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Effects of Air Pollutants on Plants

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Abstract

Many anthropogenic reasons have triggered air pollution, which is growing rapidly at a global scale in the recent Anthropocene era of rapid industrialization and urbanization. It causes multi-dimensional effects on every single living creature of the earth to a great extent. The authors of the present paper have highlighted its effects on plants. Air pollutants are harmful to plant growth by interfering with resource accumulation. The plant leaves when exposed to the atmospheric pollutants in the form of O_3 and NO_x, SO_2, SPM, CO_2, etc affect the metabolic function of the leaves and consequently lead to carbon fixation by the plant canopy. Generally, the plant part above the ground is more likely to be affected by the air pollutants, and this part is of more economic importance, required to sustain dietary requirements, but it affects little the root part also. Moreover, the pollutants cause damage to cuticular waxes by which entering the leaves through stomata. The air pollutants may cause small changes in stomata which may have serious consequences concerning the survival of the plant. Besides, these effects can further lead to disturbing the water balance of the leaf or the physiology of whole plant. The present paper deals with the effect of air pollutants on plants physiology as well as on plant respiration.

Keywords: Air Pollution; Pollutants; Respiration; Morphology; Water Balance

Abbreviations: COPD: Chronic Obstructive Pulmonary Disease; VOCs: Volatile Organic Compounds; ROS: Reactive Oxygen Species.

Introduction

The prime concern for today's world is the changing gaseous composition of the earth's atmosphere. It is disturbing the availability of clean air for respiration which is required to sustain a healthy life on earth. However, the today's industrial world is unable to make it available. Fossil fuel consumption has accelerated due to the increase in the human population that triggered many anthropogenic changes, the industrial revolution, technological advancement, and unplanned urbanization, responsible to disbalance the sustainable concentration of gases [1]. The increasing number of industries and automobile vehicles are continuously adding toxic gases and polluted substances to the environment [2] which contribute to urban air pollution in both developing and developed countries [3]. These pollutants include sulphur dioxide and solid particulates sourced from the combustion of fossil fuels, soot particles, and radioactive isotopes [4]; photochemical oxidants and carbon monoxide from motor vehicles; and miscellaneous pollutants such as hydrogen sulphide, lead and cadmium emitted by smelters, refineries, manufacturing plants and vehicles [5] expected to be doubled by the middle of the next century [6]. In the recent past, plants may be injured following exposure to the higher concentration of various atmospheric pollutants. Air pollution stress leads to stomatal closure, which reduces CO_2 availability in leaves and inhibits carbon fixation [7]. Prolonged exposure to Lower concentration may also result in plant damage. The injury appears progressively as leaf chlorosis (yellowing), abscission, necrosis (death), and restricted growth and yields. However, plant damage by pollutants depends on meteorological factors leading to air stagnation, the presence of a pollution source, and the susceptibility of the plants [8].

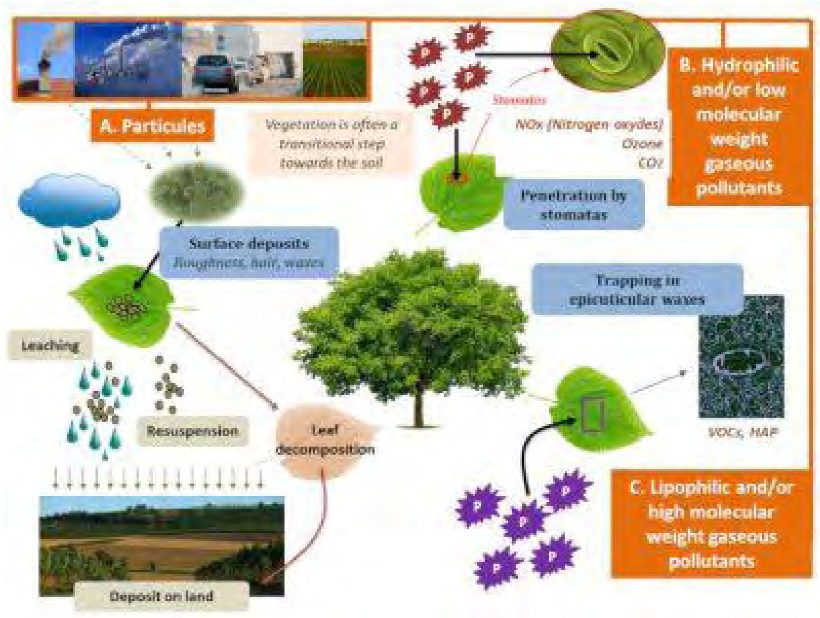

Figure 1: Ref: Encylopedie de l'environnement.

