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A SHORT REVIEW ON URBAN AIR POLLUTION AND INNOVATIVE BIOREMEDIAL APPROACHES

BY

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Abstract. In the European Union air pollution is a significant threat to human health and to environment, with more than 400,000 premature deaths estimated annually. Romania experienced an increase in air pollutants from 2016 to 2018, followed by a decrease from 2019 to 2021, with values lower than the WHO guideline recommendations. However, air pollution remains a public health concern in Romania, with heart disease and stroke being the leading causes of death associated with it. Innovative techniques for air (bio)remediation are necessary to mitigate the negative effects of air pollution. Indoor phytoremediation, which uses plants to remove pollutants from the air, is a promising solution for urban spaces. Indoor plants systems, including green walls and biofilic systems, can reduce air pollutant levels and improve indoor air quality, thereby reducing associated health risks. In conclusion, it is essential to take active measures to lessen its impact on both the quality of life and the environment.

Keywords: air pollution, health effects, (bio)remediation, green walls.

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1. Introduction

Globally, air quality is a key environmental issue, with air pollution causing significant threats to human health and to nature. Europe has been identified as one of the world's most polluted regions, with air pollution causing over 400,000 premature deaths annually (European Environment Agency, 2022).

As a result of increased industrialization and urbanization, Romania, a member state of the European Union, has also seen deteriorating air quality being ranked 8th in terms of air pollution in Europe (Global Alliance on Health and Pollution, 2019).

In densely populated urban regions, air pollution arises from a mix of stationary and mobile sources (Iorga, 2016). Indoor air quality levels in homes and offices in urban area, are normally 2-5 times inferior than outside air pollution levels (United States Environmental Protection Agency, 2020) and individuals typically spend approximately 87% of their day within residential or commercial structures, and an additional 6% inside enclosed modes of transportation (Klepeis *et al.*, 2001).

The detrimental impacts of air pollution on human health include respiratory disorders, heart disease, and cancer. Long-term exposure to air pollution can result in the development of chronic illnesses and a shortened lifespan. (World Health Organization, 2021).

Therefore, it is important to develop technologies to remove indoor air pollutants such nitrogen oxides (NO_2), formaldehyde, lead (Pb), particulate matter (PM), and volatile organic compounds (VOCs) (United States Environmental Protection Agency, 2023).

Beside the traditional method for air purification such as, electronic filtration (Mili and Xin, 2015), photocatalytic oxidation (Huang *et al*., 2016) and adsorption (Ki-Joong and Ho-Geun, 2012) phytoremediation is recognized as a potential solution for depollution, offering benefits such as remarkable efficiency, user-friendly operation, cost-effectiveness and the prevention of additional pollution (Dela *et al*., 2014; Su and Liang, 2015).

This work aims to provide an overview of air quality in Europe as well as in Romania, highlighting its sources, effects, and current mitigation efforts.

2. Annual Evolution of the Average Concentration of Different Pollutants in Urban Areas in Romania (2013-2021) in Relation to WHO and EU Air Quality Objectives and Limits

In order to fulfill the objective of this study, some major air pollutants such NO_2, C_6H_6, Cd in PM, Pb in PM, PM_{10} and $PM_{2,5}$ were monitored between 2013-2021.

The following charts represent the analysis of the annual average values in urban areas reported by Romania at the European Union level. The number of average annual reports is also specified, varying according to their typology: traffic, industrial or background.

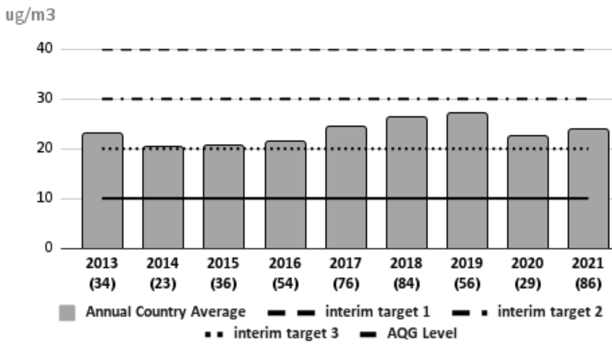

Fig.1 – Annual evolution of the average NO_2 concentration in urban areas in Romania (2013-2021) in the context of the interim targets set by the WHO.

