

Air Quality Management for Decision Makers in Indian Cities

Training Manual



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Train4CleanAir (T4CA)

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INTRODUCTION

National Clean Air Programme (NCAP), launched in 2019, is India's flagship program for better air quality. NCAP designated 122 cities as non-attainment from 21 states and 2 union territories (Chandigarh and Delhi) based on the ambient monitoring data from the network operated by Central Pollution Control Board (CPCB). As of August 2021, the number of non-attainment cities has increased to 132. NCAP in its first round of activities aims to increase the capacity of the Pollution Control Boards both CPCB and SPCBs to measure, evaluate and manage air pollution. This includes improving capacity in preparation of an information baseline for emissions and assessment of source contributions, communication strategies to maintain and disseminate information, clean technology assessments and review, management development on inspection monitoring, awareness generation and designing strategies for air pollution mitigation.

Train for Clean Air (T4CA) is a regional training approach that aims to assist cities to create and implement Clean Air Plans (CAPs) and make informed policies and decisions. It includes standardized modular training courses customized for different stakeholders – decision-makers, technical staff, researchers, NGOs, and the media. Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ) in partnership with Clean Air Asia in 2008 developed T4CA modules for an international audience. Clean Air Asia has used these modules to conduct several trainings to build the capacity of officials and strengthening implementation and monitoring of clean air action plans of different cities of Asia.

Support to the National Clean Air Programme, the Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ) GmbH under the Indo-German Development Cooperation and Bloomberg Philanthropies supported Clean Air Asia to develop five training manuals based on the T4CA manuals. Since the implementation of CAPs lies with the city, officials involved in the mitigation of air pollution in need of capacity development could benefit through these manuals.

This manual titled Air Quality Management (AQM) for Decision Makers in Indian Cities is designed for a specific group of decision and policymakers whose functions encompass establishing the legal and regulatory framework for AQM, clean air action planning, championing air quality improvement and mitigation of climate change impacts and gaining support from national government agencies and development organizations for AQM.

The training manual shall support the decision-makers and strengthen their knowledge on air quality management and be able to make decisions on city development and help better air quality in India.

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Table of Abbreviations

ASEAN	Association of Southeast Asian Nations
AQI	Air Quality Index
AQG	Air Quality Guideline
AQM	Air Quality Management
CH ₄	Methane
CO ₂	Carbon Dioxide
COPD	Chronic Obstructive Pulmonary Disease
CPCB	Central Pollution Control Board
EU	European Union
GBD	Global Burden of Disease
GDP	Gross Domestic Product
GHG	Greenhouse Gases
GRAP	Graded Response Action Plan
H ₂ S	Hydrogen Sulphide
H ₂ SO ₄	Sulphuric Acid
HC	Hydrocarbon
HF	Hydrogen Fluoride
HFC	Hydrofluorocarbons
HIA	Health Impact Assessment
LRI	Lower Respiratory Infections
Km	Kilometre
MNO ₃	Manganese Oxide
MoEFCC	Ministry of Environment, Forest and Climate Change
NO	Nitrogen Oxide
NAAQ	National Ambient Air Quality Standards
NAAQM	National Ambient Air Quality Monitoring
NAMP	National Air Quality Management Program
N ₂ O	Nitrous Oxide
NCAP	National Clean Air Programme
NCR	National Capital Region
NMVOC	Non-Methane Volatile Organic Compounds
NH ₃	Ammonia
NO _x	Nitrogen Oxides
O ₃	Ozone
OCEMS	Online Continuous Emission/Effluent Monitoring System
OECD	Organisation for Economic Cooperation and Development
PAH	Polycyclic Aromatic Hydrocarbons
PAN	Peroxyacetyl Nitrate
Pb	Lead
PCB	Poly Chlorinated Biphenyls
PFC	Per Fluoro Carbons
PM	Particulate Matter
S	Sulphur
SPCB	State Pollution Control Board
SF ₆	Sulphur Hexafluoride
SO ₂	Sulphur Dioxide
SO ₃	Sulphur Trioxide
USD	United States Dollar
USEPA	United States Environmental Protection Agency
VOC	Volatile Organic Compounds
WHO	World Health Organization

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Air Quality Management for Decision Makers in Indian Cities



Target Audience

This manual is aimed at decision and policymakers whose functions encompass establishing the legal and regulatory framework for air quality management (AQM), clean air action planning, championing air quality improvement and mitigation of climate change impacts and gaining support from national government agencies and development organizations for AQM.

