Cross Current International Journal of Agriculture and Veterinary Sciences
Abbreviated Key Title: Cross Current Int J Agri Vet Sci
ISSN: 2663-2454 (Print) & Open Access
DOI: 10.36344/ccijavs.2021.v03i06.001

Volume-3 | Issue-6 | Sept, 2021 |

Review Article

Role of Phytoremediation in Removing Air Pollutants: A Review

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| **Received:** 16.08.2021 | **Accepted:** 25.09.2021 | **Published:** 01.10.2021 |

Abstract: Air pollution has become a global issue in recent years due to increasing health and socioeconomic risks. It has negative effects on human health in both indoor and outdoor environments. There is a growing severity and impact of these threats, especially in developing countries such as Pakistan that have no adequate systems of alert, management, and protection. The main problem facing the scientific community now is to reduce air pollutant emissions properly. Phytoremediation seems a promising prospect: an environmentally sustainable, low-cost, plant-based approach to maintenance, soil stabilization, and aesthetical pleasure. The present review discusses Pakistan's indigenous plants, which have the potential to mitigate specific air pollutants.

Keywords: Air Pollutants, Phytoremediation, Native Plants, Human Health, Emissions.

INTRODUCTION

The accumulation of toxic or poisonous substances in the earth's atmosphere, which has negative consequences for human health and the ecosystem, is referred to as air pollution. The planet is on the verge of a global climate crisis, with air pollution being the primary cause. It is a critical global problem, the most serious environmental threat to human health, and the cause of 4.2 million deaths every year (WHO, 2021). Due to a lack of pollution controls and air quality regulations, Pakistan has some of the world's most polluted cities (Colbeck *et al.*, 2009). Particulate matter (PMs), Nitrogen oxide (NO_2), Sulphur dioxide (SO_2) and Ground-level ozone (O_3) are all major air pollutants. The first step in reducing air pollution is to eradicate or minimize anthropogenic-caused emissions (Ahmad and Aziz, 2013). Due to the serious consequences of air pollution, Pakistan's lack of progress in implementing various technological steps to avoid pollution is cause for concern. The second step is to clean up any toxins that have already been released into the environment.

Various air pollution reduction techniques, policies, and models have been proposed (Macpherson *et al.*, 2017). Biological remediation, also known as bioremediation, can be used to reduce air pollution. It is the process of species assimilating, degrading, or transforming harmful substances into less harmful or non-toxic forms. Phytoremediation is the process of using plants to remove toxins from the air, soils, and water (Raza *et al.*, 2021). The key benefits of phytoremediation technology are that it is an aesthetically appealing and solar energy-driven cleanup technology and that it can treat a range of environmental pollutants at the same time. It is a cost-effective technique since the cost of phytoremediation is 60-80% less than that of traditional physio-chemical or mechanical systems (Singh and Verma, 2007).

Citation: Hasnain Raza *et al* (2021). Role of Phytoremediation in Removing Air Pollutants: A Review. *Cross Current Int J Agri Vet Sci*, *3*(6), 54-59.

S.r.	Pollutant	Sources	Diseases	References
1	Particulate matters (PMs)	Industrial activities, Forest fires, Volcano eruptions, Agricultural activities, Resuspension of soil, Combustion of fossil fuel, Vehicle emissions, and energy production.	Diseases in nervous system and respiratory system. Heart, bladder and lung cancer and Cardiovascular morbidity.	(Kelly and Fussell, 2015)
2	Nitrous oxide (NO_2)	Industrial manufacturing, Vehicular traffic, Fossil fuel combustion, Industrial activities, and Domestic heating.	Respiratory disease, Lung illness, Asthma, and Breathing disorder.	(Peel *et al.*, 2013)
3	Sulfur dioxides (SO_2)	Burning of fossil fuels, oil, coal and diesel. Sources that contain sulfur from burning of material are power plants, metals processing and smelting facilities, and vehicles.	Asthma, Chronic bronchitis, Lung diseases, and Emphysema	(Manisalidis *et al.*, 2020)
4	Ozone (O_3)	This happens when pollutants emitted by cars, power plants, industrial boilers, refineries, chemical plants, and other sources chemically react in the presence of sunlight. Ozone is most likely to reach unhealthy levels on hot sunny days in urban environments, but can still reach high levels during colder months.	Asthma, emphysema, and chronic bronchitis and climate change	(Zhang *et al.*, 2019)
5	Heavy metals (HMs)	Industrial activities, Agricultural activities, and Combustion of fossil fuel.	Carcinogens, lung, liver, kidney and brain damage, skin irritation, reduced fetal growth, damage to blood vessels, cancer, and death.	(Lentini *et al.*, 2017