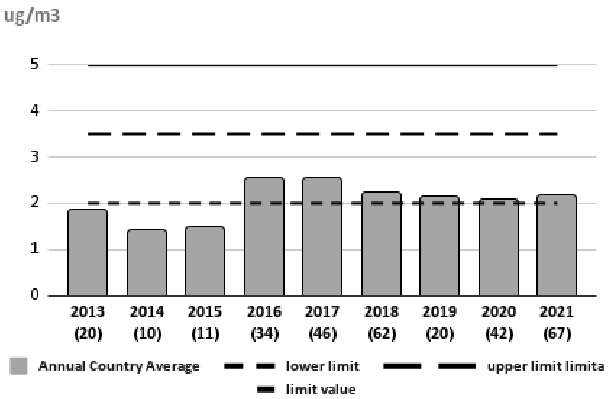

Fig. 2 – Annual evolution of the average C_6H_6 concentration in urban areas in Romania (2013-2021) in the context of the interim targets set by the EU.

The analysis of the data on the annual average of NO_2 concentration in Romania urban areas, for the period 2013-2021 (Fig. 1), shows a fluctuating trend with no clear direction of increase or decrease. The data are based on the number of annual averages obtained at each measuring station in that year, shown in brackets. As well, the straight lines express the interim targets and the recommended air quality target, all of which recommended by WHO in the global air quality guidelines. The data used in the analysis are open source from the Annual AQ statistics (AirBase & e-Reporting merged) of the European Environment Agency.

In comparison with the interim targets and the World Health Organization (WHO) recommended air quality guidelines level for air quality, the results show that in all years analysed, the annual average of NO_2 concentration is below interim target 1 (40 µg·m^{-3}) and interim target 2 (30 µg·m^{-3}). However, in no year is interim target 3 (20 µg·m^{-3}) or the WHO recommended air quality guidelines level (10 µg·m^{-3}) was reached.

The highest annual average NO_2 concentrations were recorded in 2019 (27.19 µg·m^{-3}) and 2018 (26.37 µg·m^{-3}). In 2020, the annual average concentration was 22.49 µg·m^{-3}, the lowest value in 4 years probably due to health crisis caused by COVID-19 virus.

In conclusion, annual average NO_2 concentrations in urban areas in Romania remain below interim targets 1 and 2 set by the WHO, but exceed interim target 3 and the recommended AQG level. This indicates a continuing air quality issue and the need to take action to improve the situation in order to achieve the WHO targets.

Also, the data analyses on the annual average concentration of C_6H_6 in urban areas (Fig. 2) provides insight into the evolution of C_6H_6 pollution over time. In this context, it is important to observe whether the values are within the limits set by the European Union. For the whole period analysed, the annual average values of C_6H_6 concentration varied between 1.43 and 2.55 µg·m^{-3}. These values are below the EU recommended maximum limit of 5 µg·m^{-3} but exceed in some cases the lower limit of 2 µg·m^{-3}. However, no year in the period under review recorded a C_6H_6 concentration value above the upper limit of 3.5 µg·m^{-3}.

In terms of the number of annual average measurements reported each year, it increased significantly from 20 in 2013 to 67 in 2021, suggesting an improvement in the monitoring of C_6H_6 pollution in urban areas in Romania.

In conclusion, based on the data provided, it can be seen that C_6H_6 pollution levels in urban areas in Romania were generally within the limits set by the European Union, although there were a few cases where concentrations were above the recommended lower limit. Given the increase in the number of measurements carried out in recent years, it is important that monitoring continues to ensure compliance with the regulations and to further assess trends in C_6H_6 pollution in Romania.

The analysis of data on the annual average concentration of $PM_{2.5}$ in urban areas in Romania in the period 2013-2021 (Fig. 3) shows a general downward trend in air pollution. During this period, annual average concentrations ranged from 11.52 µg·m^{-3} in 2015 to 19.10 µg·m^{-3} in 2017. The number of measurements taken each year fluctuated between 9 (in 2019) and 25 (in 2021), suggesting an increasing concern for air quality monitoring in recent years. The data are based on the number of annual averages obtained at each measuring station in that year, shown in brackets.

