3 Primary Criteria Air Pollutants: Environmental Health Effects

Abstract

A polluted air is a harmful complex combination of primary and secondary pollutants in the atmosphere. The US Environmental Protection Agency (USEPA) listed the six most common air pollutants as criteria air pollutant under the Clean Air Act. The primary criteria air pollutants (CO, SO_2, NO_2, PM and Pb) are released into the atmosphere directly from their emission source. Due to their highly reactive nature, they get easily participated in a variety of reactions during atmospheric chemical transformation reactions. Due to the dry and wet deposition process, they may easily settle down onto ground/vegetation/ ecosystems/water surfaces/building materials and show negative impact on their health/life/durability/beauty. The primary criteria air pollutants also produce adverse health effects to human being after their short-term/long-term exposure. Asthma, bronchitis, lung cancer and cardiopulmonary problems are the major noticed due to inhalation exposure of these pollutants. Mental disorder, kidney disorder and abortion are other harmful impacts. The WHO reported the level distribution and harmful effects of air pollutants several times in the past few decades. The direct and indirect effects of criteria air pollutants in changing climate are also discussed.

Keywords

Air pollution · Human health · Atmospheric processes · Impacts

3.1 Introduction

The Clean Air Act (CAA) of 1970 identified six common air pollutants of concern, called criteria air pollutants, viz. particulate matter, tropospheric ozone, carbon monoxide, nitrogen dioxide, sulphur dioxide and lead. The previous chapters of this book already discussed about the sources, level distributions, atmospheric chemistry and sinks of these criteria pollutants. As per the origin/emission, criteria

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pollutants are categorized into primary and secondary air pollutants. Primary pollutants are released directly into the atmosphere from their respective sources, whereas the secondary pollutants formed through atmospheric transformation reactions in participation either with primary air pollutants or other chemicals in the atmospheres. The primary criteria pollutants include particulate matter (PM), tropospheric ozone (O_3), carbon monoxide (CO), sulphur dioxide (SO_2), nitrogen dioxide (NO_2) and lead (Pb). Several governmental and nongovernmental agencies have discussed about the burden of primary air pollutants in the atmosphere; they had also discussed about the environmental health impacts due to their increasing levels across the world especially in developing nations. The rapidly growing population, urbanization and industrialization are the most significant factors for degrading the air quality particularly in Asian countries. Urbanization is a significant factor for the increase in air pollution in many cities in Asia, Africa, the Near East and Latin America (Ashmore 2005). In the year 1960, less than 22% of developing world's population was urban, and the increment is 34% by 1990. As per extrapolations, population is expected to increase by 50% in urban areas by 2020 (World Bank 2009). The uncontrolled use of fossil fuels in industries and transport sectors has also become the dominant source of gaseous pollutants like SO_2, NOx, VOCs, etc. and also the particulate matter. These anthropogenic activities pose a huge burden on environmental health and have several impacts such as increased mortalities and morbidities, degradation in ecosystems, impact on crops and biodiversity loss, etc. These conditions of atmospheric pollution significantly affect humans, animals, vegetation, or materials (Seinfeld 1986). The sources of air pollution already discussed in previous chapters briefly include both natural and anthropogenic sources. The natural sources can be forest fire, emissions from trees, lightning, volcanic eruptions and erosion of surfaces of rocks/minerals/buildings. On the other hand, anthropogenic sources comprise of transportation, biomass burning, industrial activities, vehicular emissions, mining, etc. (Chandrappa and Kulshrestha 2015). The exceeding levels of the criteria air pollutants in the atmosphere affect adversely both the living (plants, animals and human beings) and nonliving things (materials and buildings). Earlier the air pollution was considered as a local problem, but now it is a regional and global concern due to the application of tall stacks and long-range transport of pollutants. Remote area also suffers from large amount of pollution load and their impacts due to the transboundary movement. Apart from the urban air pollution sources, rural areas also have large amount of the pollutants into the atmosphere due to the activities such as biomass burning, crop residue burning and cooking activities using dung cake, coal and wood. The impacts of these air pollutions released from different sources not only cause mortalities but also morbidity and shortening of life expectancy. The present chapter focused on the discussion about the environmental health effects by the exposure of primary criteria air pollutants. The environmental effects include human health, acid rain, eutrophication, haze, global climate change and impacts on crops and forests.

3.2 Environmental Health Effects

Industrialization and urbanization are the major causes for the degradation of the environment. Since the last three decades, many authors explained the untold relationships between air pollution and health effects due to air pollution exposure. Most commonly discussed environmental health-related issues include acid rain, eutrophication, haze, global climate change and impacts on crops and forests. Human health is also considered under the umbrella of environmental health effects, which further includes cardiovascular diseases, respiratory (asthma and changes in lung function) and pregnancy outcome and even deaths.

3.2.1 Impact of SO_2 and NO_2 on Environmental Health

3.2.1.1 Acid Rain

Precipitation in the form of rain, hail or snow is known as acid rain. The term “acid rain” was first used in 1972 after the discovery of acid rain by Robert Smith in 1852. Broadly, wet deposition (rain, cloud water, snow, dew, hail, fog) and dry deposition (SO_2, NO_x, other acidic gases and particles) of acid compounds are responsible for the acid rain. Natural and anthropogenic sources emitted large amount of the SO_2 and NO_2 gases into the atmosphere. Both natural sources (volcano emissions, lightning and microbial processes) and anthropogenic emission sources (industrial and vehicular emissions) are the important sources of oxides of sulphur and nitrogen. Both oxides act as precursors for the sulphuric acids and nitric acids in the atmosphere. Acid rain (pH range, 4.2–4.7) is one of the leading problems of regional air pollution. It is the result of transformation of atmospheric sulphur and nitrogen emitted from different sources across the different locations throughout the world. The high level of these gases causes the high acidity. Increased combustion of the fossil fuels after industrial revolution causes acid rain. The atmospheric transformation reactions converted them into the sulphuric acid and nitric acids (Fig. 3.1).

The normal pH of the rainwater in the unpolluted atmosphere is around 5.6 due to the presence of carbonic acid formed after dissolution of the carbon dioxide (CO_2) in cloud water.

$$CO_2 + H_2O \rightarrow H_2CO_3$$

Carbonic acid further dissociates to form bicarbonate ion in the water:

$$H_2CO_3 \leftrightarrow HCO_3^- + H^+$$

Further decrease in the rainwater pH in the unpolluted area is due to the presence of the organic acids. Moreover, the formation of the sulphuric acid and nitric acid in the atmosphere is a result of oxidation of the SO_2 and NO_2.

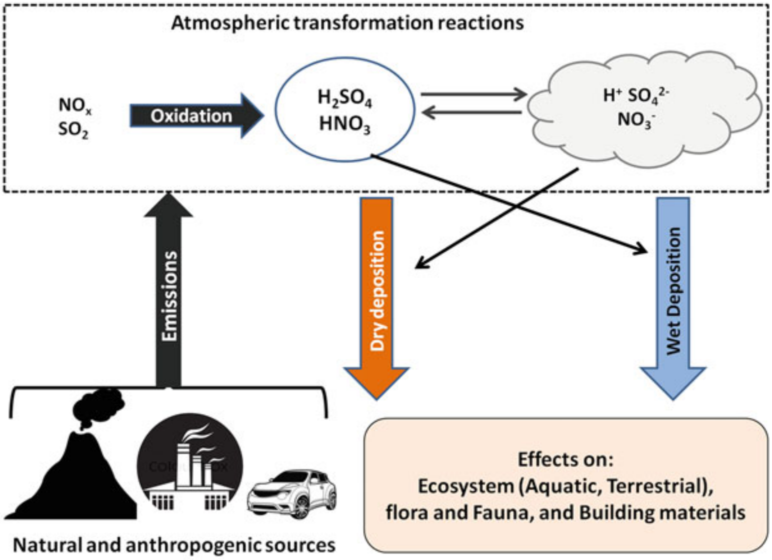

Fig. 3.1 Process involved in the acid rain. (Adopted from Sonwani and Maurya 2018)

$$SO_2 + OH^o \rightarrow HOSO_2$$

$$HOSO_2 + O_2 \rightarrow HO_2 + SO_3$$

$$SO_3 + H_2O \rightarrow H_2SO_4$$

Homogeneous aqueous phase reaction of SO_2 takes place by its dissociation in the water.

$$SO_2 + H_2O \leftrightarrow SO_2H_2O$$

$$SO_2.H_2O \leftrightarrow HSO_3^- + H^+$$

$$HSO_3^- \leftrightarrow SO_3^- + H^+$$

NO_2 undergo gas phase oxidation reaction (faster as compared to SO_2):

$$NO_2 + OH^o \rightarrow HNO_3$$

Apart from the above-mentioned reactions, nitric acid also forms by NO_3 radical reactions, in which NO_3 radical forms by the reaction between NO_2 and tropospheric O_3 during daytime.

