# AMBIENT AIR POLLUTION: OVERVIEW OF EVIDENCE FOR INTEGRATED LOCAL AND GLOBAL ACTION

**Rupsha Mitra[19] [1] and Vivek U. Padvetnaya[20] [2]**

*Abstract:*
*Air pollution has emerged as a serious health emergency both locally and globally. The same air pollutants that cause illnesses and premature deaths also trap heat and cause global warming, interfere with rainfall and accelerate icecap and glacier melting, affect vegetation and ecosystems, and also have trans-boundary effects. This complex set of effects poses a serious challenge for public policy. While policy action itself has to gather momentum to meet the clean air targets across cities and regions to protect public health, policy action will also have to respond more holistically to a range of scientific evidence that has now established more a complex link between air pollution and several other environmental and climate impacts. But this is also an opportunity to adopt policy indicators that can be mainstreamed across sectors to align a full range of interventions for effective mitigation and achieve multiple co-benefits related to health and climate security and sustainable development goals.* *Keywords:* Government, intervention, challenges, nutrition, maternal, mortality, resources

*Keywords:* Air pollution, climate change, global burden of disease, global warming, sustainable development, sustainable development goals, World Health Organisation (WHO), public health, public policy.

*There's so much pollution in the air now that if it weren't for our lungs there'd be no place to put it all* – **Robert Orben (1927)**

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[19] Corresponding author; Senior Research Executive at Tech Mahindra Foundation, 17jsgp-rmitra@jgu.edu.in

[20] Associate Professor, O.P Jindal Global University; vupadvetnaya@jgu.edu.in

## THE CONTEXT

While air pollution is most visible as a serious public health threat at the local and global level today, air pollution science is increasingly pointing towards widely different impacts of air pollutants, ranging from adverse health impacts to environmental impacts on vegetation and ecosystem to climate change impacts. While this creates a complex set of risks for mitigation, this is also an opportunity for public policy to align its multi-sectoral interventions to maximise air quality, public health and climate change mitigation gains.

Adverse public health impacts of air pollution are the primary concern. Globally, nine out of ten people live in areas that do not meet the World Health Organization's air quality guidelines (WHO 2018). The ambient air pollution is contributing to about 4.2 million premature deaths annually (ibid). The total welfare loss because of these premature deaths is estimated at USD five trillion (World Bank, IHME 2016). The message from the World Health Organization (WHO) is clear and blunt '… (T)o date air pollution is the biggest environmental risk to health, … and effects economies and people's quality of life … it is a public health emergency' (WHO 2016). It is said that air pollution is the largest environmental cause of disease and premature death in the world today, widely exceeding the number of deaths from war, violence, AIDS, tuberculosis, and malaria combined.

Even though the sources of air pollutants are local, the consequences of pollution can be global due to various natural and anthropogenic reasons. The emerging science indicates that local pollutants like black carbon (fractions of particulate matter), and tropospheric ozone that are short lived pose health risks locally and also cause global warming as they trap heat. Also with more global warming, the formation of ground level ozone and secondary particulates due to an atmospheric reaction also increases, enhancing local air pollution and health risks. This cyclical link must be well understood for defining mitigation strategies. Combating air pollution is therefore inherently linked to achieving several of the sustainable development goals and addressing health and climate change consequences together.

There is also a substantial trans-boundary movement of pollutants that harm people beyond the geographies of their origin.

Equally, a big concern is the inequitable incidence of the consequences of air pollution across social and demographic gradients, especially in developing and poorer countries (UNICEF 2016). Developing countries have to bear a disproportionate health burden due to a high incidence of poverty and malnutrition and lack of adequate welfare measures. While poor people are the most vulnerable to air pollution related diseases, they also face the economic brunt of air pollution control measures that often adversely affect their livelihood bases causing economic distress. Sustainable development goals will have to be pursued not only for environmental security but also for poverty alleviation, and the two need to be explicitly linked.