Compared to the interim targets set by the World Health Organization (WHO), the annual average $PM_{2.5}$ concentration in Romania was between interim target 2 (25 µg·m^{-3}) and interim target 3 (15 µg·m^{-3}) during the period under analysis. However, it is important to note that the WHO recommended optimal air quality level (air quality guidelines - 5 µg·m^{-3}) was not reached in any of the years analysed.

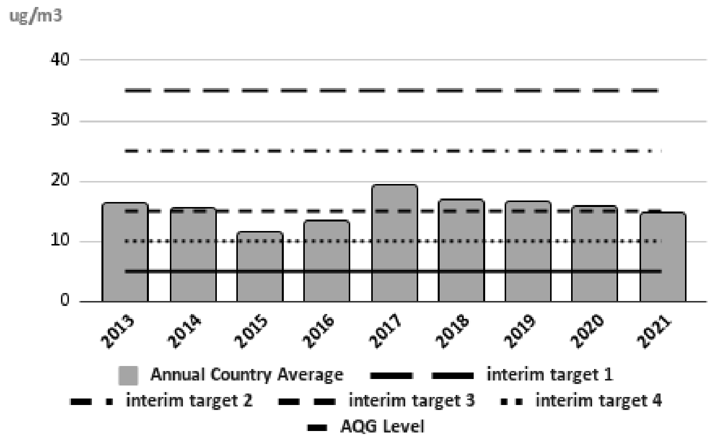

Fig. 3 – Annual evolution of the average $PM_{2.5}$ concentration in urban areas in Romania (2013-2021) in the context of the interim targets set by the WHO.

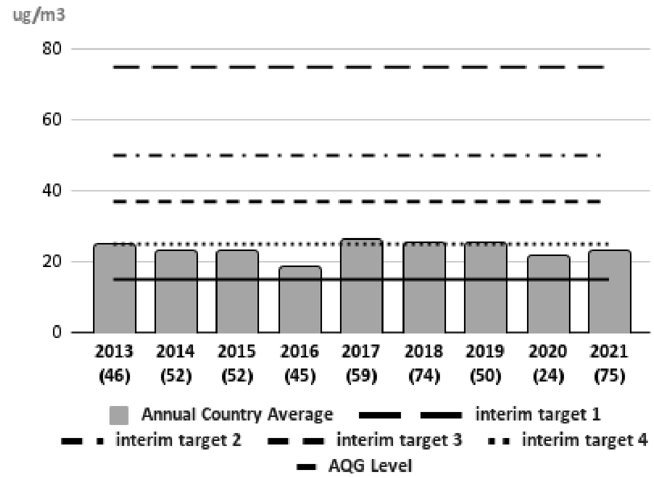

Fig. 4 – Annual evolution of the average PM_{10} concentration in urban areas in Romania (2013-2021) in the context of the interim targets set by the WHO.

Also, analysing the data on annual average PM_{10} concentration in urban areas (Fig. 4), a general trend of decreasing values is observed until 2016, followed by a slight increase and subsequent fluctuations. The data are based on the number of annual averages obtained at each measuring station in that year, shown in brackets.

Compared to the interim targets set by the World Health Organization, annual average PM_{10} concentrations in Romania were generally below interim target 3 (37 $\mu g \cdot m^{-3}$) and interim target 4 (25 $\mu g \cdot m^{-3}$) during the period analysed. However, values remain above the recommended AQG level (15 $\mu g \cdot m^{-3}$) in all years analysed.

Although Romania has seen an overall improvement in the reduction of $PM_{2.5}$ and PM_{10} concentration in urban areas between 2013 and 2021, the values remain above the World Health Organization recommended AQG level.

Based on these findings, it can be concluded that, despite the improvements observed in air quality in urban areas of Romania between 2013 and 2021, there is still a need for effective actions and strategies to achieve the optimal $PM_{2.5}$ concentration levels proposed by the WHO in order to protect the health of the population and the environment.

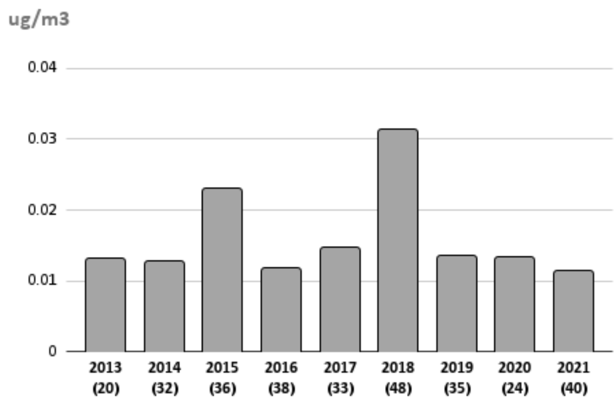

Fig. 5 – Annual evolution of the average Pb in PM concentration in urban areas in Romania (2013-2021).