Contents of Manual

In the *manual, Air Quality Management for Decision Makers in Indian Cities*, participants will examine the causes of air pollution, the different types of air pollution which exist as well as the basic stages in air quality management system. The manual contents include:

- Causes of air pollution
- Range of air pollutants and their impact on human health and environment
- Steps of air quality management
- Air pollution control measures
- Co-benefits of addressing urban air quality and climate change

Objectives of the Manual

The manual can be used to support training around *Air Quality Management for Decision Makers in Indian Cities*. With the help of this manual participants can:

- Assess the importance of actions and measures aimed at reducing air pollution in cities
- Link city development with air quality management (AQM) and pollution control
- Review the organizational structures needed in the city government for a better integrated AQM
- Develop future policies to support AQM in cities

Learning Objectives

Goal

This manual enables participants involved in decision making roles to develop basic understanding of air pollution and the key components required to develop a programme to manage urban air pollution and to achieve better air quality. By working through this manual participants will gradually achieve a higher level of understanding of urban air pollution and the measures to be taken to monitor air quality and to prevent and control urban air pollution in India.

1. Urban Air Pollution



1.1 Introduction

From smog in cities to smoke in the home, air pollution poses a threat to human health and the environment. Around 91% of the world's population now live in areas with unhealthy outdoor air, causing 4.2 million premature deaths each year.¹ In India, air pollution is responsible for an estimated 1.2 million premature deaths each year and is costing the economy an estimated 3% of Gross Domestic Product (GDP).²

Urban air pollution affects the health, wellbeing and life chances of hundreds of millions of men, women and children every day. In particular, exposure to fine particulate matter (PM_{2.5}) pollution has been identified as the largest risk to human health. This is due to their small size (less than 2.5 micrometres (µm)), which enables PM_{2.5} particles to penetrate deep into the lungs where they can cause serious negative health impacts.

Indian cities have high annual mean concentrations of PM_{2.5} which exceeded the 40µg/m³ limit set by the National Air Quality Standards (NAAQS). In 2015, an estimated 670 million people in India were exposed to PM_{2.5} concentrations that did not comply with the NAAQS.⁴

It is often the poor and socially marginalised who tend to suffer disproportionately from the effects of deteriorating air quality because they live and work near sources of pollution. Polluted air kills an estimated 600,000 children (under the age of five) every year.⁵

The health impacts of air pollution are well documented; however, new evidence suggests a link between air pollution and dementia⁶ and Alzheimer's disease, and changes in behaviour.⁷ In London, researchers found a link to air pollution levels and increases in petty crime such as shoplifting and pick-pocketing.

1 WHO (2020) https://www.who.int/health-topics/air-pollution#tab=tab_2

2 State of Global Air (2019) India, Health Effects Institute, USA

3 Lim, S.S., Vos, T., Flaxman, A.D., Danaei, G., Shibuya, K., Adair-Rohani, H., AlMazroa, M.A., Amann, M., Anderson, H.R., Andrews, K.G., Aryee, M., Atkinson, et al (2012) A comparative risk assessment of burden of disease and injury attributable to 67 risk factors and risk factor clusters in 21 regions, 1990–2010: a systematic analysis for the Global Burden of Disease Study 2010. The Lancet 380, 2224–2260.

4 IASA/CEEW (2019) Pathways to achieve national ambient air quality standards in India. International Institute for Applied Systems Analysis/ Council on Energy, Environment and Water, New Delhi, India.

5 UNICEF (2016) Clear air for children. United Nations Children's Fund, New York, USA.

6 Killin, L. O. J. et al. (2016) Environmental risk factors for dementia: a systematic review. BMC Geriatrics, 16:175.

7 Pascencia-Villa, G. et al. (2016) High-resolution analytical imaging and electron holography of magnetite particles in amyloid cores of Alzheimer disease. Science Report, 6:24873.