$$NO_2 + O_3 \rightarrow NO_3^o + O_2$$

Table 3.1 Showing critical pH level of aquatic animals

Animal	Critical pH levels
Frogs	4.0
Perch	4.5
Salamanders	5.0
Trout	5.0
Mayfly	5.5
Crayfish	5.5
Bass	5.5
Snail	6.0
Clams	6.0

NO_3^o formed at days and is consumed at night after reaction with NO_2, resulting in the formation of HNO_3:

$$NO_3^- + NO_2 \leftrightarrow N_2O_5$$

$$N_2O_5 + H_2O \leftrightarrow HNO_3$$

Gas-particle reactions of SO_2 and NO_2 undergo heterogeneous oxidation reaction. SO_2 is quickly converted into sulphate by H_2O_2 in liquid phase. The surface of the freshly emitted soot is involved in the formation of sulphate by oxidation of SO_2. But after achieving saturation condition by particle surface, the rate of oxidation reduces. Region having high level of dust, where the oxidation of the SO_2 takes place onto the soil dust particles, leads to the formation of the calcium sulphate ($CaSO_4$) rather than sulphuric acids (H_2SO_4). On the other hand, the oxidation of NO_2 takes place with the salts and forms sodium chloride (NaCl) and sodium nitrate ($NaNO_3$). Moreover reactions get slower on saturation of the particles surfaces.

Impact of Acid Rain on Ecosystem

Table 3.1 shows the crucial concentrations of different types of organisms at which they may lose their life due to rising acid in their surroundings. An ecosystem is an interface of diverse community of plant or animals with their environment. Any disorder in any part of the ecosystem may damage the function of other life forms significantly.

Impact of Acid Rain on Plants and Trees

Plant exposure to acid rain causes several damages related to their foliage and leaf which make them vulnerable for several bacterial and viral infections and harmful UV radiation coming from sun At high altitudes, acidic rain can remove nutrients from trees' foliage, leaving them with brown or dead leaves. The trees are then less able to absorb sunlight, which makes them fragile and unable to withstand freezing temperatures.

Impact of Acid Rain on Fish and Wildlife

Table 3.1 is showing the critical pH levels for different aquatic animals. The acid rain significantly alters the pH of the aquatic environment such as pond, river, lakes, and marshy lands which ultimately harm the life forms. Acid rain is responsible for lowering the pH of soil and water which makes the water unfit for life forms in water bodies. As it flows through the soil, acidic rain water can leach aluminium from soil clay particles and then flow into streams and lakes. Thus it makes that particular soil deficient in aluminium.

Some of the plants and animals tolerate the acidic and aluminium-rich water ecosystem. But several sensitive animals lose their life due to the lowering in pH of water bodies. Generally, young one and elderly animals are very sensitive to these changes. At pH ≤ 5, most of the fish eggs cannot hatch. Most of the non-chordates barely survive at pH 5, while frogs have a critical pH around 4, but the mayflies they eat are more sensitive and may not survive pH below 5.5.

Some of the areas are not affected by the acid rain, and it is due to the special properties of the soil of that location. This type of soil has some buffering capacity to neutralize the acidity of the rainwater. This property of soil depends on the thickness, composition of the soil, and the type of bedrock underneath it.

Episodic Acidification

The melting of snow and heavy rain which happen in the absence of soil (with buffering capacity) deposit high amount of acids into the lakes (with very less acidity in normal days). This short duration of higher acidity (i.e. lower pH) may result in a short-term stress on the ecosystem where a variety of organisms or species may be injured or killed. The melting snow and heavy rain shower can cause increase in lake's acidity known as episodic acidification.

Effects of Acid Rain on Materials

Acid rain causes the damage in the stone and paint of the building of historic/cultural importance such as monuments, statues, tombstone, and sculptures. Bronze, limestone, carbon steel, marble, paint, and some plastics are the most vulnerable to acid deposition. The materials (foundations and pipes) immersed into the acidified water also suffer the problems of corrosion. With the effect of acid rain, calcium carbonate dissolves in dilute sulphuric acid to form calcium sulphate:

$$CaCO_3 + H_2SO_4 + H_2O = CaSO_{4.}2H_2O + CO_2$$

The process causes some effects including the removal of details by breaking stones and build-up of black skin of gypsum (calcium sulphate) in the sink areas in buildings. Once the crystal of gypsum forms into the stone, the procedure may persist up to 50 years, known as memory effect. Several studies were found linked with the impacts of acid deposition on diverse materials. Taj Trapezium Case (also known as MC Mehta Taj Trapezium Case) is one of the good examples of acid rain effects on building material. The yellowing of the Taj marbles was the major issues under Taj Trapezium Case. This petition was related to the deteriorating magnificence of Taj Mahal which was invoking for Air Act 1981 and Water Act 1974 and Environmental Protection Act 1986. The purpose behind this petition was to relocate 292 factories to prevent Taj from the emission released by the companies using coke or coal as energy sources. In this case several reports were drafted and presented which relate the pollution emission from Agra-Mathura region and its impact on Taj. These reports include one NEERI report, two Varadharajan reports and reports by the State Pollution Control Board (SPCB). They statistically explained that replacing coal by diesel in the railway yards and closing down two thermal power stations, sulphur dioxide emissions can drop down by 50%. The court on April 11, 1994, after hearing the learned counsel for the parties passed the order indicating that as a first phase, the industries situated in Agra be relocated out of Taj Trapezium Zone (TTZ). The judgement was taken by the court after considering sustainable development principle, precautionary principle and polluter pays principle. The final judgment in this case was given on December 30, 1996, and the bench consisted of Justice Kuldip Singh and Justice Faizan Uddin.

Acid Rain Effects on Human Health

Acid rain has no direct role in deteriorating the human health due to their exposure. But, the compounds causing acid rain can drastically harm after their exposure to human. There are a variety of exposure ways such as dermal, ingestion and inhalation through which harmful chemicals/pollutants enter into the human body and create adverse health impacts on human health. The SO_2 and NO_2 pollution that causes acid rain is more harmful to human health. Particularly, sulphur dioxide and particulate matter in the atmosphere may create chronic pulmonary problems. Furthermore, the oxide of nitrogen is responsible for acid rain and triggers the development of tropospheric ozone. This tropospheric ozone creates pulmonary trouble and is responsible for disease such as chronic pneumonia and emphysema.

3.2.2 Particulate Matter and Its Impact on Environment

Particulate matter (PM) is a solid or liquid and heterogeneous material present in the atmosphere of earth. Due to its spatial and temporal variations, it is hard to find the impacts of the particulates at regional/local scale. Particulate is deposited on the vegitative surfaces of the plant, and thus it significantly affects the plant metabolism after exposure. The impact of particulate on the plant depends on the physicochemical property (size, surface morphology, source origin and chemistry of the PM). Coarse (PM_{10}) and fine ($PM_{2.5}$) particulate matters have a number of contrasting properties that affect their impact on vegetated systems since two decades. PMs are having a great matter of concern due to its impacts on ecosystem function and huge potential importance for human welfare (Ayensu et al. 1999; Prajapati and Tripathi 2008a, b, c; Telesca and Lovallo 2011).

3.2.2.1 Deposition of PM

This is the process due to which the particulate matter is deposited onto some surface (solid/water/vegetative surface) resulting in the lowering of their concentration in the atmosphere. According to McDonald et al. (2007), plants play a very significant function in filtering ambient air through leaf surfaces. The plants having larger leaf surface area were identified as the efficient PM collector as compared to the trees having less leaf surface area. Similarly, broad leaves with rough surface area are found to be a good PM absorber than other plants having smooth surface (Beckett et al. 2000).

Deposition of PM (mixture of organic and inorganic substances as solid and liquid) onto various surfaces at definite mass concentration causes various types of phytotoxic responses (Tasic et al. 2006). Deposition of particulate matter on vegetation includes (a) nitrate and sulphate and their deposition in the form of acidic components and (b) trace element and heavy metals. According to McLachlan (1999) and Welsch-Pausch et al. (1995), particulate-bound trace elements may be absorbed through the stomata or be settled on the leaf. Contrarily, polycyclic aromatic hydrocarbon (PAHs) can be collected in leaves by (i) gas-particle partitioning, (ii) dry vapour deposition and (iii) deposition with particle, depending on the physicochemical nature of the examined compound (McLachlan 1999; Welsch-Pausch et al. 1995) and can also absorbed through soil, after their deposition on to the soil surfaces.

