suitable plants based upon various criterion, i.e. location, indoor or outdoor planting, climatic conditions of the site, nature of plants, as some plants has climbing or creeping nature, that easily covers the walls by self-supporting mechanism or with the special modifications whereas other needs outer structural support, some plant grow in containers or in tubs, bottles, hanging baskets, other kind of plant such as bougainvillea possess special characteristic of scambing habit, known as scandent shrubs, having wood, strong, and healthy in nature which makes them survive without pruning and structural support, method of planting such as green walls or green facades, kind of structure is adopt to support plant, soil medium, irrigation facilities etc. Therefore, selection strategy varies as per the requirements and budget, as initial cost is high. Vertical gardening can reduce the effect of Urban Heat Island by enhancing natural cooling and ventilation process. Plants absorb carbon dioxide and generate fresh oxygen through photosynthesis as well as absorbs harmful volatile organic compounds and other pollutants like CO_2, CO, NO_2 etc., and accumulates the carbon in plants and roots (Kaveheietal., 2018; Liu and Li, 2012; Velasco and Roth, 2010), thereby improving the air quality. Further, it acts as heat insulator and can become a barrier to noise pollutions through its sound- absorbing properties (Wang et al., 2018; Bakar et al., 2013). Other important advantages are, green walls provide insulation to buildings from high temperature by the process evapo-transpiration, hence lower the temperature (Raji et al., 2015), control humidity, and provides shade which ultimately reduce the consumption of electricity. In addition, it can convert an empty space into aesthetically pleasurable, fancy and innovatively eye catching, which can uplift the economic value of that concrete structure and also add ecological values by providing habitats and food for insects and birds.

Urban Heat Island effect is one of the prominent concerns of urban zones. During day time, facades of building and hard surfaces absorb radiations from the sun which ultimately causes increase in temperature. As plant can reflect the radiations, hence thermal performance of the buildings can significantly be improved by controlling solar radiation; it reduces temperature, humidity and control microclimatic conditions (Safikhani et al., *2014*), therefore to compensate the urban heat island effect, enhancing greenery vertically can be a suitable

substitute, (Mir, 2011). Moreover, as per studies, green walls depict high rate of evaporation rate as compared to green roofs (Malys et al., 2016).Vertical garden enhances the tic value by making walls, grills or trellis more appealing, conserve space and purify air with low maintenance. Additionally, the use of ornamental, flowering and herbal plants is beneficial for dwellings as well as commercial sector. Hence the vertical gardens are ecologically and financially efficient.

In tropical countries, the concept of vertical gardening is gaining huge popularity these days. One of the world's largest recorded vertical gardens is 'Santalaia Building' situated in Bogota, capital of Colombia. It is estimated that it supplies oxygen to 3100 people annually, filter about 2000 tons of harmful gaseous and trap 881 lb of dust (Wilder, 2017). Nowadays the systems of vertical gardening is not restricted to only buildings but have also started adopting on road highways, railway stations, airports, bus stations, hospitals, schools and on other public and private places.