Exposure to poor quality air can increase the stress hormone cortisol, which can influence risk perception. Higher levels of risk taking is one reason why there is a rise in criminal activity on polluted days.⁸

The state of air quality in cities is closely connected to the earth's global climate and ecosystems. Many of the causes of air pollution (i.e. combustion of fossil fuels) are also sources of greenhouse gas (GHG) emissions. Air pollution can affect the regional climate, Black carbon is among the pollutants that deposits on snow and ice, darkening surfaces. This causes greater absorption of sunlight and faster melting, threatening future water availability and ecosystem productivity.⁹ Black carbon, a PM created through the burning of fossil fuels (such as diesel) and biomass, not only affects human health but is also responsible for glacial melting of Himalayan and Tibetan Plateau.¹⁰

Policies that reduce air pollution can be beneficial for the global climate and human health; lowering the burden of disease attributable to air pollution while contributing to the near- and long-term mitigation of climate change.

This manual addresses the causes of air pollution and the different types of air pollution such as outdoor, indoor, and transboundary. It examines the issue of urban air pollution in India and outlines the key stages in an air quality management (AQM) system. An effort has been made to address India specific issues and contextualise material based on standards and norms adopted by the Government of India.



1.2 Government Initiatives

Due to the rapid growth of the industrial sector and increased vehicle transport, many developing countries face the threat of air pollution and experience its health and economic impacts. In India, outdoor air pollution is responsible for millions of premature deaths with high economic cost. To address air pollution and climate change, the government has taken several actions.

- In 1981, the Government of India enacted the Air (Prevention and Control of Pollution) Act to prevent and control air pollution in India.
- In 1984-85, the CPCB initiated the National Ambient Air Quality Monitoring (NAAQM) Network to assess the present and anticipated air pollution impacts through air quality survey monitoring programmes. Over the years, the number of stations has increased, and the programme was renamed the NAMP.
- The 1986 Environment (Protection) Act further emphasized the need to reduce air pollutant emissions.
- Under section 18(1)(b) of Air (Prevention and Control of Pollution) Act, 1986 CPCB directed the implementation of forty-two (42) measures to mitigate air pollution in major cities including Delhi and NCR comprising of action plan to counter air pollution include control and mitigation measures related to vehicular emissions, resuspension of road dust and other fugitive emissions, biomass/ municipal solid waste burning, industrial pollution, construction and demolition activities.¹¹
- In 1988, the motor vehicle act was enacted with road safety standards and pollution control measures, among others.
- On 19 January 1998, the Ministry of Environment and Forests (MoEF) established the Environmental Pollution (Prevention and Control) Authority (EPCA) for the National Capital Region (NCR) of Delhi. The EPCA was given the authority to control and tackle environmental pollution. This included taking the necessary steps to control vehicle pollution in the NCR. Based on various public interest litigation (PIL) and on the recommendation of EPCA, the Supreme Court on

28 July 1998 directed that all public transport vehicles comprising of taxis, three wheelers, and buses in Delhi were to run only on Compressed Natural Gas (CNG) after April 2001.

- Vehicles are a major contributor to air pollution in India. To keep vehicle pollution levels in check, the government introduced the Bharat Stage Emission Standards (BSES). BSES are emission standards instituted by the Government of India to regulate the output of air pollutants from internal combustion engines and spark-ignition engines. The standards and the timeline for implementation are set by the CPCB under MoEFCC. The standards, which are based on European regulations, were first introduced in 2000. Progressively stringent norms have been rolled out since then. In October 2010, Bharat stage III norms have been enforced across the country. In thirteen major cities, Bharat Stage IV emissions have been in place and are enforced for the whole country from April 2017. In 2016, The Indian Government announced that the country would skip the BS-V norms and adopt BS-VI norms by April 2020.
- In 2015, Ministry of Environment Forest and Climate Change, Government of India (MoEFCC, GoI) submitted its Intended Nationally Determined Contributions (INDCs) on climate change with the objectives of a cleaner and climate friendly economic development, reduction in emission intensity, promotion of non-fossil fuel based energy resources, development of additional carbon sink of 2.5 to 3 billion tons of CO2 equivalent through additional forest and tree cover by 2030, among other measures.
- In 2016, the Government of India published Construction and Demolition Waste Management Rules (C&D rule) to tackle the issues of pollution and waste management.
- In 2018, MoEFCC issued a Dust Mitigation notification making mandatory dust mitigation measures in infrastructure projects and demolition activities in the country.
- In 2019, the National Green Tribunal (NGT) directed state pollution control boards to install air quality monitoring stations and to report to the CPCB on the installation of the stations by 1st April 2020.¹²



8 Bondy, M., Roth, S. and Sager, L. (2018) Crime is in the air: the contemporaneous relationship between air pollution and crime. LSE Working Paper, London School of Economics, London.

