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Phytoremediation of Household Air Pollution: A Critical Review of Pollutant Sources, Health Impacts and Plant-Based Mitigation Strategies

Dr. Hemant Dnyaneshwar Chandore [1*] , Dr. Surnar Laxman Balaji [2]

[1]Head and Associate Professor, Department of Horticulture, Shikshan Maharshi Dnyandeo Mohekar Mahavidyalaya Kalamb, Tal. Kalamb (413507). Dist. Dharashiv, M.S. India
[2]Department of Horticulture, PGI, MPKV Rahuri, M.S. India
Email: hemantflori08@gmail.com[1], surnar23@rediffmail.com [2]

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Abstract— *Household air pollution (HAP) affects about 2.45 billion people in developing countries. Burning kerosene, coal and biomass releases particulate matter, carbon monoxide, nitrogen dioxide and volatile organic compounds (VOCs), and recent fuel price rises have pushed some families back to these fuels. Paints, cleaning products, furnishings and office equipment add formaldehyde, benzene, toluene and xylene. Exposure links to asthma, COPD, lung cancer, cardiovascular disease and sick building syndrome. This review classifies indoor air quality parameters as physical, chemical and biological, describes major pollutant sources, and examines monitoring approaches, with attention to data gaps in India. It then explains how phytoremediation works through the plant-microbe-soil-air interaction, including enzyme activity, dry deposition and microbial VOC degradation in the rhizosphere and phyllosphere. Experimental studies report 81 to 96% formaldehyde removal by Epipremnum aureum within 24 h, 48 to 53% PM2.5 and PM10 removal by Chlorophytum comosum, and 88% TVOC removal by Areca palm over four months. Most results come from sealed chambers, which limits how far they apply to ventilated homes. Plants work best alongside source control, ventilation and clean cooking fuels.*

Keywords— ***Indoor air quality, Phytoremediation, Household air pollution, Volatile organic compounds, Formaldehyde, Particulate matter, Botanical biofiltration***

I. INTRODUCTION

Indoor air pollution is a growing health concern, and many households are still exposed to it every day. Traditional fuels such as kerosene, coal, wood, charcoal, crop residues and animal manure produce household air pollution, and recent fuel shortages and high LPG and CNG prices are pushing people back to them. Around 2.45 billion people in developing countries are affected (Schraufnagel *et al.,* 2019., Lim *et al.,* 2010)., and household air pollution is linked to millions of premature deaths each year, mostly from stroke, heart disease, lung cancer and chronic obstructive pulmonary disease. Children, women and girls carry a heavy share of this burden. Indoor air also carries particulate matter, combustion gases, volatile organic compounds, aldehydes, radioactive gases and biological aerosols from building materials, furnishings, consumer products and poor ventilation. These pollutants cause headaches, eye and airway irritation, asthma and sick building syndrome. India still lacks enough work on monitoring, modelling and mitigation of indoor pollutants. This review covers the main pollutant sources, how they are monitored and controlled, and how indoor plants can reduce these pollutants through phytoremediation.

II. REVIEW OF LITERATURE

1.1. Household Air Pollution (HAP): Sources and Resurgence of Traditional Fuels

Indoor air pollution has more seriously discussed as people day by day awake of health. Due to modernization various chemicals and biological sources have been used in households which are major sources of indoor air pollution. This indoor air pollutant called as Household Air Pollutant (HAP) which comes from traditional sources of fuel in house like kerosene, coal, biomass sources (Wood, charcoal, crop residues, and animal manure). This use of fuel is now decreasing in some houses due to various alternatives but recent fuel crises and soaring prices or modern fuel such as LPG, CNG etc., raised because of war are again moving common people to use these traditional sources which again caused critical concern of indoor air pollution. Research shows these sources are contributing to global environmental health problems with affecting 2.45 billion people in developing countries. (Schraufnagel *et al.,* 2019., Lim *et al.,* 2010). Near about 2.8 and 4.3 million yearly premature deaths of children with alarming 7.7 % global mortality that surpass combined death of malaria, TB, HIV/AIDS. (Forouzanfar *et al.,* 2016) Report says that among these premature deaths, 3.8 million caused by non-communicable diseases (NCDs). Among those NCDs, HAP is estimated to cause 25% of all stroke deaths, 15% of ischemic heart disease deaths, 17% (280,000) of lung cancer deaths, and more than 33% (800,000) people of all deaths from chronic obstructive pulmonary disease (COPD).4 HAP is the second largest risk factor for women and girls; and for men it is the fifth largest risk factor, after smoking, alcohol use, and high blood pressure. (Naghavi *et al.,* 2013). Among 20 cities of USA found high amount of PM10 (PM ≤ 10 μm) which leads to higher mortality rates due to cardiovascular or respiratory disorders and autism spectrum disorder (ASD) during pregnancy and early life stages of children (Becerra, *et al.,* 2013. Raz *et al.,* 2015, Samet, *et al.,* 2000). AS per WHO reports indoor air pollutation leads sick building syndormes (SBS) having common symptoms such as headaches, eye and respiratory system irritation, dizziness, nausea, fatigue, drowsiness, and general impatience (Orwell *et al.,* 2006; Aydogan and Montoya 2011; Soreanu *et al.,* 2013) and respiratory and cardiovascular diseases are major concerns of inoodr air pollution where VOC are the main cause of SBS (Jafari *et al.,* 2015, Hun *et al.,* 2010).