3.2.2.2 Coarse (PM_{10}) and Fine Fraction ($PM_{2.5}$) Particles

Particle size is one of the factors related to the damaging effect of the PM; the larger size particles settle near to their source of emission as compared to the finer particles, which are usually deposited away from their source of origin. This difference is due to the difference in their residence time in the atmosphere, where larger particles have less residence time in the atmosphere as compared to the finer particles. The size of PM correlated significantly with specific leaf area, but Chl a, Chl b, carotenoid and relative water content were negatively correlated with PM fraction (Chen et al. 2015). The size of the particle is also correlated with the chemical constitution of particles (as fine mode particles are found rich in S, N and organic contents, whereas coarser mode particles are rich in base cation and heavy metals). Fine particulate matters are found associated with the combustion-related emission sources, while coarse particles are generally found associated with crustal material. Various meteorological parameters like atmospheric humidity, precipitation and wind speed affects the deposition process through different mechanisms. Figure 3.2 shows examples of particulate matter sources in relation to particle diameter.

Fine particulate matter exists in vapour phase in the atmosphere in contrast to the coarse particulate matter which has been produced from point source as fully formed particle. Fine PM is secondary in nature and formed into the atmosphere by chemical reaction from gas precursors through series of process, nucleation, condensation and coagulation. Fine particle contains oxides of nitrogen and sulphur (NO_x and SO_x). It also consists of volatile organic compounds, volatile metals and products of incomplete combustion. Coarse PM is produced from mechanical processes like crushing,

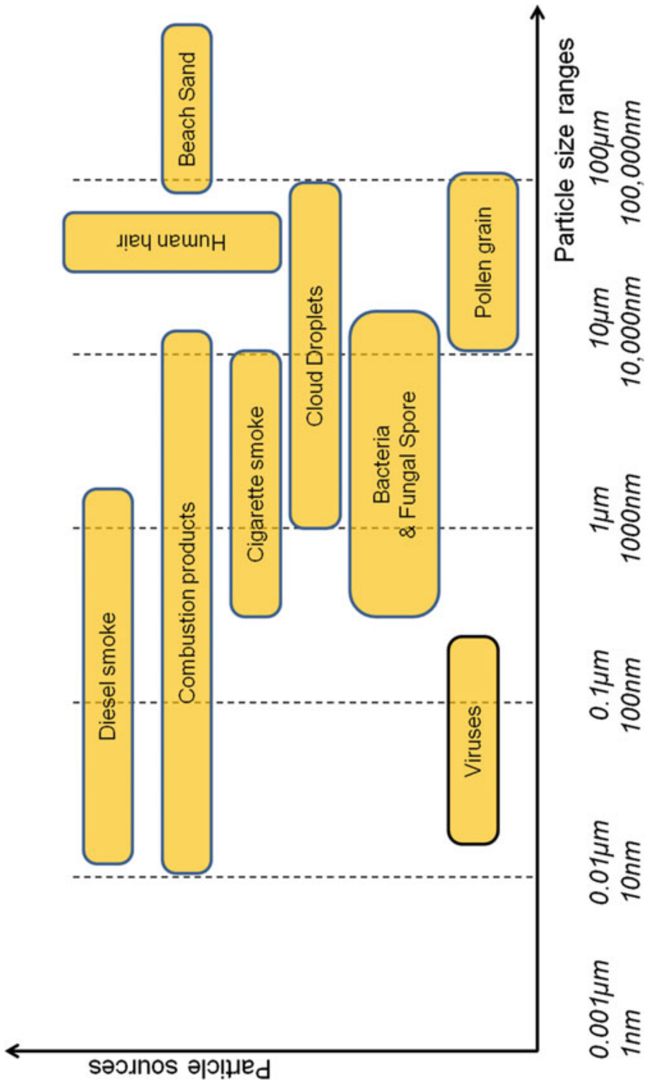

Fig. 3.2 Particulate matter, size ranges and their sources. (Adapted from Saxena et al. 2016)

Table 3.2 Type and determinants and factor controlling particulate deposition on vegetation

Type of deposition	Determinant of deposition	Quantifiable factors
Dry deposition	Ambient levels	Source location, emission potency
	Meteorological variables	Wind speed, wind direction, dew formation, mixing height, temperature and humidity
	Nature of aerosol particles	Chemical reactivity, particle solubility, aerodynamic diameter, bioavailability, hygroscopic nature
	Surface roughness	Terrain type, leaf pubescence, leaf shape, plant tissue arrangement, plant density, branch spacing
	Vegetation condition	Surface wetness, salt exudates, organic exudates, insect excreta
Wet deposition	Ambient levels	Source distance, emission potency
	Meteorological variables	Mixing height, precipitation time, precipitation intensity, time period of precipitation
	Nature of aerosol particles	Chemical reactivity, particle solubility, biological availability
	Surface roughness	Terrain discontinuity, leaf pubescence, leaf area index, nature of exposed bark and stem
Occult deposition	As above	Combination of above factors

Adapted from Gratz et al. (2003)

abrasion, soil disturbances and expansion of fine particle to coarse PM by the effect of humidity.

3.2.2.3 Mode of Depositions

The rate of particle deposition onto the vegetative surfaces depends on dust properties, characteristic of location of plant and nature of receiving material (Grantz et al. 2003; Chen et al. 2015). It also can be associated with several other factors such as diming in solar light, changes in the leaf surface temperature, etc. The exchange of energy into and out of the leaf is highly influenced by particulate matter load, size and colour as compared to gases (Rahul and Jain 2014). The effect of PM onto the vegetation is mentioned in Table 3.2 given by Grant et al. in 2003. There are three major pathways identified for the particulate deposition onto vegetation surface: (1) dry deposition, (2) wet deposition and (3) occult deposition.

Dry Deposition

Dry deposition is a collective elimination of particles from the atmosphere under the influence of some factors such as gravity, direct interception, impaction and Brownian motion. Dry deposition process is continuous and works under the influence of gravitational force especially for the larger particles (larger than few micrometers in diameters). It is the continuous process as compared to the wet and occult deposition and affects all exposed surfaces (Hicks 1986). Fine particulate matters play a very significant role in deposition of the organic compounds (polycyclic aromatics hydrocarbons, dioxins and dibenzofurans,) on to plant surfaces (Lin et al. 1993). PM deposition is also influenced by fog formation through particle removal from atmosphere, through particle growth by aqueous phase oxidation reaction (Pandis and Seinfeld 1989). The atmospheric key pollutant species like NO_3^-, SO_4^{2-} and organics are present in higher concentration in smaller droplets as compared to larger one (Collett et al. 1999).

Wet Deposition

It is known for the removal of the soluble gases and particulate matter from air through the precipitation events. In wet deposition processes, hydrometeors (raindrop, snow, etc.) play a very important role in scavenging the particulate matter. It is influenced by gravity, Brownian motion and/or turbulent coagulation with water droplets. There are two basic types of wet deposition reported:

(a) Below-cloud scavenging (washout): It is the scavenging of aerosol present below the cloud base by raindrop. It scavenges dissolve particle and gases along their fall. It is happening under the influence of interception, Brownian diffusion, impaction and turbulent diffusion.
(b) In-cloud scavenging (rainout): It is the condensation of water vapour on aerosol particle during the formation of cloud droplets. These can be brought to the ground surface through precipitation events such as rainfall and snow form during the cloud formation.

The wet scavenging for gasses depends on their solubility and parameterization following Henry's law. Moreover, the scavenging of the aerosol depends on the size, shape and properties of the aerosol.

Occult Deposition

The windblown mist and fog are usually considered as occult deposition, and such type of wet deposition is not recorded by the rain gausses. Occult deposition is basically linked to the scavenging of the primary air pollutants and removal of the ground-based cloud which is common at high altitude (Fowler et al. 1989).

The proportion/dominancy of the type of the deposition of gases and PM depends on the meteorological conditions and location.

