



MAJOR AIR POLLUTANTS AND THEIR EFFECTS ON PLANT AND HUMAN HEALTH: A REVIEW

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Abstract

Globally, outdoor air pollution is causing environmental and health issues. It is more challenging mainly in developing countries. Recent reports of World Health Organization (WHO) show about 4.2 million premature deaths due to ambient air pollution. Air pollution is a mixture of many pollutants viz. gases, liquids, airborne heavy metals and particulate matter. These pollutants have become major environmental risk for plant health in the form of suspended particulate matter, surface ozone, sulphur dioxide, nitrogen oxides, etc. Among these pollutants, sulphur dioxide and nitrogen oxides both react with water and create acid rain. The acid rain kills off many plants and animals where it falls. Foliar dust causes reduction in photosynthesis and finally retards the plant growth. These pollutants also affect human health by influencing the quality of the air we breathe and most commonly cause irritation in the upper respiratory tract, resulting cough and breathlessness. These also prove major factors in exacerbating existing respiratory diseases such as asthma and chronic obstructive pulmonary diseases. The relationships between air pollution and increased incidence and severity of respiratory and cardiovascular diseases are well supported by epidemiological, toxicological and clinical studies. Air pollution poses a serious public health concern. Significant approaches are required to improve air quality and to reduce the negative impact of airborne pollution on human health. The aim of this review article is to provide information about the adverse impact of air pollution on plants and human health and also to extend recommendations to policy makers for making necessary actions to reduce exposure to this risk factor.

Key words: Air pollution, plant health, human health, respiratory diseases.

Introduction

Air pollution has become a major environmental risk which has a harmful impact on all kinds of life. Ambient air pollution is caused not only by human activities but also by natural phenomena such as volcano eruption, forest fires, wind erosion and pollen dispersal etc. (Vallero, 2008). In human activities, different emission sources contribute to the air pollution, but automobile engines and industrial activities are the major part. There are strong evidences which prove that major air pollutants such as particulate matter (PM), ozone (O₃), nitrogen dioxide (NO₂) and sulphur dioxide (SO₂) show very harmful effects. In India, the level of air pollutants has increased up to the highest level. India is among the world's most polluted country. Eleven of the top twelve most air-polluted cities of the world are in India, out of which Kanpur, Varanasi, Lucknow and Agra belong to Uttar

Pradesh. Kanpur tops the list with an yearly average of 319 µg/ m³ of PM₁₀ (WHO, 2018).

Air pollutants create harmful effects on plant health. Leaf is most susceptible plant part because they are the primary acceptors of air pollution. The air pollutants causes significant changes in foliar morphology (Ekpemerechi *et al.*, 2014; Tiwari 2013), reduction in root growth and changes in the pattern of translocation (Kasana and Mansfield 1986). Present air concentration of O₃ has considerable negative impact on crop productivity (Ghude *et al.*, 2014), reduction in the rate of photosynthesis (Ainsworth *et al.*, 2012). Due to high reactive nature of O₃, it actively participates in reactive oxygen species (ROS) formation. The ROS causes oxidative stress resulting into serious damage to DNA, protein and membrane lipids (Saxena *et al.*, 2016). Roadside dust causes leaf surface injury. Dust deposition

causes clogging of stomata also which results into poor gaseous exchange, decrease in carbon assimilation and reduction in plant growth (Sett 2017). Increased concentration of air pollutants is associated with a delay in spring phenology which affects the CO₂ uptake via stomata and the start of pollination which is crucial for human health when allergenic plants are taken into consideration (Jochner *et al.*, 2015).

Air pollutants are the major environmental risk factors in the incidence and progression of many diseases in human beings. With the decline in air quality, the risk of stroke, heart diseases, lung cancer, and chronic and acute respiratory diseases such as chronic obstructive pulmonary disease and asthma is increasing in human population. Air pollution causes millions of death globally each year. Approximately 91% of the world's population is living in places where air quality is exceeding WHO guideline limits. Ambient air pollution contributed 7.6% of all death in 2016 and accounts for an estimated 4.2 million deaths every year due to chronic respiratory diseases, lung cancer, stroke and heart diseases (WHO, 2018).

