Air Pollution Tolerance Index

Subjects: Environmental Sciences

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Air pollution is a global environmental issue, and there is an urgent need for sustainable remediation techniques. Thus, phytoremediation has become a popular approach to air pollution remediation.

air pollution | phytoremediation | indigenous plant | environmental pollution | API | APTI

1. Introduction

Globally, clean air is essential for the environmental–public health nexus; however, the deterioration of air quality due to the discharge of pollutants from numerous sources into the environment is becoming a global health issue for climate and human health [1][2][3]. Air is considered polluted when there is a high concentration of one or more contaminants in the atmosphere [4]. Anthropogenic or natural pollutants found in the atmosphere comprise gaseous pollutants, such as sulphur dioxide (SO_2), carbon monoxide (CO), nitrogen oxides (NO_X), ozone (O_3), lead (Pb), and particulate matter ($PM_{2.5}$ and PM_{10}); these are known as the criteria pollutants [5][6][7]. The pollutant concentrations in the atmosphere vary depending on the sources, distribution pattern, meteorological conditions, and topographical features of an environment [8]. These pollutants are no doubt proven to be dangerous to the environment and human health, causing various diseases to humans, plants, and animals [1]. Air pollution has been reported to alter the ecosystem and has negative effects on plants by reducing photosynthetic pigment, stomata conductance, net photosynthetic rate, and grain protein contents [9]. The persistence of these pollutants in the environment could pose problems in distant areas, while in some cases posing an additional problem of transboundary pollution due to variation in meteorological factors, such as wind and speed, which disperse these pollutants far and wide [10].

Both ambient and indoor air are contributing to a wide range of potentially life-threatening health problems, and they have been reported to negatively affect the population in low-income countries. In addition, air pollution has been declared “the silent killer” with about 7 million deaths every year as estimated by the World Health Organisation [11][12]. Likewise, over 95% of the world’s population was reported to be breathing unhealthy air in 2016 [13]. This led to the death of 6.1 million people due to long-term exposure to contaminated air for which India and China were found to be jointly responsible for over 50% of global deaths attributed to $PM_{2.5}$ [13]. Epidemiological studies have shown that air pollution could cause several human health diseases, such as pulmonary, cardiac, vascular, and neurological diseases [14][15], chronic respiratory symptoms, and diseases among elderly people worldwide [16]. Further, a consistent increase in cardiac, respiratory disease, lung cancer, and mortality in the world is attributed to exposure to air pollution from different sources [17][18].

Atmospheric particulate matter ($PM_{2.5}$) as one of the air pollutants is estimated to cause 3.3 million premature deaths yearly, particularly in Asia, and poses a range of negative effects on human health [19]. Thus, bio-monitoring studies in the field of air pollution science concerning urban ecosystem restoration are extremely relevant because, once the pollutants are released into the atmosphere, they disperse and affect the environment negatively. Therefore, the role of plants in air pollution abatement has been increasingly recognised and reported by several researchers [20][21][22][23][24][25]. The application of plants for reducing and absorbing pollutants from the atmosphere has been proposed as the only ecomanagement approach (approach to lessen the harmful impact of human activity on the environment) for air pollution [9][26][27]. This is an eco-friendly approach, as it is safe, preserves the environment through energy efficiency and reduction of the contaminant in a cheaper way, has no adverse effect on the environment, and uses a sustainable source of energy [23][28][29]. Based on the responses of plants towards air pollution, the analysis of some biological parameters of each species helps in determining tolerance levels. The appropriate plant species can be identified by evaluating certain biochemical and socio-economic characteristics, which could be obtained from the two indices commonly known as the air pollution tolerance index (APTI) and anticipated performance index (API), respectively.

Several studies have been conducted by researchers on either plant APTI or API for air pollution reduction [9][26][27][30][31][32]; hence, there is a need to integrate these two indices to ascertain the tolerance level for sustainable green ecomanagement development.

2. Components and Impacts of Ambient Air Pollutants

Ambient air pollutants include gaseous pollutants and particulate matters that are present in the atmosphere at normal temperature and pressure. Various anthropogenic activities are responsible for releasing pollutants into the atmosphere; these include coal power generation [33][34][35], domestic fuel burning [36][37], brick industries [38][39], mining activities [40], and vehicular emission, among others [41]. Meanwhile, the impact of long-time exposure of humans to air pollutants can cause several respiratory diseases, such as chronic bronchitis and asthma, and cardiovascular, reproductive, and gastrointestinal problems [1][42]. The pollutant's concentrations are measured in micrograms per cubic meter ($\mu g/m^3$) or parts per million (ppm) [6].