1.2 Respiratory Effects of Traditional Fuels and Indoor Pollutants:

Lung infection [Bhat *et al.,*2012, Ezzati and Kammen, 2001 Sharma *et al.,* 1998] which correlated with respiratory syndrome and tuberculosis [Öztürk *et al.,* 2014] caused because of traditional biofuels such as kerosene, coal, and firewood. In baltimore (USA) region sudden rise of symptoms of asthma and COPD among 150 preschool-aged children are reported (25) whersas reduction of pulmonary function of school-age children who exposed to indoor PM2.5 particles and do not use inhaled corticosteroids (Koenig *et al.,* 2005). There is correlation of higher concetration of NO2 leads to asthma (Hansel *et al.,* 2008) or allergene effect (Strand *et al.,* 1998), exposure of VOC leads to asthma with non significant cooraltion between them (Kwon *et al.,* 2018, Nurmatov *et al.,* 2015), VOC alongwith other pollutant caused COPD and lung cancer (Kurmi *et al.,* 2010).

1.3 Indoor Air Quality, Exposure Factors and Health Hazards:

In human household environment Indoor air quality (IAQ) is an important component of for his and his lovale pet overall health either mentally or physiobiologically. This environment has three parameters physical, chemical, and biological which not only includes residential buildings but also contains educational institutions, offices, healthcare facilities, and industrial workplaces. The exposure of interior environments with substantial times are affected with indoor pollutant which depends on the building characteristics, ventilation, occupancy, outdoor air infiltration, combustion activities, consumer products, and emissions from construction materials and furnishings (Van Tran *et al.,* 2020; Saini *et al.,* 2020). The effect of indoor pollutant leads to various health hazards like respiratory irritation, allergic reactions, asthma exacerbation, cardiovascular effects, and other adverse health outcomes, depending on the pollutant, concentration, exposure duration, and individual susceptibility. Hence we systematically reviewed the possible pollutant sources, alongwith its monitoring approaches, and control strategies to alongwith valuable indoor plants which reduce this adverse toxic effect on occupant health by phytoremediation (Pillarisetti *et al.,* 2022; Nazli *et al.,* 2024.)

1.4. Research Gaps and Major Indoor Pollutants in the Indian Context

Specially in india we need to identify the gaps in monitoring, modelling, and mitigation, indicating a need for more comprehensive assessments of indoor environments (Thakur *et al.,* 2023). As far as indoor pollutants are reviewed which came form indoor and outdoor soruces we found that particulate matter, combustion gases, volatile organic compounds (VOCs), aldehydes, radioactive gases, biological aerosols, and allergens are the major concerns of occupant health which are need to source identification and integrated management approaches (Pillarisetti *et al.,* 2022; Thakur *et al.,* 2023; Deng *et al.,* 2024).

2. Classification of Indoor Air Quality Parameters (Figure 1.a and 1.b).

Air Quality Index are framed into three parameters such as physical, chemical and biological. Which determines environmental conditions (Saini *et al.,* 2020; Van Tran *et al.,* 2020) and the presence of airborne contaminants. However alone this not completely found to be independent: for example, particulate matter may contain chemical compounds or biological materials, while temperature, humidity, and ventilation influence pollutant concentrations and persistence (Nazli *et al.,* 2024; Chawla *et al.,* 2023).

2.1. Physical Parameters

Physical parameters relevant to indoor environmental assessment include temperature, relative humidity, particulate matter ($PM_{2.5}$ and PM_{10}), air velocity, ventilation rate, and pressure differences between indoor and outdoor spaces. Temperature and humidity influence thermal comfort, chemical emissions, and the conditions that support microbial growth. Particulate matter originates from cooking, combustion, cleaning, resuspension of settled dust, construction activities, and outdoor infiltration. The concentration and distribution of indoor particles are also affected by occupant activities, air exchange, filtration, and deposition processes (Li *et al.,* 2023). Recent research has emphasized the importance of understanding both indoor-generated particles and particles infiltrating from outdoor environments when evaluating exposure and developing mitigation strategies. These review also supllemtary support by various researchers . (Baeza Romero *et al.,* (2022)., Saraga, D. E., *et al.,* (2023).