3.2.2.4 PM Deposition onto Vegetation and Their Effects

Deposition of PM on plants is affected by the particle size, dimensions and density of the foliage elements in the dispersion path. PM can cause several adverse impacts on plants and is responsible for stomata clogging, reduced photosynthetic activity, leaf fall and death of tissues (Farooq et al. 2000; Shrivastava and Joshi 2002; Garg et al. 2000). Due to PM deposition, many physicochemical changes take place on aerial parts of plants (Grantz et al. 2003). A major proportion of the stomata may be covered by PM which reduces the rate of transpiration and rate of evaporative cooling (Sharifi et al. 1997). PM deposition on plant materials is also responsible for the chlorosis in the leaf and ultimately affects chlorophyll content (Seyyednejad et al. 2011). Due to the presence of several dust types (fertilizer or lime), a number of adverse effects were caused to the plant after being exposed to PM. These plant responses are the result of the dust chemistry in the atmosphere. Other study also reported the impact of the air pollutants (PM, SO_2, NO_2 and O_3) on crop yield by considering emission trend, movement of air parcel and leaf uptake and plant's biochemical defence mechanism (Rai et al. 2011). Agrawal et al. (2003) reported SO_2, NO_2 and O_3 and related plant responses measured in terms of physiological characteristics, pigment, biomass and yield and found that air pollutant affects the crop yield negatively. Several chamber-related studies also reveal that particulate air pollution is responsible for commercial yield and biological parameters of several important crops (Wahid et al. 1995; Schenone and Lorenzini 1992; Heggestad and Lesser 1990). Joshi et al. (2009) reported the impact of industrial air pollutants (SPM, RSPM, NO_x and SO_2) on biochemical parameters like Chl a, Chl b, total Chl, carotenoid and ascorbic acid and yield in wheat and mustard plants. Parish (1910) is the earliest study, concerning cement particulate matter deposition onto shrub and grassland vegetation in California. Due to these cement industries, several plants become extinct like *Artemisia californica*, *Encelia farinosa* and *Salvia apiana*. The most effective deposition of the PM on grassland was reported by Krippelova (1982) near a magnesite factory in Czecho-Slovakia, and it was observed that the deposition of the emission from the industry caused formation of the soil surface crusts having pH ~9.5. Some studies related to limestone PM emitted from limestone processing plants which may affect the lateral growth of the plant in vicinity have been reported. According to Joshi et al. (2009), PM emitted from the stone crushing industry can affect the different plant parameters of some tree species like mohua (*Madhuca indica*), sonajhuri (*Acacia moniliformis*), eucalyptus (*Eucalyptus citriodora*), sal (*Shorea robusta*) and arjun (*Terminalia arjuna*).

Several types of the micro and macro variations were found, consisting decrees in the quantity of chlorophyll and total carbohydrate in leaf tissues pointing lowering in photosynthesis. According to Anderson (1914) deposition of the PM on stigmatic surfaces may hinder the processes of fruit production. The effect of urban road and traffic emission-related PM was also extensively investigated by several authors, and they reported various types of morphological and biochemical effects (blocked stomata, reduced diffusive resistance, increased leaf temperature, reduced photosynthesis, reduced growth, fruit lesions and partial defoliation) on the plants (*Populus tremula*, *Betula pendula*, *Rhododendron catawbiense*, *Acer campestre*, *Abies alba*, *Fraxinus excelsior*, *Viburnum tinus*, *Mangifera indica*, etc.) (Flückiger et al. 1977, 1979; Eller 1974, 1977; Eller and Burnner 1975; Thompson et al. 1984; Rao 1971; Ajuru and Upadhi 2014). Several studies related to PM effects on vegetation were reported by different authors listed in Table 3.3.

3.2.2.5 Plant Responses to Stress Caused by PM

According to Billings (1978), minimum three types of interactions occurred in plants and PM: firstly the interaction between single plant and environment, secondly

Table 3.3 Sources and effects of PM on different aspects of plants species

Site	Plant species	Source	Effect	References
Riyadh, Saudi Arabia	Leguminous crops (*Pisum sativum* L., *Vicia faba* L., *Glycine max* and *Vigna sinensis*)	Heavy traffic and industry-related sources	Bioaccumulation of heavy metals in plant parts	Alyemeni and Almohisen (2014)
Sakai 593, Japan	*Cucumis sativus* L. and *Phaseolus vulgaris* L.	Mix dust (natural and anthropogenic)	Effect on leaf temperature and photosynthetic and transpiration rate	Hirano et al. (1994)
Hubei Province, China	*Trachycarpus fortunei*, *O. fragrans*, *G. biloba*, *I. tectorum*	Industrial emission	Loss in relative water content, total chlorophyll and pH	Chen et al. (2015)
Sambalpur, Orissa, India	*Pongamia pinnata*, *Tabernaemontana divaricata*, *Ipomoea carnea*, *Ficus religiosa*, *Ficus benghalensis* and *Quisqualis indica*	Traffic emission	Inhibition in pigment content	Prusty et al. (2005)
Rajasthan	*Hibiscus cannabinus* L.	Cement kiln emission	Reduction in total protein, chlorophyll, sugar, lipid and starch	Uma and Rao (1996)
Udaipur City	Dalbergia sissoo	Industrial and vehicular emission	Chlorophyll degradation	Kapoor et al. (2013)
Kerala, India	*Abutilon indicum*, *Croton sparsiflorus* and *Cassia occidentalis*	Industrial and vehicle exhausts	Adversely effects on plant morphology	Sukumaran (2014)
West Bengal and Bihar, India	*Shorea robusta*, *Madhuca indica*, *Eucalyptus citriodora*, *Acacia moniliformis* and *Terminalia arjuna*	Stone cursing and traffic-related emission	Reduction in Chl a, Chl b, total carbohydrate content, protein contents in foliar tissues	Padhy (2013)
Mizoram, India	*Ficus benghalensis*, *Psidium guajava*, *Bougainvillea spectabilis*, *Mangifera indica*, *Lantana camara* and *Artocarpus heterophyllus*	Road dust	Effects on biochemical parameters of leaves	Rai and Panda (2014)
Gujrat, India	*Arachis hypogaea*, *Sesamum indicum* and *Triticum* species	Cement industry emission	Effects on the photosynthetic pigments	Chaurasia (2013)

population and its environment and finally plant community and its environment. The reaction of any individual towards any stress depends upon its genotype, growth phase, active resources and microhabitat (Levin 1998). Succession in the polluted environment or in natural disturbed area, energy is transferred from development to reproduction and then to maintenance, and thus succession reaches to its former stage (Waring and Schlesinger 1985). Such disturbed environment potentially affects the ecosystem structure, processes and function like physiology and biochemistry of plants, energy flow, nutrient cycling and biogeochemical cycle (Odum 1993). Deposition of the particulate matter onto soil can affect plant yield, reproduction, flowering and plant growth (Saunders and Godzik 1986). Several studies suggested that chronic pollutant injury to a plant community can result in the loss of tree canopy, sensitive species and safeguarding of a successional plant species (Smith 1974; Miller and McBride 1999).

The deposition of PM to any plant surface can cause physical and/or chemical changes in the plant and is generally found associated with chemistry rather than mass of deposited particles (Farmer 1993). Some crustal particles having slightly alkaline pH may injure plant surface due to presence of limestone (Brandt and Rhoades 1972). Several authors reported that PM emitted from cement kiln industries may affect the leaf by destroying its cuticle, hydrolyze the lipid and wax component and denature protein due to the rising alkalinity on the leaves surface by liberation of calcium hydroxide on hydration through cement PM (Guderian 1986; Darley 1966). Some of the microorganism, fungi and arthropod residents on plants play a very significant function in decay of litter fall (Miller et al. 1982; Jensen 1974).

Apart from direct effect, some of the indirect effects are also responsible for ecosystem response wrt PM. Indirect plant responses to PM are limited to soil environment (i.e. mineral, organic matter, water, air, variety of bacteria, fungi, protozoan, nematodes and arthropods), depending on chemical composition of every element present in PM. The soil is an important location for the rare biological exchanges (Wall and Moore 1999). Several organisms present in the rhizosphere are responsible for the chemical and biological transformations, which make inorganic materials available for plant uptake (Wall and Moore 1999). PM present in the soil also affects the plant populations indirectly by affecting their nutrient cycling important for plant growth, vigour and health of the biota. Guderian (1986) reported that many of the heavy metals and other contents associated with PM and reaching to the soil surfaces are more harmful than component that penetrates the foliar surfaces.