2.1. Particulate Matter (PM_{10} and $PM_{2.5}$)

Particulate matter (PM) originates from primary emissions (e.g., soot from combustion sources (such as construction sites, unpaved roads, fields, and smokestacks), sea salt, and soil from wind-driven resuspension) and the formation of secondary particles in the atmosphere [13]. Particulate matter (PM) is a term used for physical and chemical substances that exist as discrete particles, either as liquid droplets or solids over a wide range of sizes [43]. In terms of the mass concentration, PM may be characterised as particles smaller than 2.5 µm in aerodynamic diameter ($PM_{2.5}$) or less than 10 µm in aerodynamic diameter (PM_{10}), shown in **Figure 1**. Particulate matters ($PM_{2.5}$) as air pollutants have both short-term and long-term effects. Particulate matters (PMs) may cause adverse health effects on humans, affect plant life and the ecosystem and become global environmental problems if exposed to high concentrations [27][44]. Exposure to ambient fine particles has been linked to an increase in

adverse effects on human health because they can penetrate the respiratory system if inhaled, deposit into deep regions of the lungs, and cause respiratory infection, heart and lung diseases, lung cancer, premature death and mortality [16][45][46]. This is based on their quantity and physical and chemical properties; some of these chemical parameters include benzene, sulphates, chlorides, nitrate, and even some metals [1]. Continual contact with air pollution affects the lungs of growing children and may worsen or complicate medical conditions in the elderly [16].

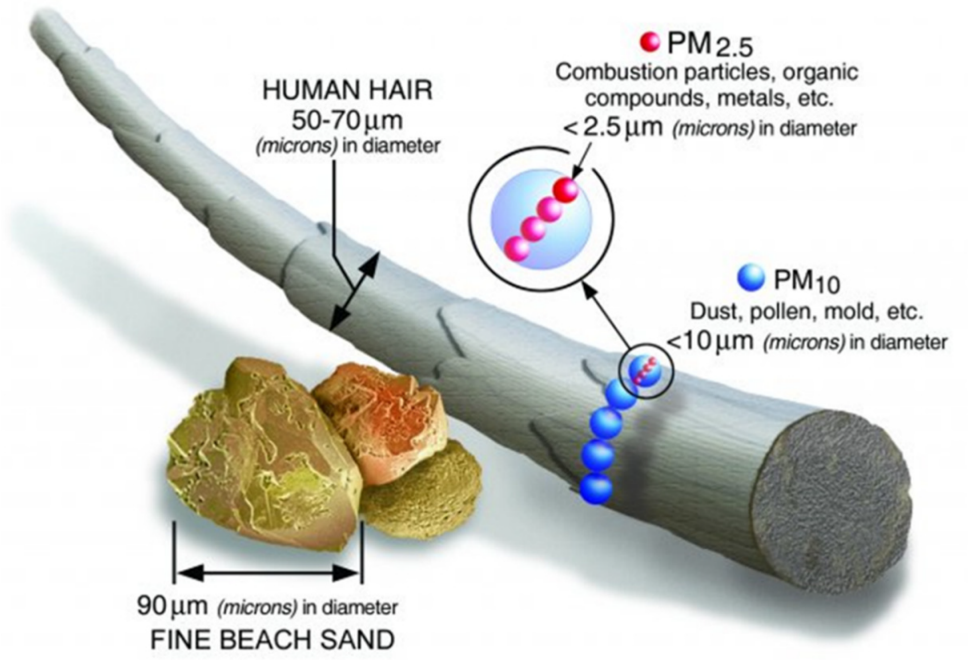


Figure 1. Comparisons of particulate matter size (PM) [43].