This review has become particularly important in the context of India which has one of the highest exposure levels to air pollution globally. In 2017, India contributed to 18·1 per cent of the global population but had 26·2 per cent of the global air pollution disability-adjusted life-years (DALYs). It has been estimated that if the air pollution levels in India were less than the minimum causing health loss, the average life expectancy in 2017 would have been higher by 1·7 years (1·6–1·9) and exceeding 2 years in the north Indian states of Rajasthan, Uttar Pradesh, and Haryana (The Lancet 2018).

The Union Ministry of Environment and Forests and Climate Change (MoEF&CC) has issued the National Clean Air Programme (NCAP) to set a national target of reducing particulate air pollution by 20-30 per cent by 2024. It has identified 102 cities that violate the national ambient air quality standards and has termed them as non-attainment cities in order to prepare action plans. In addition to this, catalysed by judicial intervention from the Supreme Court and National Green Tribunal, the clean air programme has been accelerated in Delhi and in the national capital region of Delhi. As these processes gather momentum, it becomes necessary to understand the emerging action, policy gaps and policy indicators that are needed to operationalize integrated planning across sectors for a full range of co-benefits.

Hence, the challenge that public policy faces is to align multi-sectoral policies at local, regional and global levels and to meet multiple goals related to health security, sustainable development and climate change mitigation. This co-benefit framework is critical to bring a synergy of action across sectors. Air pollution is thus a development challenge. Development policies and even international negotiations should be well-informed based on the evidence of multiple adverse impacts of air pollution that include health and environmental impacts as well as climate impacts. There should be a deliberate strategy to build multi-sectoral interventions to shape public policy to meet clean air targets.

## PROFILE OF AIR POLLUTION AND SOURCES

The mapping of air pollutants and their sources indicates the widely-dispersed economic activities that are a part of the growth trajectory and also of the consumption pattern. Air pollution can be broadly categorized into two— Ambient Air Pollution (AAP; Outdoor) and Household Air Pollution (HAP; Indoor). AAP can be natural or anthropogenic in origin (WHO 2006). Natural causes are ones such as desert storms, windblown dust, and forest fires whereas the anthropogenic causes are closely related to urbanization processes such as transportation, industries, power generation, domestic cooking based on solid fuels, waste burning, and agricultural residue-burning in rural areas. Poor urban planning, over-dependence on private vehicles, inadequate public transport, traffic congestion, poor access to clean energy for domestic cooking and dependence on solid fuels all contribute to enhancing AAP (WHO 2018).

Some of the important chemical agents which pollute the air are Particulate Matter (PM), Ozone (O3), Nitrogen Dioxide (NO2), Sulphur Dioxide (SO2) and Lead (WHO 2006). Annexe 1 provides a brief description of these pollutants, their major sources, health and environmental impacts and WHO guidelines on limit values. In addition to this, there is a range of gases, including highly toxic air toxins that are carcinogenic and occur in trace amounts. To assess the state of the air, the Central Pollution Control Board regularly monitors the key criteria pollutants of PM10 and PM2.5, NO2, and SO2 and on a limited scale carbon monoxide (CO) and ozone in cities of India.

Only limited studies have been carried out in India on pollution source inventory and source apportionment to understand the relative contribution. The process had started with six cities being the subjects of studies of the Central Pollution Control Board in 2010 in Delhi, Mumbai, Pune, Chennai, Bengaluru and Kanpur. Subsequently, more such studies by IIT Kanpur, Teri, and IITM Pune have been done for Delhi and a couple of others by NEERI in Kolkata and Mumbai. Broadly, these studies have identified key combustion sources including vehicles, industries, power plants, waste burning, diesel generator sets and incinerators; and dust sources including road dust and construction dust. To this is added the problem of episodic pollution from agricultural stubble burning that has a strong bearing on urban air quality. This problem is not confined to only Punjab and Haryana. NASA satellite imagery shows widespread occurrences of this across India. However, the relative contribution of pollution sources varies across cities.