3.2.2.6 Health Effects of PM

Figure 3.3 indicates the deposition of the different size fractions of PMs in the respiratory system. The PM10 and PM2.5 are the respirable fraction of the particulate matter present in the ambient atmosphere and get easily deposited into the respiratory system. The several health defects are caused by the deposition of these particles into the lungs. The defects depend on the size and shape of PM and concentration of the PM in the surrounding environment (Sonwani and Kulshrestha 2016, 2018; Sonwani et al. 2016; Sonwani and Saxena 2016). It also depends on the

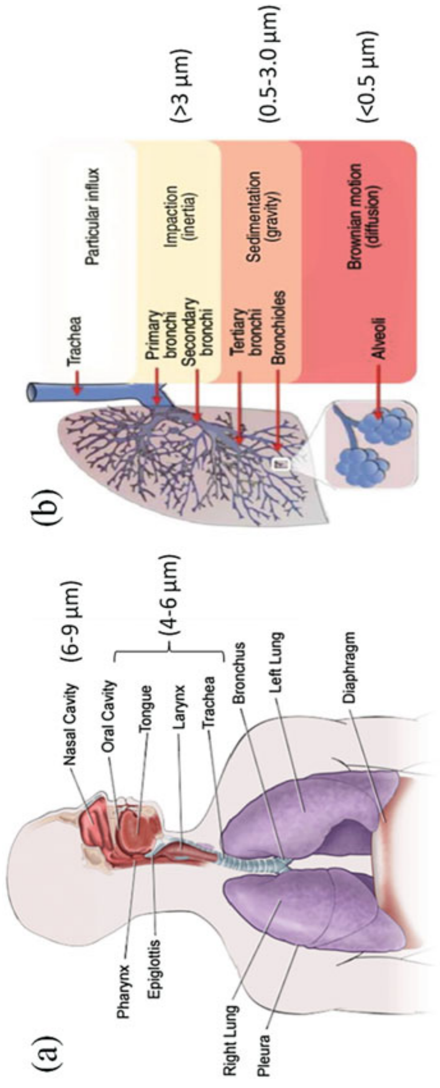

Fig. 3.3 (**a**, **b**) Deposition of the different size fractions of particulate matter in respiratory system

people's age, immunity and gender and occupancy probability of that person in a particular environment (Balakrishnan et al. 2002). Indoor environment is also discussed widely in relation to the PM level, exposure and health effects (Kulshreshtha and Khare 2011; Balakrishnan et al. 2002). Several authors also worked on controlling the air pollution problems by changing the type of fuels from nonrenewable to renewable (Sonwani and Prasad 2016; Carroquino et al. 2018). The health effect of the PM is well-known. The effects are due to the short-term (hours-days) and long-term (months-years) contact to the PM and cause several health-related defects related to circulatory system and pulmonary system and aggravation of asthma resulting in the rise of the number of patient admissions in hospitals. These patients usually suffered with the cardiovascular and respiratory diseases and from lung cancer.

There were good observations found for PM_{10} short-term exposure in relation to the respiratory health in contrast to the $PM_{2.5}$. In contrast to this, $PM_{2.5}$ plays a significant role in causing mortality due to long-term exposure as compared to PM_{10}. Thus, it is clear that the $PM_{2.5}$ is a stronger risk factor than the coarse part of PM_{10} (particles in the 2.5–10 μm range). All-cause daily mortality is estimated to increase by 0.2–0.6% per 10 $\mu g/m^3$ of PM10 (Samoli et al. 2008). Long-term exposure to $PM_{2.5}$ is linked to the rise in the long-term risk to cardiopulmonary mortality by 6–13% per 10 $\mu g/m^3$ of $PM_{2.5}$ (Beelen et al. 2008; Pope et al. 2002). The risks from the exposure of the $PM_{2.5}$ and PM_{10} are also reported in the population of Delhi (Sonwani and Kulshrestha 2016). Several other studies also reported the health risk due to the particulate matters containing polycyclic aromatic hydrocarbons (PAHs) and heavy metals (Sarkar and Khillare 2013; Jyethi et al. 2014).

Vulnerable group with pre-existing diseases related to the heart/lungs and elderly and children are more susceptible than any other adult person at same environmental conditions. Exposure of PM to children may affect development of lung tissues, and it may also harm the lung function (WHO 2011). But there is no proof of safe levels/ threshold level for exposure identified yet below which no adverse health effects occur. Currently, it was also observed that there are lack of studies reflecting the effects of the particles on the basis of their sources and chemical composition (Stanek et al. 2011).

One of the important components of the PM2.5 is black carbon (BC), which recently creates curiosity in scientists working in the area of health and climate sciences due to the significant role of BC in both fields. Several organic, metal and seas salt components are usually found attached with the BC and known as important carcinogens and toxic to the human health. The emission from motor vehicles is identified in relation to the human health and put into group 1 category (IARC 2012). This list also contains several PAHs and associated exposures, as well as the household use of solid fuels (IARC 2010).

3.2.2.7 Burden of Disease Related to Exposure to PM

It is observed that cardiopulmonary- and lung cancer-related mortality contributed around 3% and 5%, respectively, due to PM exposure globally. In the European countries, this fraction is 1–3% and 2–5%, respectively, in several sub-regions

(Cohen et al. 2017). Recent study indicates that the burden of disease connected to atmospheric pollution can be even high. It was also observed that within atmospheric pollution the annual $PM_{2.5}$ attributed for 3.1 million deaths and approximately 3.1% of world's disability-adjusted life years (Lim et al. 2012). It is also observed that the exposure of the $PM_{2.5}$ reduces the average life expectancy in the population of any region, where the traditional health impact assessment methods were used. This study reported that the average life expectancy of a population in many metropolitan cities can be increased by more than 1.5 year after following annual average air quality guideline of WHO for $PM_{2.5}$ (Fig. 3.4).

3.2.2.8 PM Effects on Climate

Atmospheric aerosols affect the climate by controlling the earth radiation budget. This happens through many diverse processes which may be classified into direct and indirect effects. According to the Intergovernmental Panel on Climate Change (IPCC) third assessment report, greenhouse gases are reasonably and highly responsible for the radiative forcing of climate with high accuracy. NASA's Terra satellite releases world-based observation of the average monthly aerosol amount over the world, and for this Moderate Resolution Imaging Spectroradiometer (MODIS) was used. The satellite measurement of the aerosols was calculated in terms of aerosol optical depth (AOD). AOD is a computation of the extinction of the solar beam by dust and haze. In other words, particles in the atmosphere (dust, smoke particles, mineral dust and biological particles) can block sunlight by absorbing or by scattering light. AOD is a dimensionless numeral specifically linked to the amount of aerosol in the vertical column of atmosphere above the study site. A value of 0.01 represents to a really clean atmosphere, and a value of 0.4 would indicate towards a very hazy state (www.esrl.noaa.gov).

Direct Effect

The direct aerosol effects include absorption and scattering of the solar radiation. Both short- and long-wave radiation produce net negative radiative forcing depending on the albedo on the primary layer which controls the total amount of radiation absorbed or scattered to space. IPCC classify the radiative forcing as a result of the primary and ultimate aerosol effects, hence classified as a first-order effect. These interactions of the aerosols and radiation are measured in terms of single scattering albedo (SSA), and it is the ratio of scattering alone to scattering plus absorption (extinction) of radiation by aerosol. SSA tends to zero on infinite absorption, increases as absorption decrease and leads towards the unity in the dominance of scattering.

PM Indirect Effect on Climate

Indirect effect of PM includes the changes in the earth's radiation budget by changes in clouds by atmospheric aerosols. The cloud droplets formed from the cloud condensation nuclei (CCN). The increasing CCN results a rise in the quantity of the cloud droplets. This directs towards extra scattering of shorter-wave radiation which means more rise in the cloud albedo, also known as the cloud albedo effect,

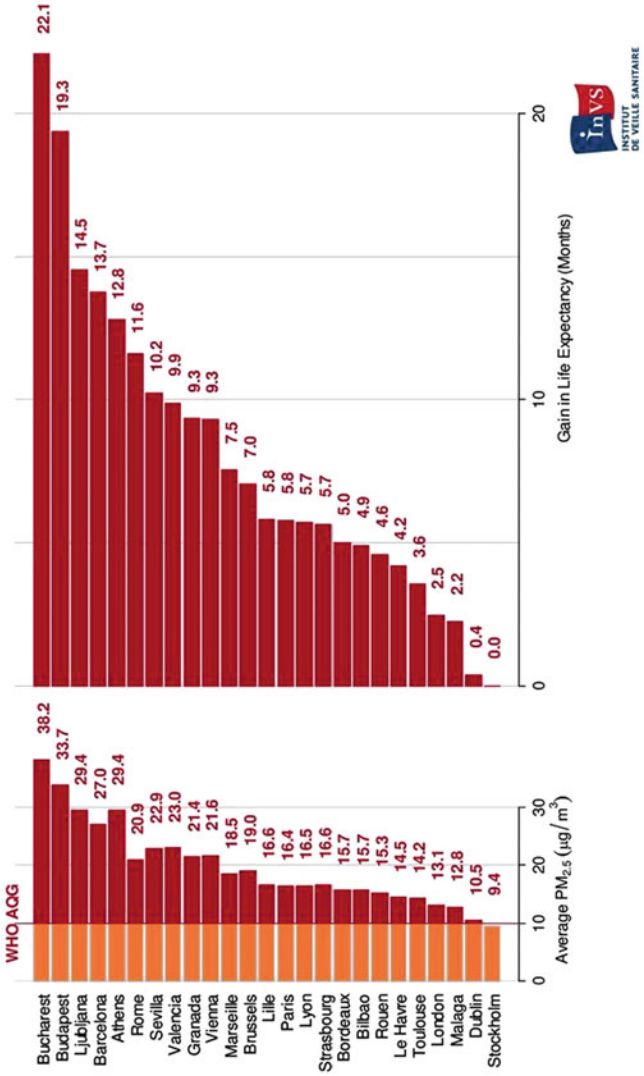

Fig. 3.4 Model prediction about mean rise in life expectancy (months) for person aged 30 years for a decrease in mean yearly concentrations of $PM_{2.5}$ down to the WHO AQG yearly average concentration of 10 μg/m^3 in 25 European cities contributing in the Aphekom project. (Source: Medina 2012)

first indirect effect or Twomey effect. On increasing the cloud droplet number concentration, the size of the drop is reduced on introduction of aerosols as similar quantity of the water is separated among more droplets. It increases the cloud lifetime, known as cloud lifetime aerosol effects or Albrecht effect.