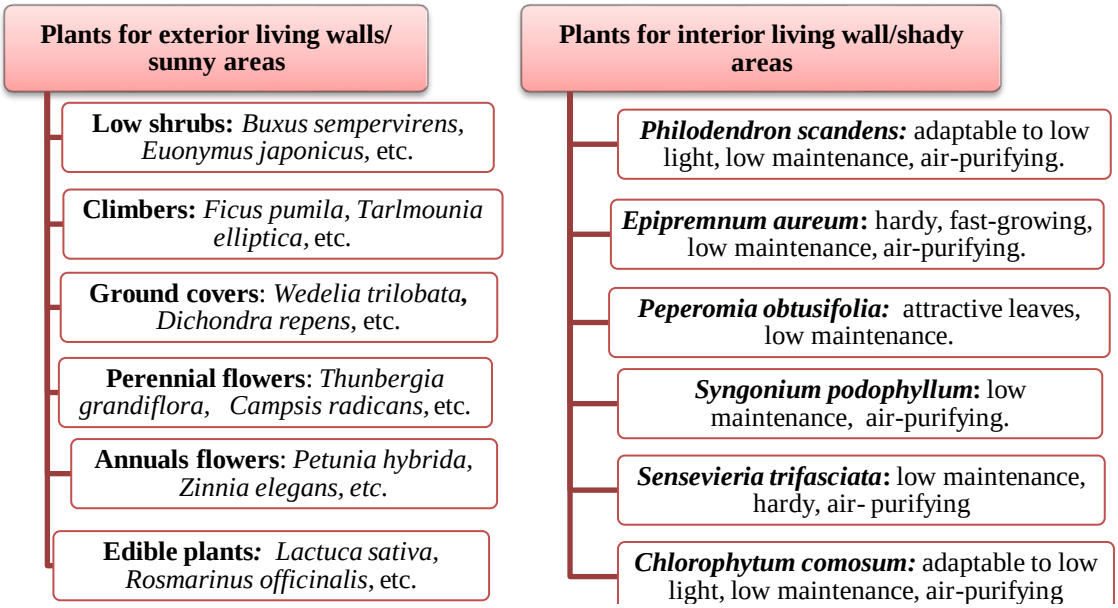
One of the best examples of vertical garden of highway in India is the vertical garden of 'Hosur Road Electronic City Flyover of Bangalore', where about 3,500 plants of 10 different species have been planted with distinctive design from all the sides. It aids in reducing the urban heat island effect, by absorbing greenhouse gases and smog, purifies air, act as a sound-proofing barrier, and make the area healthy and pleasant. According to National Green Building Councils in the world, it is said that, the most effective approach to ensure widespread implementation of vertical garden can be achieved by giving Green Label to the buildings. According to an investigation done by Charoenkit, 2017in tropical climate, it was found that, the living wall in indoor space can lower down the air temperature by 3.6ºC and can enhance the thermal resistance up to 0.05-0.09 m^2 K/W. Plants with dense, medium-sized foliage are appropriate for reducing temperature and recommended for cooling purpose. Further, living walls can sequester carbon in a range of 62.6-118.4 g ·C/m^2/year. In another study done by Rameshkumar in 2018 it was recommended that *Polysciasfruticosa* and *Philodendron erubescens* are suitable ornamental plants for vertical garden system with red soil as growing media.

Additionally, researchers have found that herbaceous flowers can fix 12.16 gm^2 D1 carbon dioxide per unit leaf area in green space (Chu et al., 2022). Moreover, the observations of Coma et al, 2016 revealed that, the green walls represent high energy saving performance than green facades and during summers and winter, energy savings by green wall was up to 58.9% and 4.2% respectively whereas by green facade it was 33.8% and 1.9% respectively. Further, the reduction in wall surfaces temperature by 21.5 ℃ by green wall and 13.9 ℃ by green facade (Coma et al., 2016).

Characteristics of plants suitable for vertical garden are (Bharti et al, 2024)

- Plants that can be planted on both sides of the frame.
- Generally dense, compact and low growing plants are selected.
- Dwarf flowering and foliage plants.
- Shallow rooted plants that require very less anchorage
- Sun loving dwarf, trailing or flowering plants. E.g., Allysum, Pansy, Nasturtium
- Shade loving foliage or flowering plant.eg. begonia, African violets, Pepromia, *Zebrina pendula*etc.
- A single vertical garden should not have a mixed planting i.e., combination of both shade loving and sun loving plants.