Phytoremediation is a process in which plants absorb contaminants from the air and then degrade or detoxify them via a variety of mechanisms. This has been shown to be a successful plant-based, environmentally friendly, and long-term method of reducing air pollutants in both indoor and outdoor settings (Weyens *et al.*, 2015). Phytoremediation stands out among existing technologies because of its self-maintaining, cost-effective procedures, as well as increased ethical and societal acceptance (Doty *et al.*, 2007). Numerous studies have been conducted on plants' ability to absorb certain toxins under various environmental circumstances. Many studies further explore their broader applications, such as the use of taller plants to remove airborne pollutants, which is particularly useful in outdoor settings.

Air quality in Pakistan and Phytoremediation

Air pollution is a major environmental challenge in Pakistan's cities and costs the national checker trillions of rupees per year (IQAir, 2021). Vehicle emissions, fossil fuel combustion of unleaded petrol, and power plants are the main sources of fine particulate pollution (Asad *et al.*, 2011). Poor air quality in Pakistan is creating problems including the development of aerosols, asthma, and lead to toxicity, and accumulation of greenhouse gas. To save 222 million lives, immediate action is needed.

Title: Top ten countries with poor Air Quality index (AQI) in 2020 by (IQAir, 2021).

S.r.	Country	Population	AVG. US AQI
1	Bangladesh	164'689'383	162
2	Pakistan	220'892'331	153
3	India	1'380'004'385	141
4	Mongolia	3'278'292	128
5	Afghanistan	38'928'341	128
6	Oman	5'106'622	123
7	Qatar	2'881'060	123
8	Kyrgyzstan	6'524'191	121
9	Indonesia	273'523'621	114
10	Bosnia Herzegovina	3'280'815	113

Particulate Matter (PM)

Particulate Matter (PM) is much more visible and intense than the other pollutants mentioned above, but it is less toxic, as it serves as a nucleus for the deposition of several hazardous chemicals found in any environment. Soot, ash, and chemical byproducts created by combustion or chemical mixing, road construction, and farming are the most common sources of PM. Pakistan as a whole was polluted with PM2.5 in 2018, and the average yearly level in 2019 was 65.81 µg/m3 (IQAir, 2021). The highest average PM2.5 mass levels in Karachi were estimated to be 668 µg m^{-3} amongst the 18 biggest cities of the world (Gurjar *et al.*, 2008). Biswas *et al*. (Biswas *et al.*, 2008) found that the average PM2.5 mass concentration in Lahore is many times higher than in Hong Kong, Seoul, and New York City. With about 105 thousand deaths per year, Pakistan is one of the most premature death rates in the world due to elevated PM2.5 levels (Giannadaki *et al.*, 2016).

The quantity of PM contaminants that plants extract from the air is usually caused by deposition. The quantity of contaminants deposited is dependent on the index of leaf area, deposition, PM concentration, and period of vegetation. The vegetation area of each soil unit surface is used to calculate the index of the leaf area, which may vary considerably between plant species (Janhäll, 2015). Some native plants in Pakistan can reduce PM levels in the air like Hedge or Field maple (*Acer campestre), Coniferous corsican,* French hales *Sorbus latifolia, Alnus spp.,)* sycamore *(Platanus occidentalis),* Popular (*Populus spp*.,), Southern blue gum *(Eucalyptus globulus),* Oak *(Quercus spp.,),* Red fir *(Pseudotsuga menziesii),* Woodland Elaeocarpus *(E. sylvestris),* English yew *(Taxus baccata),* Scots pine *(Pinus sylvestris),* Laceshrub *(Stephanandra incisa),* Mugo pine *(Pinus mugo),* Anglojap yew *(Taxus media),* Common silver birch *(Betula pendula),* Neem tree *(Azadirachta indica), Mango (Mangifera indica),* Banyan *(Ficus bengalensis), and* Hibiscus *(Hibiscus rosasinensis).*