2.2. Ozone (O_3)

Ozone (O_3) is an important secondary pollutant that forms photochemically when organic compounds react with nitrogen oxides (NO_x) [47]. For instance, this occurs when pollutants emitted by cars, refineries, chemical plants, power plants, industrial boilers, and other sources chemically react in the presence of sunlight. Hence, the presence of heat and sunlight is highly important for its formation, shown in **Figure 2**. Children and older people with lung diseases, such as asthma, as well as people who exercise and work outside under the sun, are at high risk of O_3 exposure. Its effects include reduction in lung function, increased respiratory symptoms, and possibly premature deaths [5][47]. Additionally, it affects sensitive vegetation and ecosystems, including forests, parks, wildlife refuges, and wilderness areas, among others.

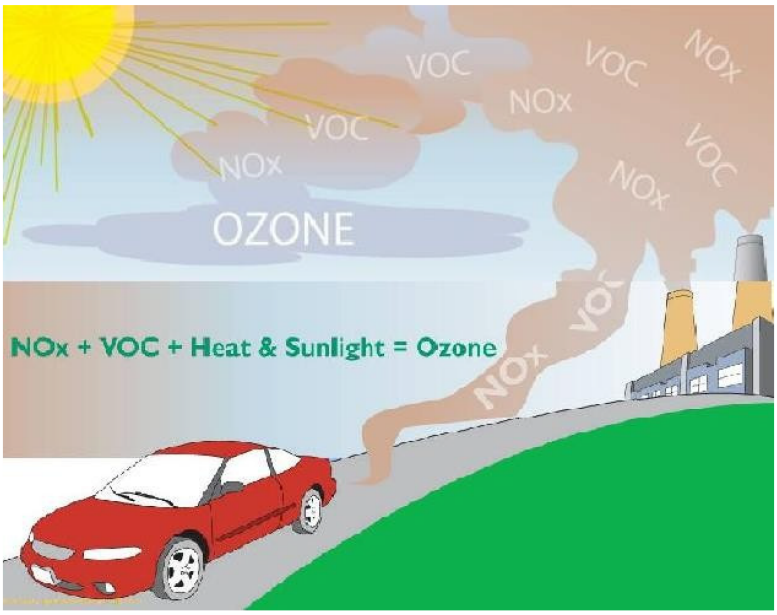


Figure 2. Formation of ozone.

2.3. Carbon Monoxide (CO)

Carbon monoxide (CO) is a colourless, odourless, and tasteless gas that is slightly lighter than air [48]. It is a by-product of combustion, present whenever fuel is burned in a limited supply of air (oxygen). CO is formed by the incomplete combustion of natural gas and any other material containing carbon, such as gasoline from vehicles, kerosene, oil, propane, coal, and wood, among others. The health risks associated with CO vary with its concentration and duration of exposure. Effects range from subtle cardiovascular and neurobehavioural effects at low concentrations to unconsciousness and death after prolonged exposure or after acute exposure to high concentrations of CO [49]. The United States Environmental Protection Agency has estimated that as much as 95% of CO comes from vehicle emissions. A high level of CO is harmful to human health because CO has a great effect on oxygen delivery to the body's organs (e.g., heart and brain) and tissues (e.g., skin) [5]. Normally, CO will cause headaches and even visual impairment. At comparatively high levels, CO can directly cause death, especially to people with heart diseases [50].

2.4. Sulphur Dioxide (SO_2)

Sulphur dioxide (SO_2) is an acidic, colourless, and poisonous gas that may remain in the atmosphere for periods of up to several weeks. It can be detected by taste and odour in a concentration that ranges between 0.38–1.15 ppm and above 3 ppm, with an irritating odour. It is estimated that 65 million tonnes of SO_2 per year enter the atmosphere because of human activities, primarily from the combustion of fossil fuels. Other possible sources include fuel-based industry, vehicle emissions, smelting of mineral ores, and refinery. Of these, energy-producing companies using coal are by far the greatest contributor. In the United States, it is estimated that almost 65% of SO_2 emissions are from coal-fired power stations [51]. The adverse effects on human health are coughing, asthma, and chronic bronchitis [52]. Effects of a high concentration of SO_2 in the environment include damage to plant

foliage, harming trees and decreasing their growth. It also contributes to acid rain, which can harm sensitive ecosystems.