On a national scale, studies have found that among the leading contributors to PM2.5, ~25% was attributable to residential biomass burning (this does not include exposure to indoor biomass burning), ~15.3% to coal combustion (7.7% from industry and 7.6% from power generation), ~9%

to dust such as fugitive dust from roads and fly-ash from coal burning and waste burning, 5.5% to agriculture residue burning, and ~2% each to transportation, distributed diesel and brick production (Health Effect Institute 2018). These numbers are more granular at the city level. For instance, one study by Tata Energy Resource Institute, Automotive Research Association of India and another by Indian Institute of Tropical Meteorology have been carried out in Delhi in 2018 that show the relative contribution of different pollution sources (ARAI- Teri 2018 and SAFAR - IITM 2018). Contributions from vehicular sources in cities can be as high as 40%.

Such scientific assessments and knowledge of good practices enable and refine pollution source-wise mitigation strategies, both for the management of ambient air quality and to reduce local exposure.

## AIR POLLUTION AND MULTIPLE RISKS

Air pollution has direct implications on population health, social equity, sustainable development, and climate change.

## HEALTH RISKS

There is a compelling and growing body of evidence on the contribution of air pollution to disease burden. There is robust evidence to show that the health risks posed by the pollutants have no threshold level, the dose-response relationship is often linear (Kelly et al 2015). As the level of pollutants increases, the health risks they pose also uniformly increase, and exposure to even very low levels over a period of time can have health consequences. Global Burden of Disease studies has pointed out that most of the premature deaths related to diseases influenced by air pollution like Ischemic heart disease occur at a much lower level of ambient air pollution. That is the reason why the safe threshold determined by the WHO is so stringent. Annexe 1 provides a brief description of the health risks posed by the major pollutants and their permissible levels.

The health risks from air pollution manifest as illnesses related to the respiratory system, the cardiovascular system, the central nervous system, disorders of the blood and of the urinary system (Requia et al 2018, IARC 2013). Global Burden of Disease shows that air pollution is also linked with Ischemic heart disease, chronic obstructive pulmonary diseases, lung cancer, and stroke among others. Air pollution also affects birth weight and reduces the head circumference in babies born to women who have been exposed to air pollution (Marie Pedersen et al 2013 Lancet Respiratory Medicine).

Many of these conditions can be co-morbid, meaning they co-exist and aggravate each other (IARC 2013). Figure 1 provides a disease-wise break up of mortality due to AAP and Figure 2 provides a demographic breakup of the mortality due to AAP. Children and women are more vulnerable to air pollution. Poor people in the grip of malnutrition are also extremely vulnerable. Risks are higher among vulnerable populations such as children and pregnant women (UNICEF 2016). Globally, 93 per cent of children live in areas where air quality is above permissible levels. Air pollution contributes to ~543,000 deaths among children less than five years of age (WHO 2018).

**Figure 1: Disease wise breakup of the deaths attributable to AAP (WHO 2016)**

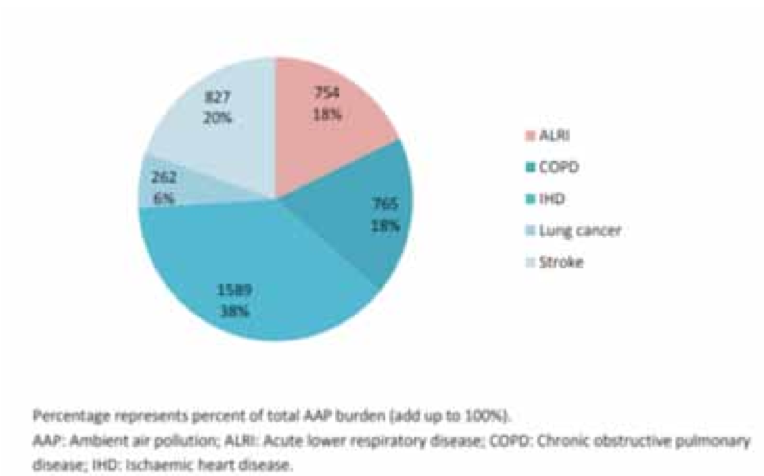
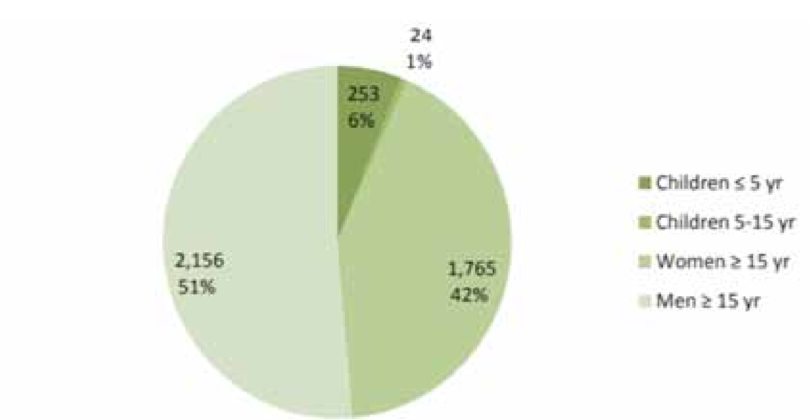