2.2. Chemical Parameters

Chemical parameters containing of carbon monoxide (CO), carbon dioxide (CO_2), nitrogen dioxide (NO_2), ozone (O_3), volatile organic compounds (VOCs), formaldehyde, and radon. Combustion appliances and traditional fuel use can release CO, CO_2, NO_2, SO_2, PM 2.5, whereas paints, varnishes, adhesives, furnishings, cleaning agents, and solvents alongwith office equipment which cant ignored like photocopiers, printers, and gas cooktops can contribute to VOC (benzene, toluene, ethylbenzene, xylene (BTEX), poly aromatic hydrocarbons (PAHs), and aldehyde emissions (Maisey *et al.,* 2013 , Myers and Maynard, 2005., Gawronski *et al.,* 2017; Wei *et al.,* 2017). Entry of Radon gas in room from soil and geological region either form indoor or outdoor. Use of various cleaning and disinfecting products augmenting release of various volatile compounds and generate secondary pollutants through reactions with other substances in indoor air. Consequently, chemical assessments should consider source-specific emissions, ventilation, chemical transformations, and the intended use of the indoor space (Salonen *et al.,* 2024; Thakur *et al.,* 2023). Saraga *et al.,* (2023) reviewed indoor air pollution source-apportionment methods and emphasized the challenges associated with distinguishing indoor emissions from outdoor contributions and secondary pollutant formation.

2.3 Biological Parameters

Biological parameters which containing various airborne bacteria, fungal spores, viruses carried in respiratory aerosols, pollen, dust-mite allergens, animal-derived allergens, and other biological particles. These contaminants may originate from occupants, pets, plants, outdoor air, damp building materials, contaminated dust, and inadequately maintained ventilation systems. Moisture intrusion and persistent dampness can support microbial growth and contribute to the presence of mould and associated biological components. Chawla *et al.*, (2023) reviewed microbial contamination in indoor environments, addressing its sources, sampling approaches, health risks, and mitigation strategies. Biological assessment requires appropriate sampling and analytical procedures because airborne microbial concentrations vary with occupancy, humidity, ventilation, sampling duration, and environmental conditions.

3. Types and Sources of Indoor Air Pollutants (Figure 2).

Indoor air pollutants can be classified according to their physical state, chemical or biological nature, and source of origin. Based on physical state, they include particulate pollutants (fine and coarse particles, dust, soot, fibres, and airborne biological materials), gaseous pollutants (combustion gases, VOCs, aldehydes, ozone, and radon, organic vapours), and biological aerosols (microorganisms, pollen, allergens, and biological fragments). Unfortunately, some categories are overlap such as fungal spores came in both biological contaminants and airborne particles. The entry of origin of these sources are either generated indoor or entering form outdoor environments. They are formed by chemical or biooogical process within home. Some indoor sources are identified as cooking and heating appliances, tobacco smoke, candles, incense, cleaning products, pesticides, building materials, furnishings, and human activities. Similallrly outdoor sources that includes road traffic, industrial emissions, dust, smoke, and pollen entering through windows, doors, and ventilation systems (Van Tran *et al.,* 2020; Saraga *et al.,* 2023). Source apportionment studies indicate that identifying the contribution of individual sources is challenging because indoor pollutants are influenced by multiple emission sources, chemical transformations, deposition, and exchange with outdoor air (Saraga, D. E., *et al.,* (2023)). Research on cleaning products further demonstrates that indoor chemical pollution may arise from both directly

emitted compounds and products formed through subsequent chemical reactions (Salonen *et al.,* 2024).

The contribution of individual sources varies according to building design, fuel use, occupant behaviour, ventilation, climate, and the surrounding environment. Source identification is therefore a central component of IAQ management. Saraga *et al.,* (2023) demonstrated that indoor source-apportionment studies commonly investigate particulate matter and that the contribution of outdoor sources can vary substantially between buildings and studies. More recent reviews have also examined the use of continuous monitoring and real-time data to identify pollutant sources and support mitigation decisions (Chojer, *et al.,* 2024).

4. Integrated Assessment and Monitoring of Indoor Air Quality

An integrated IAQ assessment should consider physical conditions, chemical contaminants, biological pollutants, ventilation, and potential emission sources. No single parameter can adequately represent all aspects of indoor air quality. For example, carbon dioxide can help assess ventilation in relation to occupancy, but it does not directly quantify particulate matter, VOCs, or biological contaminants. Similarly, particulate matter measurements provide information about airborne particle concentrations but do not, by themselves, establish particle composition or biological origin. Saini *et al.* (2020) reviewed IAQ monitoring systems and the application of sensor-based technologies, while Nazli *et al.,* (2024) examined research trends in indoor air quality through a bibliometric analysis of literature published between 2018 and 2023. Together, these studies support the need for appropriate monitoring strategies and continued research into pollutant measurement and control.