Apart from affecting plant and human health, air pollutants also cause serious damages to soil, air, ground water and species diversity (Ghorani-Azam *et al.*, 2016). Acid rain which is formed due to reaction of SO₂ and NO₂ causes damage to our historical buildings and vegetation (Bashkin and Radojevic, 2003). Global warming is due to emission of greenhouse gases and temperature inversions are additional impacts of air pollution (Ghorani-Azam *et al.*, 2016).

Major air pollutants and their sources

Atmospheric PM, surface O₃, SO₂, NO₂, Carbon monoxide (CO) and lead (Pb) are the major air pollutants (US EPA, 2014). PM is the complex mixture of solid and liquid particles suspended in the air. They may be formed either from naturally or as a result of human actions. Forest fire, suspended dusts in air and pollens are the natural origin of PM, where as combustion of fossil fuels in automobile vehicles and coal-fired power-generating plants are the source of anthropogenic PM. They are described as ultrafine, fine, coarse and super-coarse depending on their aerodynamic particle diameter ranging from ≤0.1 μm to >10 μm. Construction sites, road dust, etc. leads to the formation of coarse particles whereas burning of fossil fuel and automobile emissions are responsible for the formation of fine particles. Particles which have aerodynamic diameter ≤10 μm are known as PM₁₀ and are inhalable while the particles having aerodynamic diameter ≤2.5 μm are called PM_{2.5}. These PM_{2.5} are very small and easily cross into the pulmonary

and circulatory system (Ghorani-Azam *et al.*, 2016; US EPA 2016c; Laumbach and Kipen 2012; Nelin *et al.*, 2012).

O₃ is a colorless gas in two layers around the earth. Near the earth surface at 0-10 Km (troposphere) it works as pollutant and is called bad ozone, it is a major part of smog. In the upper atmosphere at 10-40 Km from earth surface (stratosphere) it functions as a protective layer and is called as good ozone, which filters out the harmful ultraviolet rays coming from the sun. In troposphere, O₃ is formed by the reaction of nitrogen oxides (NO_x) and volatile organic compounds (VOC) in the presence of sunlight. NO_x come from the burning of fossil fuels while VOC are emitted from natural sources and also due to anthropogenic activities (US EPA 2016c; Cacciottolo 2013; Sierra-Vargas and Teran 2012; Harmens *et al.*, 2011).

NO_x + VOC + Heat and Sunlight → Troposphere O₃ (Bad ozone)

NO₂ is a reddish brown gas. It is a traffic related air pollutant, so mainly emitted from automobile engines and also from power plants due to burning of fossil fuel coal. It is formed when nitrogen in the air reacts with oxygen. SO₂ is a highly reactive colorless gas and is produced due to volcanic activities, and burning of coal in locomotives or in coal operated power plants. CO is a colorless, odorless gas formed due to incomplete combustion of carbon. In limited supply of air, when hydrocarbon fuels such as natural gas, petrol, diesel etc. are burned, only half as much oxygen combines with the carbon atom, CO is formed (US EPA 2016d, 2016b; Thompson 2005).

Emission of Pb is different from one place to another. Major sources of lead in the air are ore and metals processing factories, Pb smelters, Pb-acid battery manufacturing sites, waste incinerators and vehicles operating on leaded fuel. In the beginning of 1920, tetraethyl lead (TEL) an organo-lead compound was used as a petro-fuel additive to reduce the knocking and increase the efficiency of petrol (gasoline) engines which cause Pb pollution in the air after emission from engine exhaust. Due to EPA's (US Environmental Protection Agency) regulatory guidelines, the removal of TEL from motor vehicle gasoline, levels of Pb in the air decreased by 98% between 1980 and 2014 (US EPA 2016d).

Health hazards of air pollutants on plant and human life

As plant leaves are the first receptor for PM pollutants of the surrounding atmosphere, they damage the leaf surface by interacting it. PM pollutants effect the plant at morphological, physiological and biochemical levels

(Rai 2016). Deposition of dust on foliar surface causes reduction in plant growth by interfering gaseous exchange through stomata (Sett 2017), reduction in leaf area and number due to decrease in leaf production rate and increase in senescence (Seyyednejad *et al.*, 2011). Alkaline dust from cement factories enter the leaf through stomatal openings and disturb the physiological processes of plants such as the reduction in photosynthesis, plant growth, hormonal imbalance and late flowering (Jochner *et al.*, 2015; Farmer 1993; Armbrust 1986). Oil content in mustard plants (*Brassica campestris*) has been found to be reduced when treated with cement dust (Shukla *et al.*, 1990).