**Figure 2: Age and gender wise breakup of the deaths attributable to AAP (WHO 2016)**



The WHO and the International Agency for Research on Cancer (IARC) have now declared air pollution as carcinogenic to humans. For instance, experts at the IARC after reviewing more than 1,000 scientific publications, observe; *"We now know that outdoor air pollution is not only a major risk to health in general but also a leading environmental cause of cancer deaths". The risk of developing lung cancer is significantly increased in people exposed to air pollution. Classifying outdoor air pollution as carcinogenic to humans is an important step … a strong signal to the international community to take action without further delay"* (IARC 2013).

## INDIA'S PUBLIC HEALTH RISK

According to India's state-level disease burden (ICMR, PHFI and IHME 2017), air pollution is the second-highest risk factor for disability adjusted life years (DALY), which in short means the potential healthy life years lost due to illness. Air pollution contributes substantially to non-communicable disease burden, which is already showing a rising trend in India. As much as 99.9 per cent of the Indian population is estimated to live in areas where the World Health Organization (WHO) Air Quality Guideline of 10 µg/m3 for PM2.5 was exceeded in 2015. In 2015, particulate matter (PM) air pollution was responsible for approximately 1.1 million deaths, or 10.6 per cent of the total number of deaths in India (Health Effect Institute 2018). In the last 25 years (1990-2015), the average exposure to PM2.5 has increased from 60 µg/m3 to 74 µg/m3, with the steepest increase happening in the last 10 years. In this period, the summary exposure value (SEV) of AAP increased by 16.6%. India's specific morbidity and mortality due to air pollution have been highlighted by the Expert Committee Report of the Ministry of Health and Family Welfare (MoHFW, 2015). In 2015, PM2.5 air pollution contributed to 10.6% (1.09 million) of total deaths. This is an increase of 48% from the levels in 1990. Of these, 25% were due to residential biomass burning, 15.5% were due to coal combustion, 9.2% were due to anthropogenic dust, 28.8% due to windblown and mineral dust, 6.1% were due to agriculture residue burning., and ~2% each to transportation, distributed diesel, and brick production.

Of the 4.2 million deaths attributed to ambient air pollution, 17% were due to ischaemic heart disease (IHD), 16% to lung cancers, 25% to chronic obstructive pulmonary disease (COPD), 26% to lower respiratory tract infections (LRI) and other diseases. In 2016, PM2.5 contributed to 5.9% of the total DALYs (29.6 million years of healthy life lost) and was second only to undernutrition (14.6%). Of this 44 % were due to IHD and CVD, 29% were due to LRI, and 25% due to COPD.

The economic cost of increased health burden due to air pollution was estimated at a lost labour output equivalent to USD 55 billion and welfare loss equivalent to USD 505 billion, in the year 2013 (World Bank, IHME 2016)

If no action is taken, population exposures to PM2.5 are likely to increase by more than 40% by 2050. If no action is taken, the deaths attributable to PM 2.5 can rise to 3.6 million. But mitigation of PM2.5 can provide health gains. If the pollution levels were brought down to WHO permissible limits, then the average life expectancy would increase by 4.3 years on a pan-Indian level, by 8.6 years for residents of Uttar Pradesh and by more than 10 years for residents of Delhi (EPI 2018)

Several studies have emerged at the city level as well. In Delhi, every third child has impaired lungs (CPCB 2012). Children growing up in a polluted environment have smaller lungs, by at least 10% when compared to the children in developed countries (SK Chhabra 2017).