Plants suitable for vertical garden:



For Living Walls for Green Facades (Green Screens)

Any variety of climbing plants (vines) can be used for making green facades which may include:

- Plants with tendrils e.g., grapes (*Vitis* Spp), Passion flower (*Passiflora*), *Pyrostegiavenusta.*
- Plants with twining stems or leaves -e.g., *Clematisgouriana*, *Adenocalymaalliaceum*, *Jasminum auriculatum*, *J. grandiflorum*
- Hold fasts, plants with aerial roots or stem roots -e.g., *Hedera helix, H. hibernica, Tecoma radicans, Monstera* spp., *Phelodendron*spp.
- Scramblers which have no direct means of attachment e.g., *Bougainvillea* spp., roses (*Rosa* spp.) *Petrea volubilis, Vernonia elaegnifolia,Quisqualis indica, Thunbergia, Stigmaphyllonperipocifolium, Tristellateia australis* etc.

Rooftop Gardening

Roof gardens are human made green spaces at the uppermost levels of any residential, industrial, public, private or commercial structures. It can be meant for different purposes such as, to produce organic vegetables, create greenery with ornamental plants, provide space for recreational or leisure activities, shade and shelter for humans as well as habits for several birds. It has been suggested that green roofs can be efficiently utilized to enhance sustainability in urban or industrial areas (Kosareo and Ries, 2007), Moreover, green roofs also help in carbon dioxide sequestration through photosynthesis during day time and store the carbon in the form of stems, branches or roots (Rowe and Getter, 2010; Weissert et al., 2014). Further, it can conserve energy through reduced heat transfer and can keep the lower portion cool by evapo-transpiration, reduces noise pollution, turn down heat island effect, and decreased the runoff load on the sewage system. (Gagliano et al., 2016) and ultimately decreases building energy consumption (Sadineni et al., 2011). As roof gardening can sequester carbon and decrease the temperature of roofs and the surrounding hence it adds positive impact on cooling of local climate, and also plants absorb the rain water and reduces

overflowing impact on infrastructure. As per the reports, *Sedum acre*, *Frankenia thymifolia*, and *Vinca major* depicts potential capacity to counter carbon emission and can cut down the demand for annual energy consumption of building by 8.5%, 8.0%, and 7.1%, respectively.Moreover, the annual CO_2consumption for photosynthesis by these three plants was estimated to be 0.14, 2.07, and 0.61 kg/m^2 respectively (Seyedabadi et al., 2021).

A survey conducted by Thomas and Cherian in 2021, in urban area of city Cochin, India with sample of 102 respondents depicted that, on rooftop, 59% participants were interested in vegetable gardening and 13% were interested in ornamental gardening, whereas 28% were interested in both. On the other hand, the reasons for practicing roof gardening, it was noticed that, 66% responded practiced it to get better family health and 29% respondent started to pursue their hobby, whereas 16% and 14% of them wanted to get rid of pesticides and to become self-sufficient respectively. Discarding practices of garden waste, results out that 75% of the respondents were managing their waste from rooftop through composting, 21% of them burn the waste and 15% were disposing the waste to municipal waste bin.

The phenomenon of roof top gardening has evolved due to disproportion at exploitation of the urban lands. Hence roof gardening is a potential source for urban horticulture. It can efficiently reduce the toxicity around dwellings, improves aesthetic sense, reduces stress and protect environmental pollution.

Table 4. Plants Suitable for Roof Gardening

Flowering plants	Summerannuals -Zinnia, Kochia, Portulaca, Tithonia, Gaillardia, Gomphrena, Sunflower, Daisy, etc.
	Winter annuals - Antirrhinum, China aster, Cornflowers, Larkspur, Sweet Sultan, Phlox, Verbena, Candy tuft, Petunia, etc.
	Rainy season - Balsam, Cock's comb, Celosia, Gaillardia, etc.
	Herbaceous-Periwinkle, Foxglove, Lavender, Aster, Peony etc
Succulents and herbaceous plants	Aloe, Snake plant, Sedums, Jade, *Euphorbiaspp*, Portuluca, Crassula, Kalanchoe, Zebra plant, Agave, Echeveria Echinopsis, Opuntia, Alpinia, Asparagus etc.
Bulbous plants	Amaryllis, Begonia, Canna, Crinum, Fressia, Glorosia, Hedychium, Tuberose, Gladiolus etc.
Groundcovers, vines and climbers	*Setcreasea purpurea*, Vadelia, Gourds, Ficus Pumila, Passion Flower, Bougainvillea, Money Plant, Nasturtium, Curtain Creeper, Blue Moring Glory, etc
Grasses	*Zoysia*and *Bermuda*etc.
Herbs and vegetables	Thyme, Rosemary, *Ocimum Tenuiflorum*, Basil, Coriander, Ginger, Turmeric, etc.
Dwarf trees and shrubs	*Plumeria alba*, Pomegranate, *Acalypha Sp. Codiaeum variegatum*, *Ligustrum ovalifolium*, Duranta, *Ficus benjamina*, Hibiscus etc.