In addition, indoor air quality research has particular relevance to India, where building characteristics, household energy use, urban pollution, and ventilation practices can produce different exposure conditions. Patel *et al.,* (2023) reviewed the status of indoor air quality research in urban India and identified limitations in the availability and scope of measurements compared with research in several developed countries. Further investigations should therefore consider locally relevant sources, building types, seasonal conditions, and occupant activities when designing IAQ monitoring programmes (Thakur *et al.,* 2023; Chawla *et al.,* 2023; Deng *et al.,* 2024). These considerations provide a scientific basis for classifying indoor air quality parameters, identifying pollutant sources, and developing targeted strategies to improve indoor environmental conditions.

5. Research Need and Scope of the Review

Despite advances in indoor air monitoring, the assessment of indoor air pollution remains challenging because multiple pollutants and emission sources interact within enclosed environments. Differences in sampling methods, monitoring duration, building characteristics, and source-identification techniques can also complicate comparisons between studies. A systematic synthesis of physical, chemical, and biological IAQ parameters, together with their major indoor and outdoor sources, is needed to support consistent assessment and effective pollution management. Accordingly, this review focuses on the classification of indoor air quality parameters, the types and sources of indoor pollutants, monitoring approaches, and the implications of pollutant exposure for indoor environmental health.

6. How Phytoremediation Works: Plant–Microbe–Soil–Air Interaction in Indoor Environments

6.1. Mechanism of Pollutant Removal by Indoor Plants

Indoor plant ecosystem can help to prevent or minimize most of the pollutant by phytoremediation process where upper zone of the plant helps to absorbs some of the pollutant and lower part of rhizosphere alongwith microbes helps to degrade or absorbs fallen leaves or scavenging its absorbed pollutant by filtration, metabolism (Nowak *et al.,* 2006, Brack, C.L 2002 , Van Tran Lee *et al.*, 2020; Supreeth 2021 Kim *et al.,* 2020) , sequestration, or excretion methods which detoxify indoor environment. Some of the pollutants are also uptake by plant and utilized for its devlopment while extra are stored in their stomata or other parts which latter fall on and recycled it in soil. This plant-microbes-soil -air interaction acts as a proper cycle of controlling indoor air pollution.

6.2. Role of Plant–Microbe Symbiosis

The symbiotic relationship of microbes alongwith plants are important where microbes help to cop plant in biotic and abiotic stress, assist their host for better nutrient and water uptake , production of plant hormones, siderophores, and suppressing allelopathic effect of chemicals (Bulgarelli, 2013, Weyens 2009).

6.3. Microlevel Processes: Enzymes, Microbial Degradation and Biostimulants

In microlevel studies shows that plant metabolites, such as enzymes (catalase, dehydrogenase), decomposed hazardous air pollutants (Rachmadiarti *et al.,* 2019; Han *et al.,* 2022) while CO2 utilized during photosynthesis , VOC degraded by rhizosphere/phyllosphere microorganisms that caused deportation of PM on plant surface ad dry deposition (Orwell *et al.,* 2006; Gawronska and Bakera 2015; Torpy *et al.,* 2018). Active biotsimulant produced by soil micboes are hlpes to convert that aerial and filtered leached pollutant

in substarte to utlised it carbon source of plant mostly using VOC, CO_2 . In indoor enrionment aerial and root zones of of potted plant are equally important for reducing indoor air pollutant (Pettit *et al.,* 2015, Wang *et al.,* 2014, Xu *et al.,* 2010, Xu *et al.,*2011)

6.4. Aerial (Phyllosphere) and Root Zone Contributions:

On upper zone of the indoor plant where plant leaves and stems are zone of phyllosphere bacteria and endophytic bacteria which detox some pollutant by absorption, degradation, transformation or sequestration process. While during watering process some part of the air pollutant around the plant are drained out on lower zone of the plant (Weyens *et al.,* 2015). Structural representation of this plant-microbes-soil -air interaction (PMSAI) is shown in figure 3