From a public health policy perspective, framing city-level as well as nation-wide mitigation strategies with legally binding reduction targets will be a necessary intervention to reduce health risks.

## CLIMATE CHANGE RISK

What is not clearly understood at the policy level is that there is also mounting evidence of the interaction between air pollution and climate change concerns such as global warming. While long-lived climate forcers like carbon dioxide ($CO_2$) that have a residence life of 100-500 years in the atmosphere, the local air pollutants that are short lived – from a few hours to 20 years – also have significant warming potential. These are black carbon, methane and others.

The atmospheric brown clouds (ABC) generated by air pollutants and part of the regional haze, adversely impact climate in several ways (Ramanathan et al 2009, Ochoa-Hueso et al 2017). First, the aerosols (sub-micron size particles) both reflect and absorb sunlight (dimming effect) with a surface cooling impact which influences the hydrological cycle and hence the rain patterns. Second, the carbons in ABC absorb solar radiation and thereby amplify the greenhouse warming effect on the climate. It also accelerates the melting of icecaps.

The International Panel on Climate Change (IPCC) had initially listed six greenhouse gases (the "Kyoto six") including the long lived $CO_2$ . Also listed were methane, nitrous oxide, sulfur hexafluoride, and two fluorocarbons that have much shorter lives. The IPCC has now included black carbon in the list. The IPCC report (AR5) released in 2014 has doubled the estimate of the warming caused by black carbon – it is now considered to cause warming at least 800 times more than its previous estimate over a 100 year period when compared to CO2.

Ozone, aside from its health impacts, is also a short-lived climate pollutant. Tropospheric ozone is one of the most important greenhouse gases (GHG). The Sulfur Dioxide (SO2) combines with water in the air to form sulfuric acid, which is a primary constituent of acid rain. Despite its short atmospheric lifetime, black carbon is one of the largest contributors to global warming after Carbon Dioxide (CO2). Black Carbon is also known to decrease agricultural yields and accelerate glacier melting.

This implies that a severe mitigation of air pollution will give the co-benefit of reducing local or regional warming impacts and their adverse impacts on rainfall as well as reducing glacier melting, both of which are serious threats. The WHO has linked its health agenda with the UN Framework Convention on Climate Change (UNFCCC) (A. Roychowdhury, CSE 2016).

## AIR POLLUTION AND SOCIAL EQUITY IMPACTS

Yet another dimension of air pollution mitigation is the disproportionately high health and cost burdens on the lower income classes, especially in developing countries like India. These countries are also the most vulnerable to health costs associated with climate change and extreme weather events. The incidence of poverty is high in the least-developed and developing countries. The results of several studies suggest that socio-economic status can be a potential effect modifier (IARC 2013). Poverty is a strong correlate of the degree of exposure to environmental health risks. Globally, the burden of diseases attributable to air pollution falls heavily on lower and middle-income countries (LMIC). 91% of premature deaths due to air pollution occur in LMIC (WHO 2016).

In India, the disease burden is generally highest in north-Indian states with low socio-demographic Index (SDI) levels. The states were categorised into three Socio-demographic Index (SDI) levels as calculated by GBD 2017 on the basis of lag-distributed per-capita income, mean education in people aged 15 years or older, and total fertility rate in people younger than 25 years (K Balakrishna et al, 2018 Lancet).

Studies carried out in Europe and North America have shown that low economic status increases the rates of morbidity and mortality related to air pollution and determines the vulnerability of the population to environmental risks. Variations in socioeconomic status influence exposures to air pollution and the exposures can be different from the developed countries. Poverty in India and Asia also indicates large scale malnutrition, poor health status and a range of other underlying diseases that further enhance health risks. Also, other determinants including the location of the residents, proximity to traffic and small-scale or informal industries, and overall activity patterns and time spent near the pollution sources have a significant bearing on the health risks from air pollution. In developing countries, the use of solid fuels for indoor cooking is a major detrimental factor and cause of exposure to pollutants (Atmospheric Environment, 2014).