Avenue Planting/ Planting of Tress

Trees (and shrubs) are unique among plants in the way that they have a woody stem and roots that grow annually and these woody parts last for decades or evencenturies. Tree stems and roots are excellent, long-term carbon storage sites because most of the carbon in this wood comes from carbon dioxide. Planting of 44 million more urban trees per year in the U.S. for the next 50 years, for a total of 2.2 billion trees, would replace trees lost to mortality and increase urban tree cover by 5% (Rowntree and Nowak 1991). While trees alone cannot solve the problem of climate change, they can significantly contribute to reducing fossil fuel consumption and carbon dioxide emissions. The influence of forests on the climate is primarily connected to the biochemical processes of trees, particularly photosynthesis, which regulate atmospheric CO_2 levels and play a crucial role in the carbon cycle (Bonan et al., 2008).Through photosynthesis, trees and other plant organisms in forests absorb CO_2 from the atmosphere, aiding in carbon sequestration.The benefits of trees in given in the Fig.2and Fig 3.

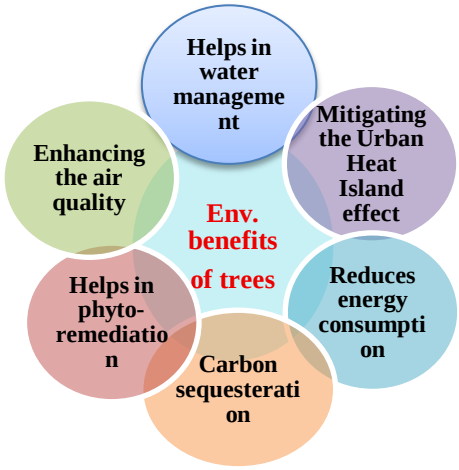


Fig. 2 Environmental benefits of trees (Mylan, 2022)

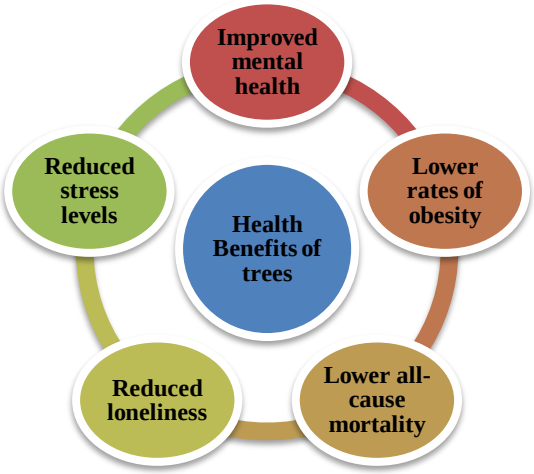


Fig. 3 Health benefits of trees (Feng, Xiaoqi et al., 2022)

Table 5. List of the Trees that Absorbs Pollutants

Tree species	Pollutants absorbed	Other benefits
English Oak	Nitrogen dioxide, Sulphur dioxide, Particulate matter	Provides habitat for wildlife
Eastern White Pine	Ozone, Nitrogen dioxide, Sulphur dioxide, Particulate matter	Reduces noise pollution
Red Maple	Ozone, Nitrogen dioxide, Particulate matter	Tolerates urban environments
Honey Locust	Particulate matter, Carbon monoxide	Provides shade and reduces energy consumption
Green Ash	Ozone, Particulate matter	Tolerates a wide range of soil types

In a study conducted by Begum and Harikrishna, 2010 at Industrial locations in Bangalore it was found that among various tree species, the most tolerant one with respect to ATPI and heavy metal concentration were *Ficus religiosa*, *Azadirachta indica* and *Pongamia pinnata* (L.). So, these plants can be considered as tolerant species in the industrial areas.