Previous researchers reported a significant reduction in different leaf variables in the polluted environment in comparison with the clean atmosphere [4]. Plants have frequently been used as bioindicators as they are stationary and often sensitive to the quality air pollutants of local environments [9,10]. Net photosynthetic rate is a commonly used indicator of the impact of increased air pollutants on tree growth [7]. The SO_2 is a widespread phytotoxic air pollutant in the environment with an ambient concentration of about 0.001 ppm in the air, which is increasing and causing damage to autotrophs [11]. Furthermore, due to their fixed life, and position, and wide distribution, are among the first victims of air pollution, and when consumed by humans, pollutants enter the food chain and affect other organisms. During high heat, they emit volatile organic compounds (VOCs) such as terpenes (one of the precursor gases of ozone). Plants also emit fine particles (pollens, spores, wax compounds, various particles) which can have negative effects on human health. The diseases occurring from the aforementioned substances include principally respiratory problems such as chronic obstructive pulmonary disease (COPD), Asthma, bronchiolitis and also lung cancer, cardiovascular events, central nervous system dysfunctions, and cutaneous diseases.

Literature Review

In urban areas, trees and other indoor and outdoor plants that owe the brunt of air pollution to them, and play a vital role in improving the air quality [1,12-15]. However, they also get negatively affected, and experience changes in important and biochemical processes of photosynthesis, respiration, carbon allocation, and stomatal function, etc. The degree of impact or interference varies greatly with specific types of pollutants, the concentration of pollutants, time and degree of exposure, plant species, soil type, weather conditions, and other factors. These pollutants are sulfur dioxide, ozone, nitrogen oxide, and hydrogen fluoride, etc. The pollutants entered into the tissue through stomata, which opens at low concentrations of air pollution, and close at injuriously high concentrations, that later inhibit photosynthesis, and cause partial denaturation of chloroplast, decrease pigment and lead to a reduction of soluble sugar and other organic substances [16]. The studies have shown the impact of air pollutants in the reduction in protein content in Cassia fistula due to the enhanced rate of protein denaturation [17], increase in the concentration of free amino acids due to more nitrate reductase activity or may also be due to more protein denaturation, increase in ascorbic acid content may be due to the more rate of production of reactive oxygen species (ROS) such as SO_{3-}, HSO_{3-}, OH^-, O_2^-, etc [18].

Sulphur dioxide and other toxic gases are rising progressively around the world, especially in developing countries due to anthropogenic stress, which are prominent phytotoxic byproducts of fossil fuel burning. Sulphur is necessary for the general metabolism of plants because it is a major component of amino acids, proteins, and some vitamins, and contributes to plant growth, and its total requirement could be met by direct uptake from the atmosphere. Its content in healthy leaves ranges from 500 to 14,000 ppm by dry weight (0.5–14 mg/g dry weight) depending upon plant species. Concentrations below 250 ppm are considered critical, giving rise to deficiency symptoms and to the substitution of selenium (when available) for Sulphur in amino acids and proteins [19,20]. Sulphur dioxide is can cause positive effects on physiology and growth when is at low concentrations, especially in plants growing in sulphur deficient soil [21].

On the other hand, if the concentration of SO_2 increases beyond a certain level, it can result in the general disruption of physiology, and biochemical processes such as photosynthesis, respiration, and other fundamental cellular processes, which simultaneously affect the economic and healthy dependence of human health and environment [22] due to accumulation of sulphite or sulphate in tissue [21,23]. Chronic injury, leaf damage in the older leaves after long exposures, caused substantial reductions in leaf area at the end of the growing period. These injuries may be related to a disturbance of intracellular pH regulation. These pollutants trigger the immune system of plants and help them to sustain themselves and other dependent organisms like humans, from these pollutants. Such as the free radical production under SO2 exposure would stimulate the transcription and translation of genes that encode enzymes involved in primary protection mechanisms of plants.