Differential impacts occur through differential exposures and differential susceptibilities. These differences occur due to housing quality and air exchange rates and the presence of indoor pollution sources. Poverty status further increases susceptibility due to differences in underlying health status and access to medical care. Poverty leads to substandard medical care, substandard nutrition, substandard housing, and reliance on inefficient and excessively polluting vehicles and cooking appliances.

Air pollution control measures need to be based on the principle of environmental justice as poor people are more susceptible to health risks, and are also vulnerable to economic dislocation due to air pollution control measures that target their livelihood base, all largely in the informal sector.

## LOCAL SOURCES AND GLOBAL CONSEQUENCES

The scientific evidence also indicates that mitigation of air pollution will require regional and global cooperation to reduce the trans-boundary effects of air pollution. Seasonal air currents can also carry pollutants from their local source to faraway places, which make combating air pollution not just a local problem, but a national and international problem too (Freidman et al 2014).

Local air quality can be affected by long distance atmospheric transport of pollution from distant sources. Studies have also found that in international trade patterns, production of goods in one region for consumption in another region drives this problem to a great extent. One study shows that in 2007, of the 3.45 million premature deaths related to PM2.5 worldwide, about 12 per cent was related to air pollutants emitted in a region other than the one in which the death occurred. (Qiang Zhang, Nature International Journal of Science 2017). This builds a strong case for global action.

Moreover, there is also the problem of domestic transboundary movement of pollution. In India, it has been found that in a city like Delhi approximately 26% of its particulate pollution is due to outside influence (TERI-ARAI 2018). The regional influences are substantial. For instance, the satellite imagery shows pollution build-up across the Indo-Gangetic plain that influences cities in the entire region. This phenomenon is evident in the periodic and temporary movement of smoke and pollutants from agricultural stubble-burning from the fields of Punjab and Haryana to Delhi. Air pollution mitigation, therefore, requires both local and regional action.

## CONCLUSIONS

This overview of scientific evidence on the diverse impacts of air pollutants brings out the complex challenge that policy-formulation faces. This calls for policy action. While public health concern over air pollution will remain the primary driver of policy action and rightly so, the policy design and implementation detail will have to be worked out in a way so as to achieve multiple goals and co-benefits. This indicates that the next level of policy action cannot remain fragmented in its scope but needs to be integrated and aligned for maximum co-benefits. This will also help influence investment decisions and resource allocation across sectors and bring greater economic efficiency while maximising benefits in terms of reducing health and climate risks, environmental and ecosystem risks, and reduce transboundary effects of pollution.

This will require a more deliberate and explicit connection with the sustainable development goals (SDGs). In developing countries like India SDGs have been formally ratified and are expected to be integrated with the mainstream policies. This is an opportunity to improve the quality of life. In fact, Indian cities have already been mandated to adopt SDGs for sectoral planning.

Combating air pollution is inherently linked to achieving Sustainable Development as air pollution is linked with several of the United Nations 17 Sustainable Development Goals. For instance, achieving Sustainable Development Goals (SDG) 3.9.1 (pollution-related mortality), SDG 7.1.2 (clean energy in households), and SDG 11.6.2 (air quality in urban areas) needs an effective strategy to mitigate air pollution (UNICEF 2016). Strategies aiming at improved air quality interact directly with climate mitigation targets, access to clean energy services, waste management, and other aspects of socio-economic development. If integrated policies are followed to meet the interlinked goals that are related to energy access, limiting climate change and reducing air pollution, a significant reduction in pollution is possible. By

2040, emissions of main pollutants are projected to drop by 60–80% from the current baseline (PeterRafaj et al, 2018; Science Direct 2018).

This builds a strong case for bringing synergy between air pollution and climate change mitigation policies as well as SDGs. Already India has adopted wide ranging policies including Climate Action Plan with eight missions, National Clean Air Programme, National Habitat Standard, Smart City Programme, Renewable Energy Policy, National Urban Transport Policy, and Energy Conservation policies. These are supported by wide-ranging environmental regulations for industry, power plants, transportation, clean energy, building sector, waste sector and the agricultural sector.