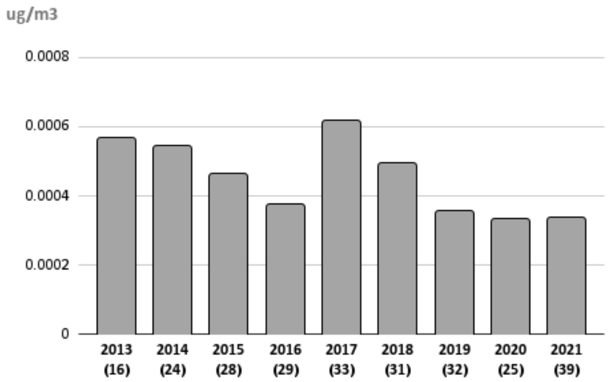

Fig. 6 – Annual evolution of the average Cd in PM concentration in urban areas in Romania (2013-2021).

Based on the analysis of data on the annual average concentration of cadmium (Cd) in particulate matter (PM) in urban areas in Romania between 2013 and 2021 (Fig. 5), several significant trends and variations can be observed. During this period, the number of nationally reported annual averages in the urban area varied from a minimum of 16 in 2013 to a maximum of 39 in 2021, indicating a general increase in air quality monitoring efforts during the period analysed.

The annual average concentration of cadmium in PM showed significant variations over the period analysed. In 2013, the annual average concentration was 0.000565438 $\mu g \cdot m^{-3}$, which decreased to 0.000464 $\mu g \cdot m^{-3}$ in 2015. A sharp increase was observed in 2017, when the annual mean concentration reached 0.000618788 $\mu g \cdot m^{-3}$, the highest value in the studied interval. In the period 2018-2021, lower annual mean concentrations were recorded, ranging from 0.00033432 $\mu g \cdot m^{-3}$ in 2020 to 0.00049307 $\mu g \cdot m^{-3}$ in 2018.

These data suggest a general decreasing trend of cadmium concentration in PM in the urban area of Romania, with temporary fluctuations. However, it is important to note that this analysis is limited by the variation in the number of measuring stations per year and their geographical variation.

In order to obtain a more complete picture of air quality trends and population exposure to cadmium, additional analyses would be needed, such as local and regional analyses and investigation of potential sources of cadmium pollution.

Also, analysis of data on lead (Pb) concentration in particulate matter (PM) in urban areas in Romania for the period 2013-2021(Fig. 6) shows an annual variation in average Pb levels. Based on the data provided, it can be seen that the number of average annual measurements reported each year varies, which may influence the understanding of the overall trends.

In 2013, with a number of 20 annual average reports, the national average was 0.013 $\mu g.m^{-3}$. The same value was recorded in 2014, when 32 reports were made. In 2015, there was a significant increase in the average Pb concentration to 0.023 $\mu g \cdot m^{-3}$, with a total of 36 reports. Subsequently, in 2016 and 2017, decreases in average Pb levels were recorded, reaching 0.012 $\mu g \cdot m^{-3}$ and 0.015 $\mu g \cdot m^{-3}$ respectively.

A substantial increase occurred in 2018, when the national average reached 0.031 $\mu g \cdot m^{-3}$, registering the highest level in the whole period under analysis, with a total number of 48 reports of annual averages recorded. In 2019 and 2020, average Pb levels decreased again, recording values of 0.014 $\mu g \cdot m^{-3}$ and 0.013 $\mu g \cdot m^{-3}$. In 2021, the lowest average Pb concentration of the whole period analysed was observed at 0.011 $\mu g \cdot m^{-3}$, with 40 reports of annual averages made.

Over the period 2013-2021, the annual average level of lead in particulate matter in urban areas of Romania varied, showing both significant increases and decreases. A general decreasing trend of Pb concentration in PM has been observed in recent years, with the lowest level recorded in 2021. However, it is important to note that the varying number of sampling returns performed each year may influence the interpretation of trends and therefore a more detailed analysis of the data would be useful to better understand the evolution of lead levels in the urban environment in Romania.