3.2.2.9 Acid Rain and Eutrophication

Figure 3.5 is showing the eutrophic processes and components in the lake. Eutrophication is a condition of water body enriched with the nutrients such as nitrogen and phosphorus. The atmospheric deposition (e.g., in the form of acid rain) can also affect the nutrient levels in the water body, particularly in the industrial regions. This excess amount of nutrient triggers algal bloom which is ultimately responsible for the loss of animal and plant diversity. Eutrophication is also identified as excessive plant and algal growth due to higher accessibility of one or more limiting factors such as sunlight, fertilizers and carbon dioxide of photosynthesis (Schindler 2006). It is a natural ageing process of any lake due to the deposition of sediment into it over centuries (Carpenter 1981). The N, P and K originated on agricultural land and fertilizers or animal waste are the principal nutrients reaching to the surface water and involved in the eutrophication. Urban and industrial runoff also contributes to eutrophication. Anthropogenic factors also affect eutrophication severely by increasing the rate of adding nutrients into the water bodies. Emissions from thermal power plants and vehicles also contribute a large amount of nitrogen oxides entering aquatic ecosystem.

The eutrophication of the lakes can be also deteriorated by climate change on increasing the water temperature. The bacterial activities increase on increasing the

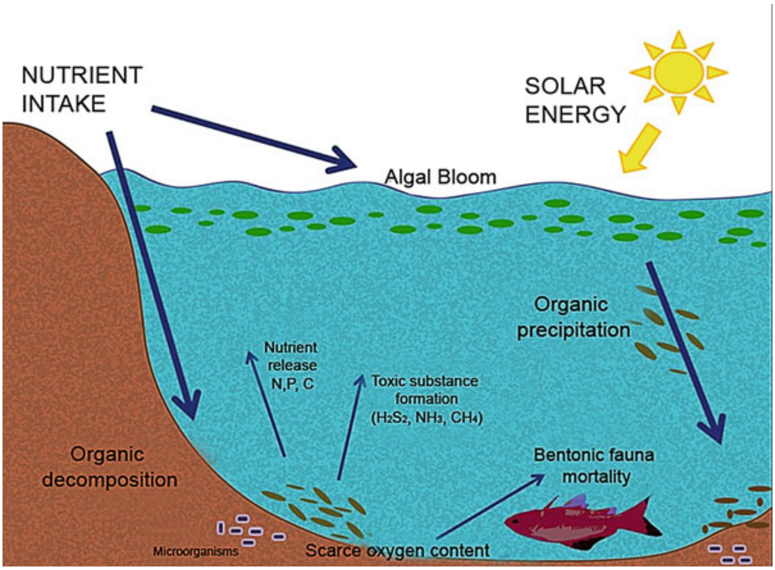

Fig. 3.5 Components and process of eutrophic lake. (Source: Arpa Umbria 2009)

temperature of water body and result the drop in level of dissolved oxygen content. The warm water bodies are the home of the several fishes which eats on zooplankton (the microscopic animals). The zooplankton depends on the algae for their food; thus they control their number. *Daphnia* is one of the zooplanktons reported to be efficient and beneficial in controlling the algal population. Eutrophication reduces the algal controlling ability of zooplankton, and hence blue-green alga dominates the lake habitat. Overall, climate change and eutrophication act synergistically to restrict the capacity of the zooplankton to manage the algal population, which enhances the blooming of lakes. Higher nutrient concentration leads to loss of the submerged aquatic vegetation that provides shelter to fishes. There are several steps involved in the eutrophication process; major steps are listed below:

Lakes and streams receiving more fertilizers become more productive. The rich nutrient contribution triggers the development of algae to increase their populations. The following are the conditions considered as population explosions or “blooms”:

(a) Due to the algal bloom conditions, the diffusion of light into water is diminished which ultimately decreases the productivity of plants in deeper waters.
(b) Thus the water becomes depleted in oxygen. Low oxygen results in more algae to die. Low oxygen level also affects the lowering of primary production in the deep water.
(c) Low level of oxygen results in the dying of large fishes which required high amount of dissolved oxygen (“DO”), like trout, salmon and other attractive sport fish.

3.2.2.10 Atmospheric Haze

Industrialization and urbanization activities over the world have led to a rise in air pollution and haze condition in both developing and developed countries (Fig. 3.6a–f). When sunlight encounters minute suspended particles in the atmosphere, it reduces the visibility called as haze or smog. Power plants, vehicular traffic, industrial facilities and construction activities play significant role in the formation of haze by emitting various pollutant especially fine particulate matters (Watson 2002). High levels of pollutants trigger more the haze due to their absorptive and scattering effects. Haze reduces the clarity and colour of objects we see. Some of the pollutants like sulphate particles may scatter more light during humid conditions (Li-Jones and Prospero, 1998). Haze mainly originates from the cities or crowded area and disperses to the rural and urban background area through wind. Smog can change the weather conditions due to the presence of definite dark particles containing carbon, which play significant role in altering earth radiation budget by scattering and absorbing nature of carbon particles. Haze can decrease the quantity of the solar energy up to 30 percent reaching the earth’s surface (Chameides et al. 1999). Apart from the visibility degradation, air particles are involved in forming cloud condensation nuclei (CCN) which ultimately affect rainfall pattern. Finer particles (apart from soot particle) were found involved in the formation of the CCN. Apart from finer particles, oxides of sulphur and nitrogen are also found involved in haze formation. The scavenging processes (dry and wet deposition) were found involved

Fig. 3.6 (**a–f**) Haze problem around the different countries around the world from a to f (UK, USA, Singapore, India, China and Pakistan)

in the cleaning of atmospheric pollutants (Gu et al. 2010; Arakaki et al. 2013; Sonwani and Kulshrestha 2017; Sonwani and Kulshrestha 2019). Therefore, the atmospheric visibility is directly linked to the pollution level in the atmosphere.

3.2.3 Impact of Carbon Monoxide on Environmental Health

The NAAQS suggested highest safe CO level is 10 ppm (parts per million). Many persons do not have sign of the CO toxicity under 70 ppm, but the exposure over this may be responsible for headaches, fatigue and nausea. The signs may be alike to a cold or flu, and several persons mistake CO poisoning for these sicknesses. Levels of 150–200 ppm often result in disorientation/coma and occasionally even death.

3.2.3.1 CO Toxicity

In the process of breathing, O_2 from air come into the pulmonary system through nasal passage, where it reacts with the red blood corpuscles (RBCs) and is transported to every cell in the body. The haemoglobin (Hb) is the main oxygen-transporting protein in RBCs. Every haemoglobin molecule consists of a group of four iron-containing units called *haem*. In the normal condition (in the absence of CO), every *haem* reacts with one molecule of oxygen (O_2) and forms oxyhaemoglobin complex ($Hb(O_2)4$). Oxyhaemoglobin is a darker red than haemoglobin. The oxyhaemoglobin travels across the body, and when it reaches cells that do not have plenty of oxygen, it frees its oxygen to them. In the normal condition (in absence of CO), Hb reacts with the oxygen and forms oxyhaemoglobin in the blood.

$$\mathrm{Hb}(aq) + 4\mathrm{O}_2(g) \leftrightarrow \mathrm{Hb}(\mathrm{O}_2)4(aq)$$

Carbon monoxide is poisonous as it hinders above-mentioned course of action. CO has high binding affinity to haemoglobin than oxygen, and it is about 200 times better. It denotes that the carbon monoxide more easily binds with haemoglobin to form carboxyhaemoglobin (COHb) even in the presence of far more oxygen. Thus, haemoglobin readily reacts with CO instead of oxygen and form carboxyhaemoglobin.

$$\mathrm{Hb}(aq) + \mathrm{CO}(g) \rightarrow \mathrm{Hb}(\mathrm{CO})(g)$$

As a bioindicator of CO exposure, COHb is accurate and directly related to the mechanisms of toxicity.