Such alignment and synergy can help develop a cross-sectoral integrated roadmap to maximise air quality benefits and meet the air quality targets. Accounting for the impacts and costs in the national policy development in sectors such as energy and renewable energy, transport and mobility, and waste management will provide pathways for a significant reduction.

Mitigation strategies should also be framed at regional scales as well as at a global scale to reduce not only local health exposure and environmental impacts but also to mitigate climate change and transboundary effects of air pollution at a global level. India's diplomacy will have to target global climate negotiations, country blocks and trade blocks in order to address these issues. Perceiving them as applicable for equitable access to global finance and technology flows can certainly help to meet the cost of sustainable development needed for clean air.

## APPENDIX

Key air pollutants and their sources, health and environmental impact, and WHO guidelines

| Major air pollutants and their sources | | |
|---|---|---|
| **Pollutants and WHO guidelines** | **About the pollutant and sources** | **Health and environmental effect** |
| Particulate matter less than 10 micron size ($PM_{10}$): Size ≤ 10 microns (μ)<br><br>WHO: 20 μg/m$^3$ annual mean<br><br>50 μg/m$^3$ 24-hour mean<br><br>($PM_{2.5}$): Size ≤ 2.5 μ<br><br>WHO: 10 μg/m$^3$ annual mean<br><br>25 μg/m$^3$ 24-hour mean | Mixture of solid particles and liquid droplets. These particles are made up of a varying combination of dust, soot, mineral dust, black carbon, water, sodium chloride, ammonia, sulfates, water and nitrates.<br><br>Comes from internal combustion engines (ICE, both petrol and diesel), industrial processes (building, mining, manufacture of cement, ceramic and bricks, and smelting) and power generation industries (coal, lignite and heavy oil). Also, natural dust. | Fine particles go deep into the lungs, and bloodstream; affect lungs and heart. Cause premature death in people with heart or lung disease, nonfatal heart attacks, irregular heartbeat, aggravated asthma, decreased lung function, increased respiratory symptoms, coughing or difficulty breathing. Associated with cancer of lungs, urinary tract and bladder.<br><br>Fine particles cause reduced visibility (haze) and can be carried over long distances. Depending on chemical composition they make lakes, streams and soil acidic; Contribute to acid rains |

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| Black Carbon | It is a major component of $PM_{2.5}$ and driver of climate change. It is also known as a "short-lived climate pollutant (SLCP)." SLCPs persist in the atmosphere for a shorter period compared to CO2.<br><br>Key sources are diesel combustion, brick kilns etc | While this has a similar health impact as particulate matter, it is also a potent global warming agent. It absorbs heat and warms up; interferes with rains, and accelerates snow melting. |
| Ground level Ozone $(0_3)$<br><br>100 $\mu g/m^3$ 8-hour mean | It is one of the major components of photochemical smog. It is a secondary pollutant, meaning that it is not directly emitted. Instead, it is produced when carbon monoxide (CO), methane, or other volatile organic compounds (VOCs) are oxidized in the presence of nitrogen oxides (NOx) and sunlight. Hence its levels peak during the sunlight hours<br><br>Major sources of NOx and VOCs include motor vehicle exhaust, industrial facilities, and chemical solvents. Major sources of methane include waste and fossil fuels and agricultural industry | People most at risk from breathing ozone include people with asthma, children, older adults, and people who are active outdoors, and outdoor workers. Breathing ozone can trigger chest pain, coughing, throat irritation, and airway inflammation. Reduces lung function and harms lung tissue. Ozone can worsen bronchitis, emphysema, and asthma, leading to increased medical care<br><br>Ozone affects agricultural crops, sensitive vegetation, especially during the growing phase, and ecosystems, including forests, parks, wildlife areas. |