3. An Overview on Researches Focused on Phytoremediation of Indoor Urban Air

Phytoremediation holds promise as a viable and eco-friendly solution for enhancing indoor air quality (IAQ) (Setsungnern *et al*., 2017). This type of filtration is characterized as a biologically-driven process that is capable of eliminating airborne pollutants and contaminants. Nonetheless, the effectiveness of this method largely hinges on the specific plant species involved (Gawronska and Bakera, 2014; Torpy *et al*., 2018; Pettit *et al.*, 2017b).

Past research has indicated that numerous small-scale plants can effectively reduce common indoor air pollutants, such as particulate matter, benzene, toluene, ethylbenzene, xylene, and so forth (Pettit *et al.*, 2019a).

Table 1 offers a summary of the performance of various plant species in mitigating pollutants and contaminants within indoor settings.

Table 1

Performance of different plant species on specific pollutants of indoor urban air

Plant species	**Pollutants**	**Initial concentration**	**Final concentration / Removal rate/efficiency**	**Ref.**
Hedera helix	a. Formaldehyde b. CO_2	a. 5 ppm b. 750 ppm	a. 0 ppm b. 550 ppm	Lin *et al.*, 2017
Chlorophytum comosum		500 ppm	343.85 ppm	Setsungnern *et al.*, 2017
Dypsis lutescens	a. TVOCs b. CO_2 c. CO	a. 3000 ppb b. 800 ppm c. 0.6 ppm	a. 1000 ppb b. 500 ppm c. 0.1 ppm	Bhargava *et al.*, 2021
Epipremnum aureum	a. TSP b. $PM_{2.5}$ c. PM_{10}	150 $L{\cdot}s^{-1}$	a. 27 $L{\cdot}s^{-1}$ b. 37.20 $L{\cdot}s^{-1}$ c. 42.12 $L{\cdot}s^{-1}$	Ibrahim *et al.*, 2018
Chamedorea elegans	Formaldehyde	16.4 mg	1.47 mg	Teiri *et al.*, 2018
Chamedorea elegans	a. CO_2 b. HCHO	a. 2000 ppm b. 2 ppm	a. 800 ppm b. 0.1 ppm	Su and Lin., 2015

Singonium podophyllum	Benzene	170 μg	29.04–30.36 μmol·m^{-2}·h^{-1}	
Sansevieria laurentii	Benzene	170 μg	26.82–29.58 μmol·m^{-2}·h^{-1}	
Euphorbia milii	Benzene	170 μg	27.66–27.94 μmol·m^{-2}h^{-1}	
Chlorophytum comosum	Benzene	170 μg	27.55–28.25 μmol·m^{-2}·h^{-1}	
Dypsis lutescens	Benzene	170 μg	26.79–27.41 μmol·m^{-2}·h^{-1}	
Hedera helix	Benzene	170 μg	25.26–25.54 μmol·m^{-2}·h^{-1}	
Dracaena draco	Benzene	170 μg	25.26–25.54 μmol·m^{-2}·h^{-1}	
Clitoria ternatea	Benzene	170 μg	24.30–26.30 μmol·m^{-2}·h^{-1}	
Philodendron scandens, Asplanium antiquum, and Syngonium podophyllum	Methyl ethyl ketone	30 ppbv	56.60%	Sriprapat and Thiravetyan, 2016
Spathiphyllum wallisii *Syngonium podophyllum*	Nitrogen dioxide, ozone	6.656 ppm (NO_2) 7.280 ppm (O_3)	Clean Air Delivery Rate ($m^3 \cdot h^{-1} \cdot m^{-3}$ of biofilter substrate) 661.32 and 95.04 (S.wallisii) 550 and 23 (S.podophyllum) for NO_2 and O_3	Torpy *et al.*, 2018
Zamioculcas zamiifolia	a. toluene b. formaldehyde	a. 200 ppm b. 200 ppm	a. 0.5 ppm b. 0.5 ppm	Pettit *et al.*, 2019a
Zamioculcas zamiifolia *Snake Plant*	a. toluene b. formaldehyde a. toluene b. formaldehyde	a. 200 ppm b. 200 ppm a. 200 ppm b. 200 ppm	a. 0.5 ppm b. 0.5 ppm a. 0.5 ppm b. 0.5 ppm	Ullah *et al.*, 2021
	a. toluene	a. 200 ppm	a. 0.5 ppm	