PM pollutants reduce photosynthetically active radiation (PAR) and increase the leaf temperature (Naidoo and Chirkoot 2004; Eller 1977). There is decrease in leaf blade area due to dust and SO₂ pollution (Jahan and Iqbal 1992). The epi-cuticular wax is a sign of plant health (Neinhuis and Barthlott 1998), it function as an obstacle between the plant and road dust. Deposition of road dust causes degradation of this epi-cuticular wax and promotes change in leaf wettability (Saneoka and Ogata 1987). PM from stone dust causes necrosis, brown and yellow patches on foliar surfaces. PM stress tolerant plants showed thicker epidermal cells and longer trichomes. Elements present in PM pollutants may be taken up into leaf through stomata which reduces the ability of the plants to cope up with drought and frost conditions (Saha and Padhy 2011; Shanker *et al.*, 2005).

SO₂, oxides of nitrogen and O₃ gas pollutant produce oxy-radicals in plant (Sakaki *et al.*, 1983; Shimazaki *et al.*, 1980). These oxy-radicals disrupt the cell organelles membranes and reduce the amount of chlorophyll pigments (Khan and Malhotra 1982; Sakaki *et al.*, 1983). SO₂ and NO₂ gases may decrease the rate of photosynthesis and change the gaseous exchange in the leaves of the species of woody plants when work together (Freer-Smith and Taylor 1992).

In long term, O₃ may affect food security by causing reduction in carbon assimilation and promoting deforestation (Fares *et al.*, 2013; Wilkinson *et al.*, 2012). Model based studies on tree physiology suggest that the effects of O₃ on stresses change the competitive interactions among species and species composition of the forest (Grulke and Heath 2019). Poplar clones exposed to O₃ cause change in membrane integrity due to O₃-induced oxidative damage by the formation of superoxide anion radical (Podda *et al.*, 2019). A global meta-analysis and response relationship study on poplar plant represented that high level of O₃ can significantly reduce the CO₂ assimilation rate, total biomass, plant

height and plant leaf area (Feng *et al.*, 2019).

CO functions as an anesthetic by reducing sensitivity against external stimuli in plants (Zimmerman *et al.*, 1933). A South Korean study suggests that CO, NO_x and SO₂ caused reduction in photosynthesis and increase the level of ROS production in the form of O₂ and H₂O₂ in strawberry (*Fragaria x anansa*) plants (Muneer *et al.*, 2014).

High levels of Pb, Cu and Cd disrupt the flow of electron in light reaction and inhibit the assimilation of CO₂ in Calvin Benson cycle in the leaves of cucumber (*Cucumis sativus*) (Burzyński and K³obus 2004). Foliar entry of Pb is very less and Pb mainly enters through the roots via apoplast pathway or by calcium-ion channels in exposed plants. After accumulation it retards the seed germination, root elongation, chlorophyll biosynthesis and many other physiological activities. Pb toxicity in plants depend on the concentration of Pb, exposure duration and the stage of plant development. Its toxicity is mainly due to formation of reactive oxygen species (ROS) which causes oxidative stress and DNA damage (Pourrut *et al.*, 2011).

The PM are small enough to penetrate the capillaries present in lungs and enter into the blood circulation causing serious lungs and heart diseases (US EPA 2016a; Cacciottolo 2013; Sierra-Vargas and Teran 2012). The harmful effects of PM depend on their size and composition, duration of exposure, age, gender, and sensitivity of the exposed person. Exposed person to these PM show most prevalent clinical symptoms of burning eyes, dry mouth, sore throat, persistent cough, wheezing, chest tightness and limited physical activities due to breathing problems (Bentayeb *et al.*, 2013). PM may be responsible for asthma or premature death in aged peoples with pre-existing disease such as chronic obstructive pulmonary disease (COPD) or tuberculosis (TB) (Ostro *et al.*, 2011; Künzli and Tager 2005). Outdoor active people are at higher risk because increase physical activity leads to inhalation of more PM containing air in the lungs (Carlisle and Sharp 2001).