7. Pollutant Removal Efficiency of Indoor Plants: Reported Experimental Studies:

Some Indoor plant (Wolverton *et al.,* 1989) can effectively used for natural water and air-filtration under National Aeronautics and Space Administration (NASA) scientific studies which proves that use two plants in each room of 100 square feet (9.3 m^2) [Klepeis *et al.,* 2001] helps to filter or absorb VOCs (formaldehyde, benzene, and trichloroethylene, ethylbenzene, xylene, styrene, acetaldehyde, and toluene)[Seguel *et al.,* 2016., Wolverton *et al.,* 1984., Orwell *et al.,* 2004., Hong *et al.,* 2017) Some plants like Genus ficus (Hong *et al.,* 2017) reduce VOC, *Nephrolepis Obliterata* reduce formaldehyde (up to 100%) (Teiri *et al.,* 2018) *Hedera helix, Chrysanthemum morifolium, Dieffenbachia compacta, and Epipremnum aureum* formaldehyde (up to 90%) *within 24 hr (Aydogan and Montoya 2011.). Reduction of VOC, CO and CO2 level by indoor plant (Panyametheekul, et al, 2018).*

Scientific studies on 13 different pot but shows different amoujt of formaledyhyde absorption where out of this 13 , *Asplenium nidus* having highest adsorption capacity (5.13 mg/m^2) and *Epipremnum aureum* has the has the lowest adsorption capacity (0.64 mg/m^3) per unit leaf area (HongBo *et al.,* (2010). Su *et al.,* 2019 also reported that when indoor plants are exposed under higher concentration of formaldehyde it affects growth of plant alongwith witling and leaf yellowing like symptoms. He studied that various species under green wall alongwith various kind of growth media which exposed at various concertation of pollutatnt (µg/m^3) and phytoremediation process have ben reported that *Chlorophytum comosum and Epipremnum aureum* removed CO_2 (1,800,000 µg/m^3) by 20% and 8%, respectively exposed pollutant (Torpy *et al.,* 2017); *Chlorophytum comosum* achieved 48.21–53.35% removal of $PM_{2.5}$ and PM_{10} (700 µg/m^3) (Irga *et al.,* 2017); an active green wall containing *Philodendron scandens, Asplenium antiquum*, and *Syngonium podophyllum* removed 56.6 ± 0.86% of methyl ethyl ketone (MEK) (101.63 µg/m^3) within 8 h (Torpy *et al.,* 2018); *Nephrolepis exaltata* achieved 12.8–77.3% removal of total volatile organic compounds (TVOCs) (3,900–6,600 µg/m^3) within 3 h (Suárez-Cáceres *et al.,* 2021); *Epipremnum aureum* in a hydroponic system removed 81–96% of formaldehyde (2,000 µg/m^3) within 24 h (Aydogan & Montoya, 2011), while a botanical indoor air biofilter containing *Epipremnum aureum* achieved removal rates of 54.5% for $PM_{2.5}$, 65.42% for PM_{10}, and 46% for VOCs (18,000–25,000 µg/m^3) within 16 min (Ibrahim *et al.,* 2021).

Studies in the tables (1) report that potted indoor plants remove formaldehyde (CH_2O), benzene (C_6H_6), toluene (C_7H_8), hexane (C_6H_{14}), xylene, particulate matter (PM), TVOCs, CO_2 and CO. In batch (closed chamber) exposure, *Nephrolepis exaltata*, *Chrysanthemum morifolium* and *Phoenix roebelenii* were exposed to CH_2O at 6140 µg/m^3 and removed 1863, 1450 and 1385 µg $plant^{-1}$ h^{-1} (Wolverton and Wolverton 1993). *Howea forsteriana* removed 4032 $mg/m^3/day/m^2$ of C_6H_{14} at 353,000 µg/m^3 (Wood et al. 2002). *Azalea indica* removed 95% of C_7H_8 at 339,000 µg/m^3 in 7 to 76 h (De Kempeneer et al.2004). At 3195 µg/m^3 of C_6H_6, *Spathiphyllum wallisii*, *Syngonium podophyllum*, *Cissus rhombifolia* and *Hedera helix* removed 174.5, 103.4, 50.3 and 102.8 ng m^{-3} h^{-1} cm^{-2} leaf area respectively (Yoo *et al.*, 2006). At 2456 µg/m^3 of CH_2O, *Fatsia japonica* removed 39% (day) and 98% (night), and *Ficus benjamina* 57% (day) and 94% (night) in 5 h (Kim et al. 2008). *Ficus elastica* removed 28 to 91% of C_6H_6 at 15,116 µg/m^3 in 12 h (Chun et al. 2010). At 2000 µg/m^3 of CH_2O, *Hedera helix*, *Chrysanthemum morifolium*, *Dieffenbachia compacta* and *Epipremnum aureum* removed 88, 84, 96 and 94% in 24 h (Aydogan and Montoya 2011). *Dracaena sanderiana* removed 46% (by wax) and 54% (by stomata) of C_6H_6 at 63,894 µg/m^3 in 72 h (Treesubuntorn and Thiravetyan 2012). *Sansevieria trifasciata* removed 10.17 µmol of C_7H_8 at 78,800 to 81,670 µg/m^3 in 72 h (Sriprapat *et al.*, 2014). *Hedera helix* removed 99.99% of CH_2O at 6,140,000 µg/m^3 in 67.6 h (Chen *et al.*, 2017). *Epipremnum aureum*, *Chlorophytum comosum*, *Hedera helix* and *Echinopsis tubiflora* removed 72% of C_6H_6 at 319,470 µg/m^3 in 72 h (Gong et al. 2019). Under continuous exposure, *Chlorophytum comosum*, *Aloe vera* and *Epipremnum aureum* removed 95, 53 and 84% of CH_2O at 4000 µg/m^3 (Xu et al. 2011). *Chlorophytum comosum* removed 13.62 to 19.79 µg m^{-2} leaf of PM in 2 months in a real room environment (Gawrońska and Bakera 2015). At 43.0 (toluene) and 62.3 (xylene) µg/m^3, *Schefflera actinophylla* removed 13.3 and 7.0 µg m^{-3} m^{-2} leaf area, and *Ficus benghalensis* removed 13.0 and 7.3 µg m^{-3} m^{-2} (Kim et al. 2016). *Schefflera arboricola* and *Spathiphyllum*