In Arabidopsis, these enzymes, or the free radical scavengers include superoxide dismutase (SOD), glutathione S-transferase (which catalyzes detoxification reactions involving glutathione), and phenylalanine ammonia-lyase (an important enzyme at the start of the phenylpropanoid pathway that leads to the synthesis of flavonoids and other phenolics). In environmental stress conditions, the plant also increases the concentration of reactive oxygen species (ROS), which is then converted to hydrogen peroxide (H_2O_2), a signaling molecule, which regulates the expression of the gene, and plays versatile roles in normal plant physiological processes and resistance to stresses.

Effect of Pollutants on the Plants

Pollutants affects the plants differently according to the sensitivity, specific types of pollutants, the concentration of pollutants, time and degree of exposure, plant species, soil type, weather conditions, and many other factors [4]. These pollutants could enter the plant directly via leaves or indirectly via soil acidification [24,4]. The pollutants could affect the morphological parameters, the mechanism of structure and function of stomata and cuticle, uptake of pollutants, deviation on water balance, and respiration of plant by altering the metabolism of plant; these will be discussed in the paper. Beside this pollutants also cause leaf injury, stomatal damage, premature senescence, decrease photosynthetic activity, disturb membrane permeability and reduce growth and yield in sensitive plant species [25,7]. The increased concentration of atmospheric pollutants such as SO_2 attacks the morphology and physiology of plant, and cause injury to leaves, damage stomata, premature senescence, disturbed permeability of membrane, reduced growth, and deceased photosynthetic activity would further decrease the production [7].

Entry and Effects of Pollutants on Plants

In this section we will discuss the uptake of pollutants via stomata and cuticle, and the effects of these pollutants to the physiological and biochemical parameters of plants:

Uptake of pollutants: Evidence exists that vegetation may play an important role in cleansing certain toxic air pollutants from the atmosphere [16]. The leaf is most susceptible due to presence of abundant stomata, which allow the pollutants to enter the leaf tissue. The boundary layer resistance is first barrier of gaseous pollutants, and the entry requires many other factors such as wind speed, temperature, pollutants shape and size, orientation of leaves [26]. Organic pollutants, environmental pollutants, or other agriculture pollutants are taking up by plants through roots and leaves. The HF, SO_2, NO_2 have very high absorption or displacement rate, however the displacement of NO is too slow in comparison to other gaseous transport and degree of effects it cause to internal profile substantially. The O_3 is deposited on the surface beside penetrative the inner cells. The pollutants enter the leave more often in high wind speed, and the boundary resistance decreases [16]. The plants that have waxy cutile can prevent most pollutants, but mostly epidermal cells are exposed to air pollution. Although, some gases which are acidic in nature could penetrate the cuticle by dissociating cuticle [27].

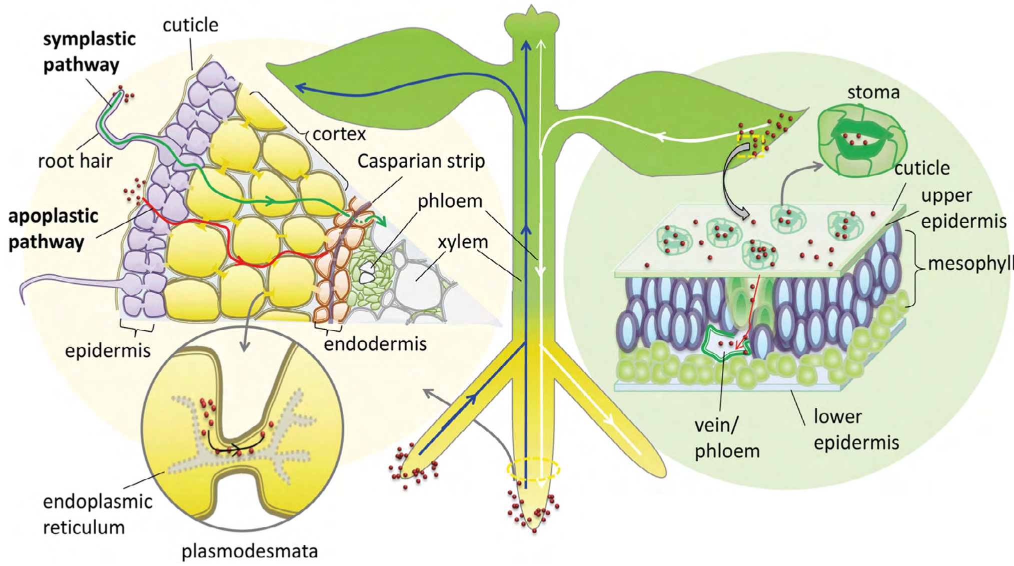

Figure 2: Cuticle and stomata are the main barrier between the interior of the leaf and the external environment.