2.5. Nitrogen Dioxide (NO_2)

Nitrogen dioxide is a suffocating, brownish gas: one of a family of highly reactive gases, the nitrogen oxides (NO_x). They are formed when fuel is burned at high temperatures. Nitrogen dioxide is also an irritant to humans and corrosive to metals. Scientists in the United States have observed the adverse effects of photochemical contaminants on human health, especially in urban areas [6]. However, the US EPA only regulates NO_2 because it is the most prevalent form of NO_x in the atmosphere that is generated by anthropogenic activities. Nitrogen oxides also play a significant role in the aesthetic impact, due to their ability to cause yellow-brown discolouration on buildings and vehicles. Nitric oxide is a gaseous air pollutant that is a precursor to nitrogen oxides, which react to form photochemical smog. For decades, it has been known for its adverse effects on humans and vegetation. Exposure to NO_x can affect the sensory perception function of humans, causing lung infection and respiratory problems.

3. Phytoremediation, an Eco-Friendly Management Method in Reducing Air Pollution

In the quest for an alternative eco-friendly approach, the impact of air pollutants on the biochemical, physiological, and morphological parameters of plants are being explored as a vital part of air pollution science [53]. Plants have been labelled as the lungs of cities, acting as natural biofilters in reducing air pollution through active absorption and accumulation mechanisms [54]. In urban environments, trees have been found to be suitable bio-monitors and bio-indicators of air pollution [55]. They play an important role in improving air quality by taking up gases and particles, depending on the plant's tolerance or sensitivity level [56][57][58]. Today, phytoremediation is now being considered as an alternative eco-friendly technology for removing pollutants from contaminated water, soils, and air, using plants [59][60].

Studies on the elemental composition and distribution of dust particles adsorbed on leaves and their tissues have been reported by some researchers [9][61][62]. Roadside deposition studies across the world have demonstrated that significant quantities of pollutants are deposited on plants in China [63] and India [62], which has drawn attention to gaseous pollutants, PM, and heavy metal accumulation in plants at high concentrations. Due to the ability of plants to absorb air pollutants without any adverse effect to them, several reports have proposed treating air pollutants by various plant parts as the new sustainable environmental health method [64][65][66], using various phytoremediation techniques [67].

However, the response and tolerance of plants to air pollutants vary with different behaviour patterns and tolerance. The air pollution tolerance index is employed in the world to develop appropriate environmental indicators and mitigation strategies to assess the sensitivity, response, and tolerance of plants to air pollutants, using only biochemical parameters [9][26]. Furthermore, for the reduction of air pollution using greenbelt

development in an area, the anticipated performance index (API) needs to be considered with the help of many socio-economic characteristics of the plant [68]. The API is an improvement over the APTI, which has been used as an indicator to assess the capability of predominant species in the clean-up of atmospheric pollutants.

Phytoremediation Techniques

The following technique can be used for the removal of environmental pollutants. The phytoremediation techniques include rhizofiltration, phytodegradation, phytostimulation, phytovolatisation, phytoextraction, and phytostabilisation, shown in **Figure 3** [58][67][68][69][70].