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| Nitrogen dioxide ($NO_2$)<br><br>WHO:<br>40 μg/m³ annual mean<br><br>200 μg/m³ 24-hour mean | NO2 is one of the many nitrogen oxides and is the main source of nitrate aerosols or secondary particulate, which forms an important fraction of $PM_{2.5}$ and, in the presence of ultraviolet light, of ozone also.<br><br>Comes from combustion sources, heating and power generation, and engines in vehicles and ships. | NO2 irritates airways and affects the respiratory system. Short term exposures aggravate respiratory diseases, asthma, coughing, wheezing or difficulty breathing leading to emergency hospital admissions. Longer exposures may contribute to the development of asthma and increase susceptibility to respiratory infections, bronchitis. Contributes to premature mortality.<br><br>NO2 and NOx contribute to forming acid rain that harms sensitive ecosystems. Also contribute to haze. |
| Sulfur dioxide ($SO_2$)<br><br>WHO:<br>20 μg/m³ annual mean<br><br>500 μg/m³ 24-hour mean | $SO_2$ is a colourless gas with a sharp odour.<br><br>Largest source is burning of fossil fuels by power plants and industrial facilities. Smaller sources are industrial processes such as extracting metal from ore; natural sources such as volcanoes; locomotives, ships and other vehicles and heavy equipment that burn fuel with a high sulfur content. | Short-term exposures to SO2 can harm the respiratory system and make breathing difficult. Children, the elderly, and those who suffer from asthma are particularly sensitive to it.<br><br>SOx also contributes to secondary particles.<br><br>SOx harms trees and plants by damaging foliage and decreasing growth. Contributes to acid rain. Also impairs visibility. |

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| Carbon monoxide (CO)<br><br>WHO: 100 mg/m³ 15 minutes<br><br>60 mg/m³ 30 minutes<br><br>30 mg/m³ 1 hour<br><br>(10 ppm) 8 hours | It is a colourless and odourless gas formed during the incomplete combustion of carbon-containing fuels.<br><br>Motor vehicle exhaust and machinery that burn fossil fuels<br><br>Indoors unvented kerosene and gas space heaters, leaking chimneys and furnaces, and gas and coal stoves also release CO. | CO reduces the amount of oxygen that can be transported in the bloodstream to critical organs like the heart and brain. At very high levels, CO can cause dizziness, confusion, unconsciousness and death.<br><br>Concern for heart disease. Short-term exposure to elevated CO may result in reduced oxygen to the heart, chest pain and angina. |
| Lead[1] | It is a naturally occurring bluish-gray metal found in small amounts in the earth's crust. Its sources are burning fossil fuels, mining, and manufacturing activities (batteries, paints, ceramic products, caulking, and pipe solder). Primarily leaded gasoline, ore and metals processing, and piston-engine aircrafts operating on leaded aviation fuel; waste incinerators, utilities, and lead-acid battery manufacturers and lead smelters. | Lead gets mixed with blood and accumulates in bones. Affects the nervous system, kidney function, immune system, reproductive and developmental systems and the cardiovascular system. Lead affects oxygen-carrying capacity of blood and has neurological effects in children and cardiovascular effects in adults. Contributes to behavioral problems, learning deficits and lowered IQ.<br><br>Lead is persistent in soils and sediments through deposition. Decreases plant growth and reproductive rates in plants and animals, and leads to neurological effects in vertebrates. |

Source: WHO 2006

[1] Centre for Disease Control (CDC) website (https://www.cdc.gov/air/pollutants.htm) [Accessed on 24 Nov 2018]

Source: WHO 2006;

[2] WHO website ( http://www.euro.who.int/__data/assets/pdf_file/0020/123059/AQG2ndEd_5_5carbonmonoxide.PDF) [Accessed on 24 Nov 2018]

[3] Centre for Disease Control (CDC) website (https://www.cdc.gov/air/pollutants.htm) [Accessed on 24 Nov 2018]

USEPA Criteria pollutants https://www.epa.gov/criteria-air-pollutants (accessed on 25 January 2019)

## CONFLICT OF INTEREST STATEMENT

The corresponding author confirms on behalf of all authors that there have been no involvements that might raise the question of bias in the work reported or the conclusions, implications, or opinions stated.

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