Effect on cuticle and stomata: Cuticle and stomata are the main barrier between the interior of the leaf and the external environment [12]. The impacts of air pollution on stomata and cuticles are too complex to be summarized concisely [13]. Stomata regulate gaseous exchange between the plant and environment and transport of gases through the intact cuticle occurs by diffusion. Stomatal responses to air pollutants vary among plant species and with concentration, environmental conditions and age of the plant [28]. The response of plant species differ due to a wide range of environmental pollutants, and the vast majority of these works allude to physiological modifications like stomatal and epidermal cell size, lower recurrence, thickening of cell wall, epicutical wax deposition alterations, chlorosis and trichomes are among the auxillary alterations in leaves [29]. Distorted shapes of stomata observed in *Pongamia pinnata* populations exposed to exhaust pollution might have resulted due to lowering of pH in the cytoplasm of guard cells and thus change in the turgor relations of the stomata complex [30] due to physiological injury within the leaf [31]. Many atmospheric pollutants, even when present at relatively low concentration, may interfere with the control of stomatal aperture, and they thus have the potential to upset the water balance of the leaf or to the whole plant. Although at high concentrations pollutants usually cause stomatal closure, at low concentration stomatal conductance is often increased [2]. Sulphur dioxide and acid deposition affects and degrade of cuticular waxes has been seen in species such as Scots Pine [32]. Sulphur dioxide enters the leaves mainly through stomata and the resultant injury is classified as either acute or chronic. Acute injury is caused by absorption of high concentration of SO2 in a relatively short time. The symptoms appear as 2-sided lesions that usually occur between the veins and occasionally along the margins of the leaves. Chronic injury is caused by long-term absorption of SO_2 at sub-lethal concentrations [33].There is no doubt that both oxidative stress and SO_2 affect stomatal guard cells directly [34]. Effects of ozone and oxidative stress are equally complex. Short term exposure to ozone stimulates a rapid reduction in stomatal aperture, whilst longer term exposure causes stomatal responses to become sluggish. The response of stomata to abscisic acid (ABA) has been shown to be slower in plants exposed to a combination of SO_2 and NO_2 suggesting an adverse effect on guard cell ABA signal transduction. There is an increasing body of evidence to suggest that air pollutants and oxidative stress can have a marked effect on the Ca^{2+} homeostasis of guard cells and the intracellular machinery responsible for stomatal movements [28]. Rahul and Jain [5] have reported that dust particles of a range less than 5 mm in diameter can interfere with the mechanism of stomatal pores. The first detoxifying layer which represents the antioxidant system found in the cell (apoplasm + symplasm) at the time of Ozone attack will scavenge ozone and its derivatives. In Foi vegetation two ozone deposition pathways act in parallel, first ozone is deposited on plants surfaces such as on their cuticles or twig and stem surfaces. Second, ozone can enter the plants stomata reach the sub-stomatal cavity and thus impact photosynthesis and other physiological process.

Effect on morphology of plant: Research shows the clear evidence of slow growth in all the morphological parameters with respect to non-polluted sites [17,35,36,27,37]. Pollutants mostly affect the most sensitive part of plant that is leaf, this is the reason most important physiological processes are concerned with leaf. Therefore, the leaf at its various stages of development, serves as a good indicator to air pollutants [38]. The most affected plants were which grow close to the busy road of the city, the reason is auto-emission [38]. These environmental pollutants after making their entry through stomata, significantly affects the petiole size, leaf color, leaf length and breadth, leaf color, and leaf blade and its dimensions in *Platanus acerifolia*, and *Ficus bengalesis*, Avicenia marine [39] the reason was reduction in the gases exchange for photosynthesis due to disturbed water content of tissue, and productivity of leaf [38].