wallisii removed 91 to 97% of C_6H_6 at 3.6 to 29.5 µg/m³ in 48 h (Parseh *et al.*, 2018). *Nephrolepis obliterata* removed 81 to 100% of CH_2O at 600 to 11,000 µg/m³, and *Chamaedorea elegans* removed 65 to 100% at 660 to 16,400 µg/m³, both in 48 h (Teiri *et al.*, 2018). *Laurus nobilis* removed 360,002 µg/m³/day/m² of CO_2 at 684,003 to 1,800,009 µg/m³ (Salvatori *et al.*, 2020). *Areca palm* removed 88.16% of TVOCs (829.4 µg/m³), 52.33% of CO_2 (1,545,092 µg/m³) and 95.70% of CO (5728 µg/m³) in 4 months (Bhargava *et al.*, 2021).

III. FIGURES AND TABLES

Table 1 . Indoor air pollutants reported in phytoremediation studies

S. No.	Formula	Chemical name
1	CH_2O	Methanal (formaldehyde)
2	C_6H_6	Benzene
3	C_7H_8	Methylbenzene (toluene)
4	$C_6H_5CH_2CH_3$	Ethylbenzene
5	C_8H_{10}	Dimethylbenzene (xylene)
6	C_6H_{14}	Hexane
7	C_3H_6O	Propan-2-one (acetone)
8	CO_2	Carbon dioxide
9	CO	Carbon monoxide
10	PM	Particulate matter
11	TVOCs	Total volatile organic compounds