Zamioculcas zamiifolia *Snake Plant* *Epipremnum aureum*	b.formaldehyde a. toluene b. formaldehyde Formaldehyde	b. 200 ppm a. 200 ppm b. 200 ppm 7.5–10 ppm; 250 ppm	b. 0.5 ppm a. 0.5 ppm b. 0.5 ppm 39.5%	Ullah *et al*., 2021; Wang *et al*., 2014;
Chlorophytum comosum	Particulate matter	~ 700; $g \cdot m^{-3}$ (TSP)	53.5% (TSP) 53.51% PM_{10} 48.21% $PM_{2.5}$	
Chlorophytum orchidastrum, Ficus lyrata, Neprolephis bostoniensis, Nephrolepis cordifolia, Schefflera amate, Schefflera arboricola	Particulate matter	19.86 $\mu g \cdot m^{-3}$ ($PM_{0.3–0.5}$) 8.09 $\mu g \cdot m^{-3}$ (PM_{5-10}) 142.23 $\mu g \cdot m^{-3}$ (TSP)	Max removal; 45.78% ($PM_{0.3-0.5}$) 92.46% (PM_{5-10})	Irga *et al*., 2017
Epipremnum aureum	$PM_{2.5}$, PM_{10} and TVOC	~ 18–25 $mg \cdot m^{-3}$	Removal efficiencies: 54.5 + 6.04% ($PM_{2.5}$) 65.42 + 9.27% (PM_{10}) 46 + 4.02% (VOC)	Pettit *et al*., 2017a
Neproplepsis bostoniensis	PM, VOCs	~ 500 – 600 ppb (VOCs) N/A (PM)	25.66% higher removal than soil treatment for benzene ~ 78% (ethyl acetate)	Ibrahim *et al.*, 2021
Neprolepsis exaltata, Peperomia obtusifolia Schefllera arborcola, Spathiphyllum wallisii	PM, VOCs (from lavender oil)	300 ppb (TVOC) 101.18 $\mu g \cdot m^{-3}$ (TSP)	~ 28% over 20 min (TVOC) 42.6% over 20 min (TSP)	Pettit *et al*., 2019a
Neprolepsis obliterata	Formaldehyde	600-11000 $\mu g \cdot m^{-3}$	90%-100% in 48 h	Pettit *et al*., 2019b
Chamaedorea elegans	Formaldehyde	660-16400 $\mu g \cdot m^{-3}$	65%-100% in 48 h	Teiri *et al*., 2018

Westringia fruticosa, Myoporum parvifolium, Strobilanthes anisophyllus Nandina.dome stica	NO_2, O_3	5-min ambient averages of 178.6 ppb, 59.4 ppb and 774.7 μg·m^{-3} NO_2, O_3,	63.17%, 38.79% and 24.84% (for NO_2, O_3, $PM_{2.5}$)	Teiri *et al.*, 2018
Nephrolepsis exaltata L	TVOC and nhexane	5.69–7.51 mg·m^{-3}	Reduction rate: 0.17 and 0.1 mg·m^{-3}·h^{-1}	Pettit *et al.*, 2020
Sansevieria trifasciata Chlorophytum comosum	Formaldehyde, acetone, benzene and xylene	120–150 ppm formaldehyde 127–145 ppm acetone 15–35 ppb xylene	80–90% (TVOC)	Suarez-Caceres *et al.*, 2021

Due to its detrimental effects on human health, indoor air pollution is a developing concern. The use of plants as natural air purifiers is a promising method for addressing this issue. Tabel 1 summarizes the performance of various plant types in mitigating specific pollutants. By analyzing this data, we can obtain a better understanding of the potential of different plants to reduce indoor air pollution.

The centralizing table includes a variety of plant species and their respective pollutants, initial and final pollutant concentrations, and pertinent references. Formaldehyde, benzene, CO_2, TVOCs, CO, $PM_{2.5}$, PM_{10}, methyl ethyl ketone, nitrogen dioxide, ozone, toluene, and n-hexane are one of the pollutants evaluated. The concentrations of these pollutants were measured, allowing for the calculation of pollutant reduction percentages.