In inhabitants with comparatively elevated exposure, there are persons continuously exposed to emission of fuel combustion sources at their occupation. These persons were drivers of taxi cars and buses, policemen, garage and tunnel workers and traffic wardens. High exposures were also noticed in the workers in metal industries and petroleum, gas and chemical plants. Currently smokers have more exposures than nonsmokers and high levels of tobacco smoke in residence, workplace and restaurant, which may also increase individual exposures significantly (USEPA 1991). Another study observed that the indoor players and skaters are exposed with highly polluted indoor environment due to strenuous exercise causing high breathing rate and poor ventilation linked with exercise levels during the sports activity (Lee et al. 1994; Paulozzi et al. 1993).

In healthy people, minute quantities of CO are produced by the breakdown of haemoglobin and other haem proteins. At relax and without exposure, this results in a COHb saturation of 0.4–0.7%. At the time of pregnancy, high maternal COHb concentration of 0.7–2.5% has been found, and the foetuses of nonsmoking pregnant woman have been also observed with rising levels of 0.4–2.6%. Hypermetabolism, particular drugs and haemolytic anaemia may raise endogenous COHb concentration by up to 4–6% (ACGIH 1991a, b; USEPA 1991). The toxicity of CO is governed by these factors and by exposure duration, respiratory minute volume, cardiac output, tissue oxygen demand and blood haemoglobin concentration (Lee et al. 1994). The rate at which arterial blood reaches equilibrium with the inspired concentration of CO is affected by the diffusion capacity of the lungs and alveolar ventilation and the duration and concentration of exposure. This model, in its non-linear form, may be used to predict CoHb levels at high CO exposures, whereas in linear form it can be made applicable to typical air pollution situations.

3.2.3.2 Health Effects

The emission and related exposure to the human being was among the top most discussions during the UN Commission for Sustainable Development 2006. There are several studies that found the evidence (COHb) of the carbon monoxide in the blood in relation to the dose responses (in the areas having high CO levels), which has the most significant health effects. Several organs are affected by the high CO exposure including circulatory system, nervous system and skeletal muscles. It also creates several long-term and short-term symptoms and effects such as headache, dizziness, vision and hearing impairment, low oxygen level in body, cerebral obstruction, oedema and death (USEPA 1991; ACGIH 1991a, b; WHO 1979). Apart from the above-mentioned health defects, some studies also mentioned other health-related problems such as tuberculosis, cataracts, different types of cancers, low birthweight, still birth and heart disease.

Effects on Humans

Neurological and Behavioural Effects

It is implausible that CO has any direct impacts on the lung function but at very high level. Its poisonous impacts on man are because of hypoxic condition, which becomes prominent in organs and tissues with high oxygen utilization including the heart, brain, exercising skeletal muscle and the foetus under development. It is worth motioning that due to the acute CO poisoning, the condition of severe hypoxia occurs, which may create both reversible, temporary nervous disorder and severe, regularly delayed, neurological damage (ACGIH 1991a, b). At a COHb concentration of around 10%, it may create a symptom of headache, but at relatively high concentration, it may create the symptoms of dizziness, nausea and vomiting. At a higher percentage levels (~40%) of COHb, it may cause unconsciousness and death, whereas 50–60% of CO is often lethal (USEPA 1991). The impact of low-level dose of CO that may affect human behaviour has been analysed by several authors (Laties and Merigan 1979; Benignus 1994). But COHb levels below 18% create no significant defects on visual or behavioural functions in normal healthy subjects. Earlier studies referred that the impacts begin from very low level of 3–5% in some cases. According to one school of thought, the highest sensitivity to carbon monoxide is because of its single blind in design, whereas some other studies says that it have been double blind which is the clear cause for the discrepancy in this point (Benignus 1993). In usual conditions, higher error may be observed in the behavioural tests where lower COHb concentration is observed at resting situation. It is also promising that unusual cardiovascular problems and disease increase the sensitivity of diseased person to CO-induced behavioural impacts (Benignus 1994).

Cardiovascular Effects

In order to identify the impact of the low-level CO toxicity during physical exercise on cardiopulmonary function due to its exposure, several subjects (healthy and person with ischemic heart disease) are taken into the consideration for the observation. During these experiments, the peoples are exposed with fresh air and air with CO level inside a chamber or through a face mask. After exposure, the concentration of the blood COHb is determined, while the person is engaged in an exercise. In somewhat healthy person, the maximum exercise interval and the maximum oxygen expenditure have lowered at COHb concentration as low as 5%. The relation between percentage loss in maximum oxygen consumption and the percentage rise in COHb level appears to be linear, with about a 1% fall in oxygen expenditure per 1% point rise in COHb level above 4% (USEPA 1991; Bascom et al. 1996). Patients with heart disease, particularly ischemic heart disease, are expected to be especially sensitive to CO. Atherosclerotic (tapering of the coronary arteries) and damaged expansion mechanism limit blood flow to the muscular tissue of the heart and prevent physiological return for poor oxygen supply caused by increasing concentration of COHb. The early studies of Aronow et al. (1972), Aronow and Isbell (1973) and Anderson et al. (1973) have observed inhalation of air having low CO level responsible for 2.5–3.0% of COHb levels. The high threat amongst the tunnel officers decreased importantly in few years after the stop of the occupational exposure, and there has also been an important decrease from 1970, when the introduction of new aeration systems decreased the CO concentration in tunnels and tunnel stalls (Aronow et al. 1972). Full-day average CO levels in tunnel were observed around 57 mg/m^3 (50 ppm) in 1961 and 46 mg/m^3 (40 ppm) in 1968. During peak period traffic in 1968, CO levels in tunnel toll stall were found high (74–189 mg/m3 (65–165 ppm)), and in 1970 the average level during 38 days was 72 mg/m^3 (63 ppm). In another study, USEPA reported that the epidemiological observations and laboratory animal analysis suggest that common environmental exposures to carbon monoxide do not leave any atherogenic effects on humans (USEPA 1991).

Developmental Effects

The exposure of the CO also leaves several adverse effects to both pregnant lady and newborn infant. At the time of pregnancy, the endogenous generation of CO can rise up to three times, the level of mother's haemoglobin is usually declined and mothers may have physiological hyperventilation. Due to this condition, the normal COHb level increased by 20% in pregnant woman as compared to the non-pregnant woman. CO defuses readily from the placenta, which easily binds with the foetal Hb as compared to the adult Hb due to its high affinity. Furthermore, CO is unoccupied more gradually from foetal blood than from maternal blood, whereas a high level (10–15%) of average foetal COHb is observed as compared to the maternal COHb level (USEPA 1991; Longo 1977). It was scientifically and theoretically proven that the foetus and the developing organs are more susceptible to CO level. The developing brain has one of the highest CO sensitivities in comparison with all other organs. There is a direct relation between the maternal smoking and weight of the developing foetus at 2–10% of COHb level. It also depends on the dose-dependent prenatal death and behavioural changes in the infants. CO is most likely one of the most significant etiological factors (factor responsible in the development of any disease) for these effects, even though there are several other toxic pollutants in tobacco smoke (Longo 1977).

3.2.3.3 Impact of Indoor CO

Emissions of CO in the domestic environment may be classified as accidental or as resulting from the intentional use of combustion devices. Accidental emissions may result from the improper use of combustion appliances and from faulty appliances; other unintentional sources include the ingress of polluted air from attached garages or from the outdoor environment. Accidental emissions can lead to very high indoor CO levels, which may result in acute and sometimes fatal health effects. Most CO emissions come from the intentional use of partially vented or unvented combustion appliances such as gas cookers and other appliances including water heaters and unvented gas space heaters, along with wood or other solid fuel burning appliances. CO emissions are highly variable between gas cookers as well as between individual burners on the same appliance. Operating a gas cooker with an improperly adjusted flame can lead to very high emission rates (up to and above a fivefold increase compared with a properly adjusted flame). Emissions from unvented gas space heaters are very variable but tend to be comparable with gas cooker emissions. Infrared gas space heaters produce higher emissions than convective or catalytic appliances. For unvented kerosene space heaters, radiant appliances produce higher emissions than convective appliances. For these types of sources, the wick setting has a significant effect with a low setting producing the highest CO emission rates. Amongst wood and other solid fuel burning appliances, the non-airtight wood burning stoves and fireplaces may produce substantial amounts of CO compared with airtight appliances. Tobacco smoking is also a source of indoor CO with emission rates varying between tobacco brands and with the total number of cigarettes smoked. As people spend a considerable amount of time indoors, levels of CO inside the home can have a significant impact on personal exposure levels (although particular subgroups such as commuters and those working in certain occupations may be more affected by outdoor levels). For example, in UK homes with CO sources such as gas cookers, peak concentrations of up to 60 mg/m^3 (52.4 ppm; the WHO air quality guideline for a 30-minute exposure to CO) have been recorded (Longo 1977), and in other cases much higher peak levels have been associated with malfunctioning combustion appliances. However, long-term CO concentrations are generally much lower. In other indoor microenvironments in which internal combustion engines are operated with insufficient ventilation, mean levels of CO can rise to above 115 mg/m^3 (100.4 ppm) for prolonged periods, with much higher short-term values.