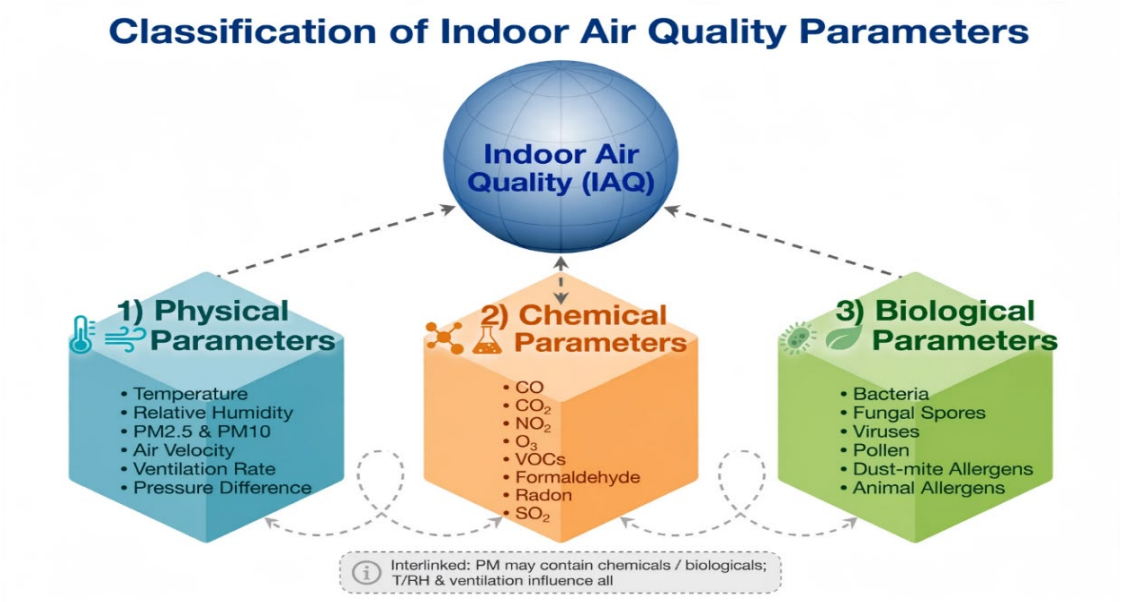


Fig.1a: Classification of Indoor Air Quality Parameters

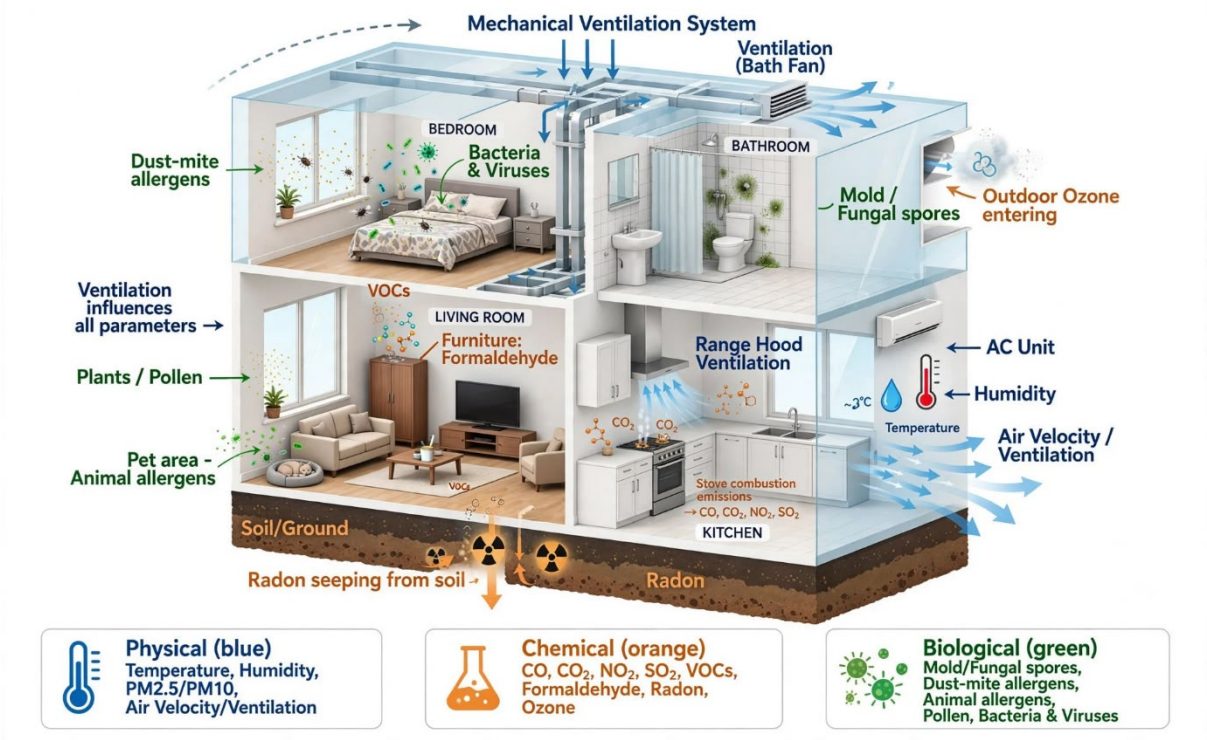


Fig.1b: 3D View of Classification of Indoor Air Quality Parameters



Fig.2: 3 D View of Types and Sources of Indoor Air Pollutants

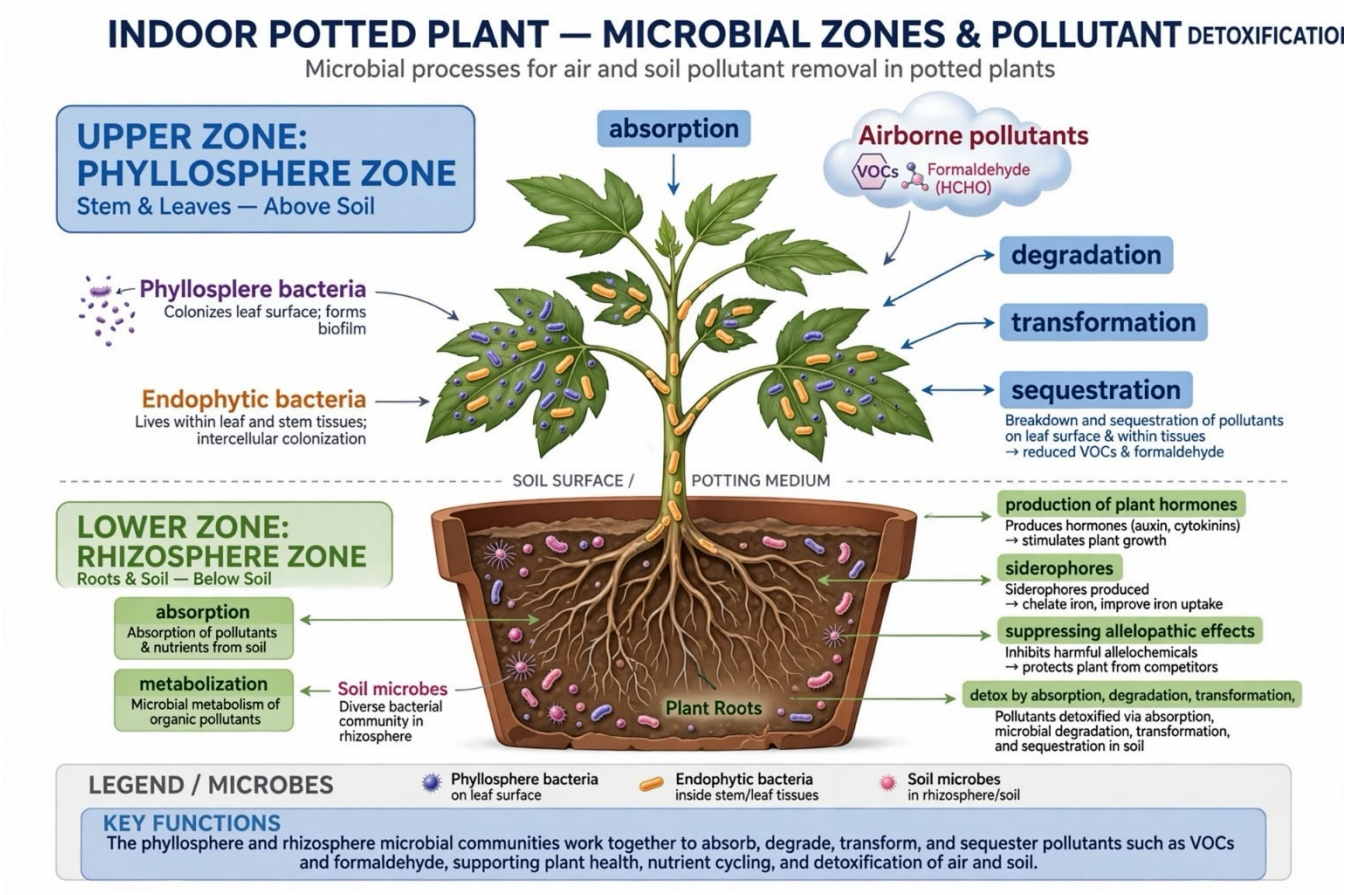


Fig.3: Structural representation of this plant-microbes-soil -air interaction (PMSAI) is shown in

IV. CONCLUSION

The literature reviewed here shows that household air pollution has no single cause and no single indicator. Solid fuel combustion, building materials, cleaning products, furnishings and infiltrating outdoor air all contribute, and the resulting mix of particles, combustion gases, VOCs, aldehydes and bioaerosols varies with fuel use, ventilation and building type. Studies in India remain few and often cover short monitoring periods in a limited range of homes, so exposure estimates for rural and low-income households are the weakest part of the evidence base.

Phytoremediation studies consistently report pollutant reduction by potted plants, active green walls and botanical biofilters. Removal is attributed to leaf and stomatal uptake, cuticular wax adsorption, particle deposition, and degradation by rhizosphere and phyllosphere microbes. Experimental studies show that potted plants, green walls and botanical biofilters can lower indoor pollutant concentrations. Reported removal reached 81 to 96% of formaldehyde by *Epipremnum aureum* in 24 h, 48 to 53% of PM2.5 and PM10 by *Chlorophytum comosum*, and 88% of TVOCs by Areca palm over four months. Removal depends on leaf uptake, stomatal and wax absorption, particle deposition, and degradation by rhizosphere and phyllosphere microbes. Most of these results come from sealed chambers with high pollutant doses and short exposure times, and studies report removal in different units. Direct comparison between species is therefore difficult, and chamber results probably overestimate what a ventilated room with continuous emissions would achieve.

Based on current evidence, plants are best treated as a supplement to source control, clean cooking fuels and ventilation. Future studies should test plants in occupied homes over months, report removal per unit leaf area per hour, include mixed pollutant exposure and PM, and pair plant systems with continuous sensors. Studies on Indian housing and locally available species would also make the findings more applicable.

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