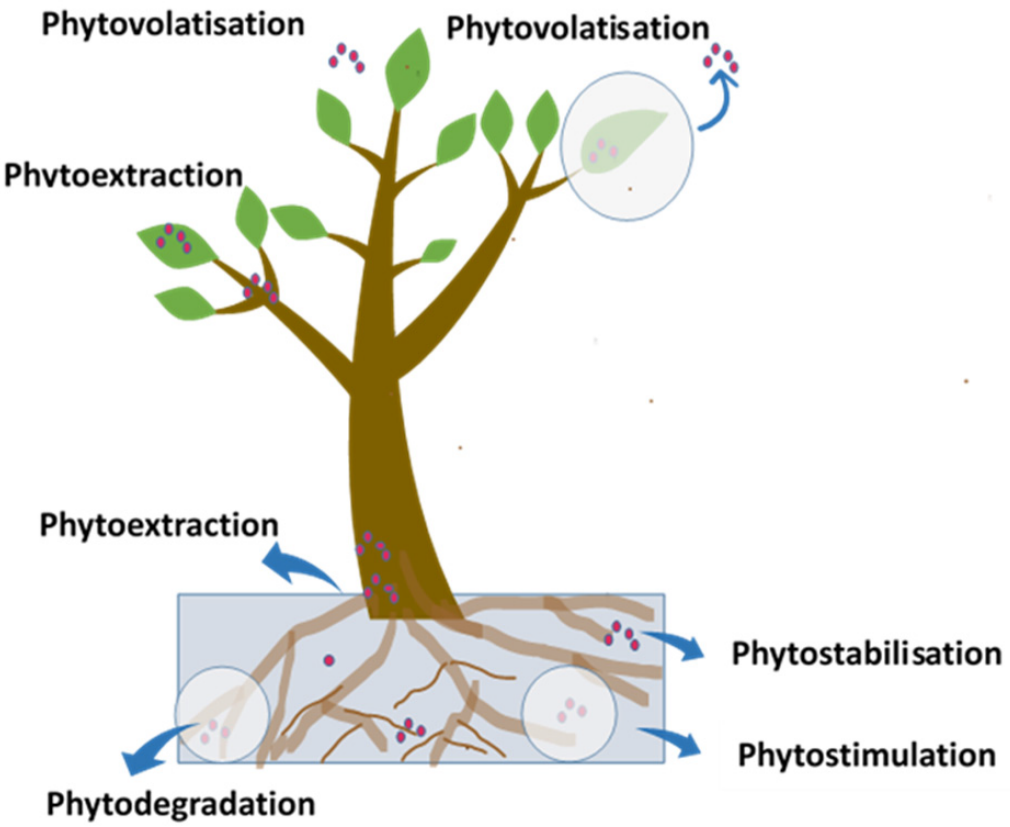


Figure 3. Schematic representation of phytoremediation techniques.

- Phytoextraction

  This is the accumulation or uptake of pollutants by the plant as they absorb water from soil and the environment, which are stored in the plant leaves, roots and shoots but are not broken down. This technology is most often applied to metal-contaminated soil and may be toxic to organisms, even at relatively low concentrations [71]. According to Kapourchal et al. [72], there was a high concentration of lead (Pb) in the soil due to continuous exposure to vehicle exhaust air pollution, and the lead was extracted from the contaminated soil using the phytoextraction method.

- Rhizofiltration

  Rhizofiltration is used basically in filtering contaminated groundwater. This is the process in which plant roots are used to take up and store contaminants (toxic substances or excess nutrients) from surface water or groundwater [71]. After the plants reach the contaminants' saturation limit, they are harvested similarly to the phytoextraction method [70]. The successive implementation of this remediation technique requires a better understanding of the plant–water interactions that control the extraction of a targeted metal from polluted water resources.

- Phytodegradation

  Phytodegradation (also called phytotransformation) is the process of breaking down harmful pollutants in plant tissues, using their enzymes after taking up and storing them for a period [71][73]. The remediation technique utilises plants and associated rhizosphere microorganisms to remove, contain or transform toxic substances or excess nutrients in soils, sediments, and groundwater, among others [73]. The transformation of organic contaminants into more water-soluble molecules enables plants to diminish the toxicity of air pollutants. This is assisted by endocytic bacteria that colonise the plant inner tissues without causing any side effects on their host (plant) [58][74]. Persistent organic pollutants (POPs) can be abated with phytoremediation techniques as reported by Erakhrumen and Agbontalor [75].

- Phytostimulation

  Phytostimulation (also known as rhizodegradation) is the technique where the plants release certain substances through their roots into the soil or groundwater. The released substances increase the microorganisms' ability to break down and destroy contaminants at a faster rate [76]. This process is critical for the applied technology of rhizoremediation that combines phytoremediation and bioaugmentation and is effective for the removal of organic contaminants in soils [58].

- Phytovolatisation

  This is the technique where pollutants are uptaken by the plants from the soil, and then converted into a volatile form and then released into the atmosphere [67][71]. This means that the contaminants present in the water taken up by the plant pass through the plant or are modified by the plant and are released to the atmosphere (evaporates or vaporises). In the case of air pollution, phytovolatilisation occurs when pollutants are diffused into the phyllosphere of plants, where the toxicity of pollutants may be lowered before being transformed into a volatile component in the atmosphere [77].

- Phytostabilisation

  Phytostabilisation is defined as the immobilisation of contaminants in the soil through accumulation and absorption by roots, adsorption onto roots, or precipitation within the root zone of plants. This is used in the

treatment of soil, sediments, and sludges [76]. Particulate matters as well as carbon dioxide (CO_2) are absorbed by plants through their foliage and shoots and accumulate in the phyllosphere, then phytostabilise and immobilise in the wax layers of the plants [58][70].

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