The plant species also showed significant variation in the growth of morphological parameters from season to season. Results showed that the overall morphological differences such as reductionin leaf length, width, area and length of petiole during different seasons at polluted sites with respect to those of non-polluted sites were found maximum during, followed by autumn and lowest was recorded during spring season respectively. Results further indicated that as the plants get ages, the reduction % of various leaf attributes of polluted plants also increased. There were also evidences of increase in average dry weight of leaves due to accumulation of pollutants. One way to increase tolerance in contrast with stress is to balance the water content of tissue by decreasing the leaf area, as defense mechanism [7]. These changes help plants minimize stress and maximize use of internal and external resources [40].

Effect on plant water balance: Many atmospheric pollutants have the potential to upset the water balance of the leaf or the whole plant, because they can interfere with the control of stomatal aperture even when present at low concentrations. Pollutants such as SO_2 and CO_2 cause stomatal closure at higher concentrations hence control the water balance because stomata do not close sufficiently in CO_2 rich air [12]. High concentration of CO_2 and salt stress inhibit the Nitrogen assimilation process in cucumber, although this CO_2 had no effect on nitrate reduction or ammonium assimilation of leaves under salt stress, inhibit only transamination. Moreover, high CO_2 concentration increased the plasma membrane's H+-ATPase activity, vacuolar membrane H^+-ATPase activity and root hydraulic conductivity under salt stress, thereby further increase the ion selective absorption and water absorption capacity. To a certain extent, this enriched CO_2 also promote the accumulation of K^+, which significantly reduced the Na^+/K^+ ratio; and improve the water state conditions and helped to maintain the ion balance in plants under stress, ensuring normal enzymatic activity.

Effect on respiration: Plant respiration is one of the key processes in terms of an understanding of plant growth and functioning in a future climate. It is environmentally sensitive component of ecosystem for plant carbon balance. It includes dark respiration and photorespiration, could be vulnerable to pollutants attacks, as it occurs in several sites in cell including mitochondria, peroxisomes, and cytoplasm [41]. It is a vital process to supply energy and metabolites for normal metabolism and growth to plant, and also for repair and detoxification of pollutants. The plant respiration is sensitive to temperature, CO_2 concentration, protein concentration, and turnover, water stress, and the environmental pollutants. Annually increasing concentration of atmospheric CO_2 and SO_2, singly or in combination interfere with the physiological and biochemical characters in wheat (Triticum aestivum), directly affect the rate of respiration, photosynthesis, oxidative phosphorylation and photorespiration in C3 species. The increased concentration of CO_2 result in decline in dark respiration, in contrast elevated SO_2 also results in increase insignificantly in dark respiration, because a series of ATP dependent reaction leading to detoxification of SO_2 are provided by respiration. Moreover, the SO_2 increase the respiration rate, total phenolics, and total soluble sugars [22]. The O_3 doesn't affect respiration in photosynthetic tissues unless plants were exposed to pollutant concentration which leads to appearance of visible injury. This was reported by Todd and Garber, 1958 [42] in Pinto Beans and on citrus leaves, however greater the stimulation, more complete was the recovery after fumigation. However, the changes in mechanism, independence from changes in protein content, and acclimation are unknown.

Respiratory response to high concentration of pollutants: Energy is utilized in the repair processes resulting in increased rate of respiration in the tissues which are not damaged (a, f) Loss of energy occurs due to increase in respiration rate in response to high concentration of pollutants. The damages occurred are proportional to the periods of exposure. If exposure period is not long, physiological processes are altered but no major damages occur. Vice versa, if exposure time is long enough, the effects may result in reductions in growth pattern in the long run [43]. Several experiments with elevated CO_2 levels have indicated reduction in respiration and stimulation of photosynthesis resulting in growth and productivity of the plants [11]. In CO_2 enriched conditions, the amount of carbon fixed becomes greater than the carbon lost, resulting in enhanced growth and productivity.

When plants get exposed to high concentrations of various air pollutants, injury ranges from visible markings on the foliage, to reduce growth and yield, to premature death of the plants [44]. When plants are exposed to high atmospheric CO_2 has affected almost all crucial biological processes, including photosynthesis, respiration and antioxidant systems as well as other key secondary metabolisms in plants. Once SO_2 enters through stomata, the route to the surface of a nearby subsidiary or epidermal cell is very short and therefore, the cells of the epidermis are most susceptible. The detrimental effects of SO_2 occur due to reactions under liquid phases after uptake in the plants [45]. Under chemical reactions, its produce reactive oxygen species (ROS), which adversely affect biochemical process of plants and reduce their tolerance capacity to other stress also [46]. Gaseous oxides of nitrogen at high concentration of Pollutants may reduce the stomatal conductance [47]. Ozone leads to inhibitory effects on photosynthesis, translocation and accumulation in different plant parts. Air pollutants produce reactive oxygen species (ROS), which adversely affect biochemical process of plants and reduce their tolerance capacity to other stress also [46].