3.2.4 Impact of Lead and Environmental Health

3.2.4.1 Lead Sources and Routes of Exposure

The most common route of the exposure for any pollutants/chemicals present in the environment has been shown in Fig. 3.7. There are occupational and environmental sources for the atmospheric lead exposures, and due to the inhalation exposure of lead particles released from the burning materials containing lead such as stripping leaded paint, smelting, recycling and using leaded gasoline or leaded aviation fuel, caused harmful impacts on human health. The most common way for the lead exposure is through inhalation, and human can be also affected through definite types of unregulated cosmetics and medicines. Young children are predominantly vulnerable to lead poisoning because they soak up four to five times as much ingested lead as adults from a particular source. A significant quantity of lead released through the mining and battery recycling activity and exposure through lead-contaminated soil/aerosol cause deaths in young children in several countries such as Nigeria, Senegal and other countries.

After the exposure of the lead in the body, it can be easily distributed all over the body organs such as the liver, kidneys, brain and bones. Lead can be easily accumulated into the bones and teeth and transferred into the blood at the time of pregnancy, and thus it is exposed to foetus. Undernourished (children with deficiency of nutrients such as calcium and iron) children may easily get affected from the lead exposure due to their more susceptibility towards lead. Developing foetus and newborn babies are very prone to the lead exposure and at highest risk to get affected from lead exposure. The severity of lead exposure and symptom to the people depends on the exposure pathway and exposure type. Some of the person may not have any symptom at low level of lead exposure, whereas the symptom also depends on the sensitivity and immunity of the people. The acute lead poisoning may occur due to the exposure of high levels of lead. The symptoms may include headache, fatigue, muscle pains, seizures, abdominal pains, nausea, vomiting and coma. The chronic exposure of the lead may produce symptoms such as irritability, lack of energy, loss of appetite, learning disabilities and behavioural problems. Lead exposure may also cause many unnecessary effects (disruption of the biosynthesis of haemoglobin and anaemia, an increase in blood pressure, kidney damage,

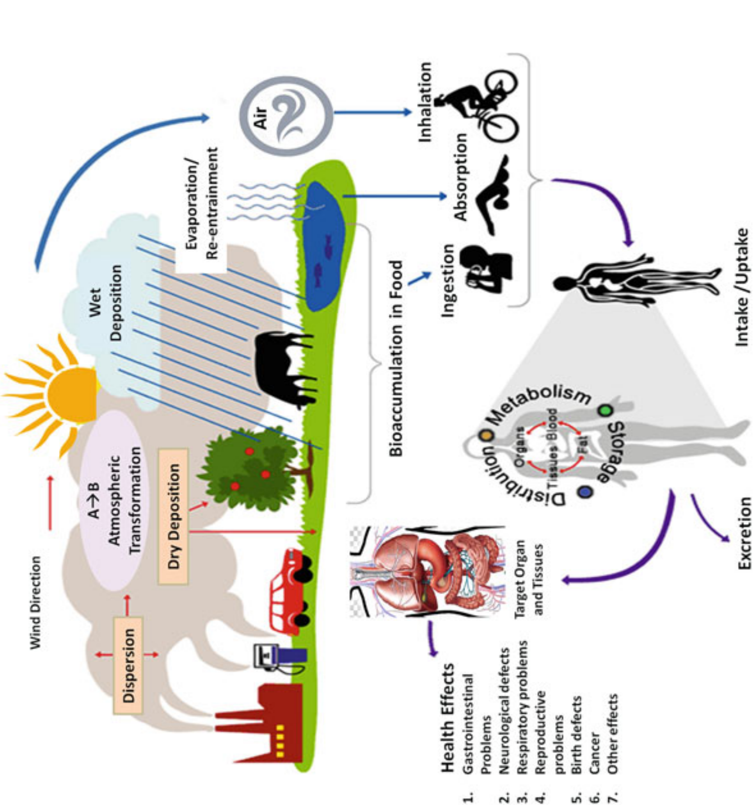

Fig. 3.7 People's exposure to chemicals in the environment and the effect of such chemicals on human health

Table 3.4 Blood lead levels and related exposure in children and adults

Blood lead level	Health effects
Blood lead levels below 5 μg/dL	*Children:* Low educational success, low IQ and low in specific cognitive measures and attention-related and behavioural problem
	Adults: Kidney malfunction, maternal blood lead linked with reduced foetal growth
Blood lead levels below 10 μg/dL	*Children:* Late puberty, decreased postnatal growth, low IQ and hearing impairment/loss
	Adults: Rise in blood pressure, elevated risk of hypertension and increased incidence of essential tremor

miscarriages/abortions, nervous disruption, declined fertility of men through sperm damage, diminished learning abilities of children, behavioural disruptions of children, such as aggression, impulsive behaviour and hyperactivity).

3.2.4.2 Effects of Lead in Children

Table 3.4 shows major health-related problems due to the blood lead levels. Lead exposure can have deleterious impact to the children health. The high exposure of the lead can cause serious health-related problems to the central nervous system (including the brain and backbone) which may lead to coma and even death. The nervous disorder and behavioural effects due to the lead exposure are usually irreversible. Low concentration levels pose no adverse impact on the human health, but higher concentration creates broad-spectrum injury and leads to multiple organ failure. It affects the developing brain and causes low intelligence quotient (IQ), low education achievements, increased antisocial activity, behavioural changes, etc. The other adverse impacts include reproductive system failure, anaemia, low immunity, renal dysfunction and hypertension. Till now there is no safe limit for lead in blood that has been decided. But, it is noticed that the severity of the symptom and effects are directly proportional to the lead exposure. Yet blood lead levels as low as 5 μg/dL, once considered as a “safe level”, can be linked to lowering intelligence in children, behavioural problems and education difficulties.

3.2.4.3 Effects of Lead in Adults

Several health impacts are observed in adult human after lead exposure. The increased blood lead concentration (>15 μg/dL) causes many problems related to fertility, cardiovascular system, nerve disorders and decreased kidney function. It may be also responsible for the late formation and negative effects on sperm and semen, such as their counts and motility.

3.2.4.4 Environmental Effects of Lead

The leaded gasoline causes the lead contamination in the environment. Other sources for the lead contamination in environment include anthropogenic activities such as solid waste combustion, industrial processes and fuel combustion which contribute in the rising lead level significantly. The presence of lead in water and soil may be due to the corrosion of the leaded pipelines in water transportation system and also through corrosion of leaded paints. After their release/emission from source, it can never be broken down but can be converted from highly toxic to less toxic forms. Lead easily gets accumulated into the different organisms after exposure. The water and soil organisms are also severely affected by the lead toxicity. Even at very low level, lead can affect shellfish. The increasing level of lead causes body dysfunction of phytoplankton (an important source of energy and oxygen in sea/ocean). Thus the health impact on phytoplankton affects the health of ocean and large sea animal and plays an important role in global balance. The soil properties and functions are also adversely affected by the presence of lead level in the soil close to the highways and farmlands. A very high level can be present. The accumulation of the lead is dangerous for organisms and ultimately for the entire food chains.

3.3 Conclusions

The environmental effects of air pollution are tremendous and are emerging due to high rate of urbanization and industrialization. These anthropogenic activities together with natural events release a large amount of toxic/harmful pollutants, responsible for their high loading to the ambient atmosphere. This chapter discussed about the wide range of the primary criteria air pollutants (SO_2, NO_2, CO, PM and Pb) with special reference to their environmental and health impacts. Acid rain, eutrophication, haze formation, climate and health effects are discussed in detail. The impact of the criteria air pollutants on environment has been discussed with proper explanation and chemical reactions. The exposure assessment, health risk assessment and total global mortality are also discussed on the basis of results discussed by several authors in their literatures. An alternative clean energy source can be a good alternative to reduce the burden of these primary criteria pollutants which ultimately decrease these environmental and health-related problems caused by their exposures. The policymakers may play a very significant role by amending the existing policies in order to keep this upsurge in air pollution under control.

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