Pragasan and Ganesan, 2022 identified pollution-tolerant tree species for the development of greenbelts for NIA in Kollar district of Karnataka. Air pollutants such as PM10, PM2.5, SO_2, NO_2, Pb, CO, NH_3, and O_3 were detected and their concentrations for the three sites ranged from 21 to 99 μg/m^3, 11 to 67 μg/m^3, 3 to 14 μg/m^3, 5 to 28 μg/m^3, 0.01 to 0.9 μg/m^3, 0.3 to 0.9 mg/m^3, 3 to 17 μg/m^3, 6 to 25 μg/m^3, respectively. Twenty common tree species to NIA were selected and their air pollution tolerance potential was determined by the Air pollution Tolerance Index. It was found that tree species, *Spathodeacampanulata* (9.58 ± 0.33) recorded maximum APTI value followed by *Terminalia catappa*, *Tabebuia avellanedae*, *Anthocephalus cadamba*, and *Syzygiumjambos* and were found to be the top air pollution tolerant species.

Landscaping or gardening is not only restricted to sophisticated system but it can be adopted anywhere, i.e. railway stations or railway lines, bus stand and highways, roundabout, airports, banks of rivers or canals, cities and countryside areas, cemeteries and burning ghats, hospitals, schools, universities, offices, market or shopping malls, public or private buildings etc. At every location greenery can be added, each plant can absorb and store the amount of carbon dioxide and prevent soil erosion hence reduces the concentration of pollutants in surroundings.

In Thiruvananthapuram capital of Kerala, a study was conducted by Jyothi and Jaya, 2010 to evaluate the performance of plant species regarding air pollution tolerance index (APTI) along roadsides. Later, it was found that, calculated APTI is maximum for *Polyalthia longifolia*, (Sonner) approx 13.59 followed by Mangifera indica, *L.* (7.56) and *Alstoniascholaris*, (6.84). Whereas in case of shrubs, uppermost APTI value was recorded in the leaves of *Clerodendroninfortunatum L* about 6.23, followed by *Eupatorium odoratum*, L. (5.23) and *Hyptis suaveolens L* (4.39). It was also noticed that, *Polyalthia longifolia*, (Sonner) can tolerate automobile pollutants and different plant species depict significant variation in their susceptibility to air pollution. Hence, plantation can maintain the concentration of greenhouse gases (Jyothi and Jaya, 2010).

Lawn

Lawn is considered as a natural green carpet formed by monocot plants and referred as heart of the garden (Jenkins, 1994). It provides space for leisure activities, professional and personal gatherings, and playgrounds, where it controls dust particles and soil erosion due to crowd (Reynolds and Flint, 2009). Nowadays, in cities, lawns are considered to cover almost, 70- 75%green open spaces i.e. private and public parks, hotels and restaurants, public and private buildings, cemeteries, and playgrounds etc. (Stewart et al., 2009).Lawns or grasses generally store most of the carbon in their roots, as their roots die it gets decomposed in soil; eventually adding the carbon to the soil. Moreover, grasses are very essential for rainwater conservation and drainage. About 60% of rain water ends ups in surface run-off in vegetation-free locality, whereas only 5–15% of the rain water becomes surface run off where lawns are present (Ignatieva et al., 2015).