Respiratory response to low concentration of pollutants: When plants are exposed to very low pollutant concentrations they may show no physiological responses or alternatively, may exhibit small physiological disturbances. These are usually reversible and do not necessarily lead to reduced growth or dry matter production [16]. At low concentration of phytotoxic gases have been shown to stimulate the growth and physiological responses [21].

Effect of pollutants on photorespiration: Photorespiration is the light-dependent release of CO_2 that is sensitive to the O_2 concentration. Indeed, it is a wasteful process, pollutant-induced effects may be beneficial to the growth of the plants because, in the short term, the rates of net photosynthesis will increase [41]. The SO_2 drastically reduce or completely abolish the rate of photorespiration. However, increased CO_2 decrease photorespiration which may accompany to reduce the activities of photorespiratory pathway enzymes [48]. The double concentration of CO_2 photorespiration would reduce to half, was sustain to most of the seasons in soybean that might contribute to increased growth and yield [48]. The products of glycolate metabolism that is amino acid Glycine and Serine are accumulated in cell, and their level is influenced by CO_2 concentration [49].

The leaf tissue of Arabidopsis thaliana unable to convert glycine to serine, and elevated CO_2 decrease the concentration of glycine, which are important precursors of many biosynthetic pathways of plant [50]. Net photosynthesis and photorespiration were suppressed 30% and 41%, respectively, by elevated O_3 during late reproductive growth in the ambient CO_2 treatment, but not in the elevated CO_2 treatment. Activities of glycolate oxidase, hydroxypyruvate reductase and catalase were decreased 10-25% by elevated CO_2, and by 46-66% by elevated O_3 at late reproductive growth. The inhibitory effects of elevated 03 on photorespiration-related parameters were generally commensurate with the 03-induced decline in A. The results suggest that elevated CO_2 could promote productivity both through increased photoassimilation and suppressed photorespiration.

Changes in respiration in association with photosynthesis: The plants perform photosynthesis at very high rate, so a small change can't affect carbon balance of plant significantly. However, if the rate of photosynthesis is already low, the changes in respiration can lead to change in growth and yield of plant [43]. If the environment is rich in pollutants, and the light and temperature are limiting the plant photosynthesis will reduce severely. The effects of enriched CO_2 and O_3 on photosynthesis and photorespiration are mediated in part through a common enzyme, ribulose-l,5-bisphosphate carboxylase/oxygenase (Rubisco) [21]. Carbon dioxide and O_2 are competitive substrates for Rubisco, and their partial pressures affect the rates of ribulose-1,5- bisphosphate (RuBP) carboxylation and oxygenation [19]. When there is increase in atmospheric CO_2 concentration, it promotes photosynthetic carbon reduction over photorespiratory carbon oxidation. Ozone enrichment suppresses photosynthesis as it decreases Rubisco activity and content [34]. The photorespiration would be expected to decline if Rubisco activity decreased, although its relative sensitivity to O_3 is unknown [51-54]. The high concentration of SO_2 could reduce photosynthesis rate. This may lead to premature leaf drop, senescence. Pieces of evidence are there to show the response to pollutants from the non-photosynthetic portion of the plant such as roots. And reduction in the activity of root will have consequences not only upon root growth but also for the whole plant if the plant is growing in a stressful environment [55-57].

Conclusion

Plants and vegetation act as a scavenger to remove or absorb some amount of air pollution present in the ambient air [58-60]. However, extensive research with proper validation needs to be taken up and encouraged to identify the type of plants which can absorb maximum air pollution. More research is to be initiated in respect of dose effect relationship between different air pollutants and category of plants [61]. A comprehensive database needs to be developed in respect of such research for making the public aware and decision makers to act [62]. The urban planners and related developmental authorities should effectively plan and implement green urbanism using plants having maximum scavenging capacity to address the problem of air pollution. The authors of the present paper have reflected some issues to make the concept popular.

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