Troposphere O₃ causes a number of health hazards. It is a powerful oxidizing agent. Along with irritation of the respiratory tract it also reduces lung function and is responsible for frequent asthma attacks, cough and breathing problems in asthmatic people. More physical exercise, increase the effect of O₃ exposure. Patients with respiratory diseases are more susceptible to the effects of O₃ (Amâncio and Nascimento 2012). In hot weather, O₃ exposure may lead to asthma exacerbations which may even lead to premature death due to oxidation

of air pollutants. Road-side pollutants may trigger the release of allergens from pollen and increase the concentration of airborne pollen allergens (Gorai *et al.*, 2014). In hot weather, increased levels of O₃ and PM cause a higher prevalence of respiratory allergic reactions. The double bonds present in cell membrane fatty acids are unstable. O₃ has strong oxidizing nature. It combines with these bonds and convert them in to lipo-hydro peroxides, aldehydes and hydrogen peroxide which changes the membrane integrity. It also damages the DNA and results into impaired cellular function (McCarthy *et al.*, 2013; Lippmann 1989).

NO₂ may irritate deep in lung and induce pulmonary edema. Epidemiologic studies demonstrate the effects in the form of eyes, nose, throat irritations, headache, dyspnea, chest pain, broncho spasm and pulmonary edema at higher concentration. A high level of NO₂ exposure causes coughs and breathing difficulty by inducing more mucus secretion. Long time exposure of NO₂ is associated with a higher chance of getting respiratory infections (Kim *et al.*, 2018; Ghorani-Azam *et al.*, 2016).

Presence of SO₂ in air affects those people who already have asthma or emphysema. It makes them more difficult to breathe. It also causes irritation in eyes, nose and throats. SO₂ destroys our vegetation and buildings, and make difficult to see long distance objects. A high level of SO₂ aggravates the existing cardiovascular disease. The inhalation of SO₂ is more into the lungs during mouth breathing as compared to the normal nasal breathing. After deposition of SO₂ on surface lining of airways, it dissolves into sulfite or bi-sulfite and which get distributed throughout the body. In the form of sulfite or bi-sulfite it activates sensory receptors of airways and causes constriction of bronchi. SO₂ is readily soluble in water which results into acid rain formation and soil acidification. Presence of SO₂ in water reduces the amount of dissolved oxygen and causing death of aquatic life. SO₂ exposure also causes redness and blisters on skin (Chen *et al.*, 2007; Dodge *et al.*, 1985).

Breathing in an enclosed environment with increased level of CO, decreases the amount of O₂ in blood. This low oxygenated blood reaches to brain and heart which may cause dizziness, confusion, unconsciousness and finally death. In an open place, very high level of CO is not likely to occur. But under intensive physical activity or increased stress, CO may result in low supply of O₂ to heart which is accompanied by chest pain or angina (Ghorani-Azam *et al.*, 2016; US EPA 2016e).

Pb enters the body by inhalation of Pb particles generated by burning of Pb containing materials. After

entering in the body, it is distributed to brain, kidneys, liver and bones. Pb is stored and accumulated over time in the teeth and bones. From bone, it is remobilized into the blood during pregnancy and enters into the foetus. Undernourished children absorb more Pb and are 4-5 times more susceptible to Pb poisoning as compare to the adults. In adults, Pb causes increased risk of high blood pressure and kidney damage. In pregnant women, high levels of Pb can cause miscarriage, premature birth, low birth weight and stillbirth. In children, high level of Pb affects brain development resulting in low intelligence quotient (IQ) and mental retardation which are believed to be irreversible (Ghorani-Azam *et al.*, 2016; US EPA 2016d. WHO Lead poisoning and health 2018).

Conclusion and Recommendations

Air pollution has an environmental problem worldwide. In this review article the effects of major air pollutants on plant and human health have been discussed. Evidence from the research studies indicate that the plants growing in polluted environment are likely to show significant changes in their physiological processes such as photosynthesis, transpiration, respiration and growth as well as harmful changes in the leaf morphology. Air pollution exposure to children and healthy people increases the risk of asthma, respiratory infections, COPD and cardiovascular diseases. In elderly people and persons with pre-existing respiratory or cardiovascular diseases, air pollutants are responsible for premature death. Outdoor active people are at greater risk due to inhalation of air pollutants in their lungs.

Thus, action to reduce the pollutants in ambient air is very important particularly in the lower-middle income countries like India. Monitoring and reduction in the generation of air pollutants should be on the top priority of the government. Proper urban planning, introduction of eco-friendly vehicles that emit very less amount of harmful exhaust should be preferred. Introduction and implementation of new environmental laws are few promising approaches for reducing the air pollution.

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