A model was developed by Zirkle et al., 2011, to find out the potential possibility of carbon sequestration by lawns in dwellings of U.S.A. and, it was estimated that the rate of soil organic carbon sequestration in soil having lawns was approximately 46.0 to 127.1 g /m^2 /year. The excess concentration of carbon dioxide is trapped by deep-rooted penetration more volume, fibrous grasses in deeper soil layer; however, in long run, it partly replenishes the

soil organic carbon. Moreover, the undisturbed grasslands can uptake considerable amount of carbon dioxide for photosynthesis in soils (McLauchlan, 2006) and grass can sequester more carbon than leguminous cover crops (Kimble et al., 1998). Further according to study conducted by Townsend and co-workers in Southern California, it was found that high amount of indirect CO^2 emission associated with turf-grass management can sequester organic carbon to mitigate GHG emissions in cities. According to them ornamental lawn can sequester organic carbon ranges from −513 +37 to −513 −73 g CO^2 m−2 yr. Lawns can also help to reduce extremes of temperature in built-up areas by absorbing the heat during the day and releasing it slowly during the evening. According to The Lawn Institute in America, the "cooling properties of turf are so effective that temperatures over turfed surfaces on a sunny summer's day will be 10 – 14 degrees cooler than over concrete or asphalt".

According a study by the University of Maryland (called Maryland Turf grass Survey: An Economic Value Study), a 25-square foot area of healthy lawn produces enough oxygen each day to meet the needs of one adult. That means a 100 square ft lawn will provide sufficient oxygen to supply a family of four.

Terrace garden

Terrace garden is a type of a garden that is built on the terrace of a building. Using planting materials on rooftops offers several ecological and economic advantages. These include effective storm water management, enhanced energy efficiency, reduction of the urban heat island effect, extended lifespan of roofing membranes, decrease in urban air temperature, attracting birds and insects and the creation of a more visually appealing and comfortable living and working environment (Anoop and Saranya, 2021). According to Kalyan et al., 2020 the selection of plant species for terrace garden should be done based on type of terrace, climate, and weather conditions in that particular zone.

Table 6. List of few ornamental plants suitable for terrace garden

1. *Chamaerops humilis* – European Fan Palm Cascade Palm
2. *Chamaedorea elegans* – Parlor Palm Bamboo Palm
3. *Phoenix roebelenii* – Pygmy Date Palm
4. *Dypsislutescens* – Areca Palm
5. *Ravenearivularis* – Majesty Palm
6. *Rhapis excelsa* – Lady Palm
7. *Livistona chinensis* – Chinese Fan Palm
8. *Trachycarpusfortunei* – Windmill Palm
9. *Adonidiamerrillii* – Christmas Palm
10. *Caryota mitis* – Fishtail Palm

The study conducted by Triguero-Mas et al. (2020) highlights the potential benefits of urban rooftop gardening, particularly for individuals with intellectual disabilities and mental health conditions. Similarly, Tuladhar (2019) confirms the interest and enthusiasm among urban residents to grow and harvest fresh, pesticide-free produce on their own rooftops.
A study was on 102 respondents residing in Ernakulam city maintaining rooftop garden was done by Thomas and Cherian in 2021**.** The COVID-19 pandemic highlighted rooftop gardening as a powerful example of self-sufficiency. During this time, urban homemakers were engaged in cultivating a variety of ornamental and vegetable plants using diverse methods.

Table 6. List of Few Ornamental Plants Suitable for Terrace Garden

			
Annual Flowers: **Summer season:** Zinnia, Portulaca, Cosmos, Balsam, Marigold, Celosia Gomphrena, Gaillardia, etc. **Winter season:** Petunia, Pansy, Phlox, Dianthus, Calendula, Aster, Verbena, Stock, Sweet Pea, etc.	**Shrubs:** **Flowering Shrubs:** Rose, Jasmine, Ixora, Camellia, Barleria, Bougainvillea, Hibiscus, etc. **Non flowering shrubs**: Croton, Thuja, Duranta, Weeping Fig, Jatropha, Aralia, Acalypha, Orange jasmine, etc.	**Climbers:** **Flowering climbers:** Morning Glory, Allamanda, Rangoon Creeper, Garlic vine, Pyrostegia, etc. **Foliage Climbers:** Money Plant, English Ivy, Philodendron, Syngonium Creeping Fig, etc.	**Foliage plants:** Calathea, Dieffenbachia, Aglaonema, Dracaena, Snake Plant, Canna, Calathea, Kochia, Caladium, Coleus, Coral Bells, Hosta, Alocasia, Begonia, Poinsettia, agave, Peperomia, Tradescantia, Pilea, etc.
			