Several studies have looked into the ability of these shrubs and trees to minimize urban PM air pollution (Freer-Smith *et al.*, 2004; Manes *et al.*, 2016; Sæbø *et al.*, 2012; Terzaghi *et al.*, 2013). Freer-Smith *et al.*, 2004, studied the capture efficiency of PM *on Alnus spp., Quercus spp., E. globulus,* and *P. menziesii* using NaCl droplets of 1 mm and wind tunnel. At a 9 m/s wind speed, *P. menziesii* and *Quercus spp* seemed to have the best overall efficiency of 0.671 % and 0.348 %, respectively. Planting trees such as *A. indica, F. bengalensis, H. rosasinensis* and *M. indica* along urban roadsides. According to Mate and Deshmukh (Mate and Deshmukh, 2015), plants can be a good way to control particulates released by vehicles. The plants that captured the most PM were *P. mugo, T. baccata, P. sylvestris, S. incisa, T. media,* and *B. pendula* (Sæbø *et al.*, 2012). Trees such as cedars and oaks planted 25 meters along roadside have been shown to reduce PM2.5 and PM10 concentrations by 50%, though tall prairie grass lowers them by 35% (Cowherd *et al.*, 2006).

Sulphur dioxide (SO_2)

Sulphur dioxides were the first air pollutants to cause harm to human health and wildlife. SO_2 has been significantly increased in the air by fossil fuels combustion (Zhang *et al.*, 2013). The expected growth in economic activity in Pakistan to increase SO_2 emissions by 8.7 between 2005-2030 [4]. The SO_2 (52.5 ppb) was found at Lahore, higher than Karachi and Peshawar (Ghauri *et al.*, 2007). During the study period the amount of SO_2 was below both the National Environmental Quality Standards (NEQS) and United States Environmental Protection Agency (USEPA) standards (Ashraf *et al.*, 2013). SO_2 in Islamabad is within safe limits (Rasheed *et al.*, 2014; Shahid *et al.*, 2019). The average daily SO_2 in Faisalabad was within NEQS limits (Asghar *et al.*, 2018). The plant leaves absorb SO_2 through stomata and are subsequently hydrated and oxidized to sulfite and sulfate, when accumulated to high concentrations, may inhibit photosynthesis and energy metabolism (Wei *et al.*, 2017).

Ground-level Ozone (O_3)

The economic yield of major agricultural crops is impacted by O_3 pollution. Many studies showed that O_3 pollution has a major impact on agricultural productivity, but the health effects of O_3 tend to be less significant in Pakistan than those of other pollutants. The permissible amount of ozone (O_3) in ambient air is 130 g m^{-3} under NEQS (Khwaja and Shams, 2020). For an 8-hour daily average, the World Health Organization has developed a guideline value of 100 g m-3 for O_3 levels. According to (Colbeck *et al.*, 2010), O_3 concentrations in Pakistan's major cities were well within WHO air quality guidelines.

Within the leaf structure of the plant, O_3 can be completely detoxified. After entering the stomata, O_3 can be extracted and subsequently reacted within the intercellular zone. O_3 build up in the intercellular space at high O_3 levels and reduce the total O_3 flux (Fares *et al.*, 2010). Plants have been shown to remove O_3 from the atmosphere on an annual basis implying that plants' metabolic pathways will permanently eliminate some O_3 (Mikkelsen *et al.*, 2004; Nowak *et al.*, 2006). In Pakistan, there are some native plants which have the potential to remediate the O_3 level in the air. These are *Larix decidua*, *Picea smithiana*, deciduous conifer, deciduous, and evergreen broadleaved and conifer forests.

So many studies have looked into the effects of various trees on O_3 elimination (Alonso *et al.*, 2011; Manes *et al.*, 2016). The O_3 uptake of the *L. decidua*, the Cembran pine, a deciduous conifer, and the Norway spruce, 1.40, 1.18, and 1.09 nmol/m^2s (Wieser *et al.*, 2003). Alonso *et al.*, (2011) looked at how various types of vegetation affected O_3 levels. For evergreen broadleaved, deciduous and conifer forests, 6.64, 6.86, and 3.98 mg/m^2 were found to be annual absorbed cumulative O_3 fluxes, respectively. Overall, it's important to remember that air pollutant removal effectiveness varies by plant species.