Table 1 illustrates the various capabilities of various plant species to mitigate specific pollutants. For example, *Hedera helix* was highly effective at reducing formaldehyde and CO_2 concentrations. *Chlorophytum comosum* showed promising results in reducing benzene concentrations. *Chrysalidocarpus lutescens* was discovered to be effective at reducing levels of TVOCs, CO_2, and CO. *Epipremnum aureum* demonstrated remarkable reduction potential for $PM_{2.5}$, and PM_{10}. These examples illustrate the wide variety of pollutants that various plant species can target and mitigate.

Table 1 provides a comprehensive overview of the effectiveness of various plant species in reducing specific pollutants. The results highlight the significance of using plants as natural air purifiers to enhance indoor air quality. By incorporating appropriate indoor plants, we can effectively reduce indoor air pollution and create healthier living and working environments. Exploring the optimal plant-pollutant combinations and improving our understanding of the fundamental mechanisms involved in air purification by plants requires additional research and experimentation.

3. Conclusions

Air pollution is a significant concern in Europe including ~~and~~ Romania, particularly in densely populated urban areas, leading to a substantial threat to human health and the environment.

Romania ranks 8th in terms of air pollution among European Union member states. Chronic exposure to air pollution can have severe health implications, including respiratory disorders, heart disease, and cancer.

Analyzing air pollutant data from 2013 to 2021 in Romania, it was observed that the annual average concentrations of NO_2 were below some WHO targets but exceeded others and the recommended level. The annual average values of C_6H_6 generally met EU limits, although there were occasional cases of higher concentrations. The analysis of $PM_{2.5}$ concentrations showed a downward trend over the analyzed period, with values falling between certain interim targets. The increase in monitoring suggests improved awareness and actions towards achieving air quality goals, emphasizing the importance of continued monitoring and interventions.

Phytoremediation, the use of plants to purify air, offers a promising solution with its efficiency, cost-effectiveness, and prevention of additional pollution.

Studies on phytoremediation for indoor air pollution have highlighted various plant species, such as *Hedera helix, Chlorophytum comosum, Chrysalidocarpus lutescens, Epipremnum aureum*, and many others, which have shown potential in reducing pollutants like formaldehyde, benzene, CO_2, TVOCs, and particulate matter. Each plant species exhibits varying efficacy depending on the pollutant and its concentration. Therefore, the selection of suitable plants should be based on the specific indoor environment and the pollutants present.

In a next study the authors will explore the possibilities of practical application of phytoremediation techniques for improving indoor air quality specifically an innovative approach (new natural carbonaceous carriers for plants and microorganism's immobilization) that have shown promising results in preliminary work (Armanu and Volf, 2022).

By investigating the benefits, limitations, and future prospects of indoor air phytoremediation, insights into sustainable strategies for creating healthier living and working environments will be provided.

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POLUAREA AERULUI URBAN ȘI ABORDARI INVOATOARE DE BIOREMEDIERE A ACESTUIA

(Rezumat)

Poluarea aerului reprezintă o amenințare semnificativă pentru sănătatea umană şi pentru mediul înconjurător în Uniunea Europeană, cu peste 400.000 de decese premature estimate anual. România a înregistrat o creștere a poluanților atmosferici în perioada 2016-2018, urmată de o scădere în perioada 2019-2021, cu valori mai mici decât recomandările ghidului OMS. Cu toate acestea, poluarea aerului rămâne o problemă de sănătate publică în România, bolile de inimă și accidentele vasculare cerebrale fiind principalele cauze de deces asociate. În acest context sunt necesare tehnici inovatoare de remediere a aerului pentru a atenua efectele negative ale poluării atmosferice. Fitoremedierea aerului din incinte este o soluție promițătoare pentru spațiile urbane. Sistemele bioactive, inclusiv aşa numiții pereți verzi precum și sistemele biofilice, pot reduce nivelurile de poluanți din aer şi pot îmbunătăți calitatea aerului din interior, reducând astfel riscurile asociate pentru sănătate. În concluzie, este esențial să se ia măsuri active pentru a diminua impactul poluanților aerului din incinte cu repercusiuni atât asupra calității vieții, cât și asupra mediului înconjurător.