Trees: Plumeria, *Bauhinia*, Juniperus, Yellow olender, Rubber plant, Fiddle leaf fig, *Callistemon*, Japanese Maple, etc. Fruit trees: Citrus, Guava, Papaya, Pomegranate, etc.	**Bulbous plants:** Crinum, Tuberose, Zephyranthes, Oxalis, Gloriosa, Freesia, Alstroemeria, Gladiolus, Amaryllis, Agapanthus, Anemone, Narcissus, Canna, Dahlia, etc.	**Succulents:** Aloe Vera, Echeveria, Sedum, Kalanchoe., Jade Plant, Senecio, Euphorbia, Opuntia, Haworthia, Aeonium, Pachyphytum, Stapelia, Crassula, Mammillaria, etc.	**Palms and Cycades:** Areca Palm, Sago Palm, Chinese Fan Palm, Lady Palm, Parlor Palm, Bamboo Palm, Cascade Palm, Kentia Palm, Metallic Palm, Lipstick Palm, Majesty Palm, etc.

Future thrust

Plants absorb pollutants this is a known fact but every plant and its part absorb different pollutants from different places such as few absorbs from soil few from air and water. Also, the concentration of sequestration is different for all the plants. Therefore, it needs research to find out which plant and which part can be used to sequester pollutant from particular conditions so That accordingly plants would be selected for gardening. Moreover, as Corporate Social Responsibility (CSR) have to invest 2% from their annual net profits if they have market capitalization over five billion Indian Rupees (INR), they can spend it on landscaping of public places i.e. highways, railways, hospitals, rivers, lakes etc. this will surely put huge impact on our surroundings.

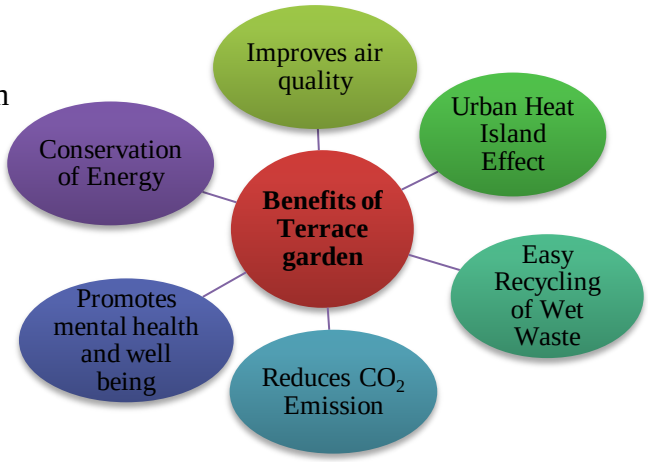


Fig. 3 Benefits of Terrace Garden

Conclusion

From the above literature, it can be concluded that gardening can be proven as one of the best alternative strategies to reduce the concentration of pollutants from our surroundings by using suitable plants. Not only it can sequester pollutants but also beautify the surroundings and bring mental peace. Moreover, it can generate income in floriculture sector and nursery management. For the proper and balanced landscape, it needs skilled landscape designers, therefore, it can provide job. It has dual benefits i.e. protection and generation of money. However, it needs a skilled landscape designer. Also, if the money of CSR would be used for landscaping it will help in improving the condition of rivers, lakes, ponds, railways, bus stands etc. and even can make them better places where tourist can be get attracted.

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