Nitrogen dioxide (NO_2)

Nitrogen dioxide (NO_2), Nitrogen trioxide ($N2O_3$), Nitric oxide (NO), and Nitrous oxide (N_2O) are some of the nitrogen (N) oxides found in the atmosphere. Since NO_2 is the most common form of NOx formed by humans, the USEPA only regulates it. The country's current levels of NO_2 to some extent higher than the WHO air quality permissible value of 40 g/m^3, according to annual NO_2 concentrations derived from 48-hour data, with the highest concentrations of 49 ± 28 $\mu g/m^3$ in Islamabad, 52 ± 21 $\mu g/m^3$ in Peshawar, 46 ± 15 $\mu g/m^3$ in Karachi and 49 ± 25 $\mu g/m^3$ in Lahore (IQAir, 2021). The ability of plants to absorb some NO_2 through their stomata while also assimilating and metabolizing gaseous nitrogen contaminants appears to allow for varying levels of permanent NO_2 elimination. NO_2 fluxes differ, much like those of other gaseous compounds (Wei *et al.*, 2017). Plants have been shown to minimize regional NO_2 levels in particular (Nowak *et al.*, 2014). The most productive woody plants in Pakistan are *Robinia pseudoacacia, Populus nigra, Eucalyptus viminalis,* and *Magnolia kobu,* and the most herbaceous plants include *Crassocephalum crepidioides, Nicotiana tabacum* and *Erechtites hieracifolia.*

S.r.	Plants	Pollutants	References
1.	*Phytolacca Americana*	HMs	(Pandey and Bajpai, 2019)
2.	*Pinus mugo*	PM	(Sæbø *et al.*, 2012).
3.	*Salix schwerinii*	HMs	(Mohsin *et al.*, 2019)
4.	*Blumea malcolmii*	POP	(Kagalkar *et al.*, 2011)
5.	*Taxus baccata*	PMs	(Sæbø *et al.*, 2012).
6.	*Sorghum x drummondii*	VOCs	(Dominguez *et al.*, 2020)
7.	*Helianthus annuus*	POPs,	(Lee and Yang, 2010)
8.	*Picea smithiana*	O3	(Alonso *et al.*, 2011)
9.	*Mangifera indica*	PM	(Mate and Deshmukh, 2015),
10.	*Sorghum x drummondii*	VOCs	(Dominguez *et al.*, 2020)
11.	*Arundo donax*	VOCs,	(Guarino *et al.*, 2020)
12.	*Typha angustifolia*	IAP	(Li *et al.*, 2016)
13.	*Phaseolus vulgaris*	HMs	(Lee and Yang, 2010)
13.	*Juncus effuses*	HM	(Najeeb *et al.*, 2017)
15.	*Spirodela polyrhiza*	POP	(Kristanti *et al.*, 2012)
16.	*Pinus sylvestris,*	PM	(Sæbø *et al.*, 2012).
17.	*Sorghum x drummondii*	HMs	(Dominguez *et al.*, 2020)
18.	*Larix decidua*	O3	(Wieser *et al.*, 2003)
19.	*Helianthus annuus*	PMs	(Lee and Yang, 2010)
20.	*Ficus bengalensis,*	PM	(Mate and Deshmukh, 2015),
21.	*Carpobrotus aequilaterus*	PM	(Terzaghi *et al.*, 2013)
22.	*Juncus effuses*	PMs	(Najeeb *et al.*, 2017)
23.	*Stephanandra incisa*	PM	(Sæbø *et al.*, 2012).
24.	*Azadirachta indica*	PM	(Mate and Deshmukh, 2015),
25.	*Sorghum x drummondii*	POPS	(Dominguez *et al.*, 2020)

CONCLUSION

Air pollution in Pakistan has a negative impact on human health and agriculture. Air quality is worsening at enormous pace and the government and many other organizations have identified it as a serious issue. In this respect, however, little work has been done. Due to the complexity of air pollution existence and origins, it is difficult to develop adequate control methods. The plant is therefore an asset to enhance air quality either by metabolization, sequestration or degradation of particular air pollutants. In some plants, toxic pollutants can be assimilated, degraded or modified in air into less toxic pollutants which allow airborne pollutants to be removed using the AP technology. There are several plants in Pakistan that can clean outdoor and indoor air. In roadsides, parks and manmade forests, plants and trees above mentioned should be grown. The phytoremediation of air pollution is therefore still a developing phenomenon on a commercial scale. The scientists and the general public are well aware of several benefits from tree planting and growing, but there are uncertainty about the capacity and adequacy of individual species for particular pollutants.

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