9 Lacombe, G., Chinnasamy, P., and Nicol, A. (2019) Climate risk and solutions: adaptation frameworks for water resource planning, development and management in South Asia. International Water Management Institute, Colombo, Sri Lanka.

10 Li, C. et al. (2016) Sources of black carbon to the Himalayan-Tibetan Plateau glaciers. Nature Communications, 7: 12574.

11 Ministry of Environment, Forest and Climate Change (2019). National Clean Air Programme. http://moef.gov.in/wp-content/uploads/2019/05/NCAP_Report.pdf

12 Times of India. 2019. Air pollution: Get 'assessed' monitoring stations in a year, says NGT. <https://timesofindia.indiatimes.com/city/delhi/air-pollution-get-assessed-monitoring-stations-in-a-year-says-ngt/articleshow/72152635.cms>

1.3 National Clean Air Action Programme

On the 10 January 2019, the Indian Ministry of Environment, Forest and Climate Change (MoEFCC) launched a five-year national clean air action programme (NCAP) to tackle the problem of pollution (see Figure 1).The overall objective of the NCAP is to take comprehensive mitigation actions to prevent, control and abate air pollution while supporting the national air quality monitoring programme (see Box 1) and strengthening awareness and capacity.



Figure 1: Overview of the National Clean Air Programme¹³

Box 1. National Air Quality Monitoring Programme

The National Air Monitoring Programme (NAMP) consists of 703 manual operating stations covering 307 cities/towns in 29 Indian states and six Union Territories. NAMP activities include determining the status and trends of ambient air quality; ascertaining whether the prescribed ambient air quality standards are violated; and identifying non-attainment cities. Under NAMP, four air pollutants have been identified for regular monitoring at all locations. These are sulphur dioxide (SO₂), nitrogen dioxide (NO₂), suspended particulate matter (PM₁₀), and fine particulate matter (PM_{2.5}). In addition, there are 134 real-time Continuous Ambient Air Quality Monitoring stations (CAAQMS) in 71 cities across 17 states, monitoring eight pollutants (PM₁₀, PM_{2.5}, SO₂, nitrogen oxides(NO_x), ammonia (NH₃), carbon monoxide (CO), ozone (O₃), and benzene).

NCAP initially identified 102 non-attainment cities that were not meeting the annual average ambient air quality standards for PM₁₀. These cities have been identified based on ambient air quality data obtained (2011-2015) under National Air Quality Monitoring Programme (NAMP), a further 20 cities were added in August 2019, increasing the total number of non-attainment cities in India to 122.¹⁴ (See Table 1) NCAP has set a tentative national level target of 20-30% reduction of PM (PM_{2.5} and PM₁₀) concentrations by 2024 using 2017 as the base year.

NCAP’s approach includes collaborative, multi-scale and cross-sectoral coordination between the relevant central ministries, state governments and local bodies. This includes coordination with existing policies and programmes, such as the National Action Plan on Climate Change (NAPCC) (see Box 2) and the Climate Smart Cities Assessment Framework (see Box 3). Under NCAP, the 122 non-attainment cities have to develop city specific action to implement mitigation actions.

Box 2. National Action Plan on Climate Change

Launched in 2008, NAPCC included eight core “national missions” which represents a multi-pronged, long-term and integrated approach for achieving key goals in the context of climate change. These include: National Solar Mission, National Mission for Enhanced Energy Efficiency, National Mission on Sustainable Habitat, National Water Mission, National Mission for Sustaining the Himalayan Ecosystem,

National Mission for a Green India, National Mission for Sustainable Agriculture, and National Mission on Strategic Knowledge for Climate Change¹⁵. In 2016, India ratified the UN Paris Agreement to combat climate change. The Paris Agreement requires all Parties to put forward their best efforts through “nationally determined contributions” (NDCs). NDCs embody efforts by each country to reduce national emissions and adapt to the impacts of climate change. The Paris Agreement (Article 4, paragraph 2) requires each Party to prepare, communicate and maintain successive NDCs that it intends to achieve.¹⁶

Box 3: Climate Smart Cities Assessment Framework



In 2019, the Ministry of Housing and Urban Affairs launched the Climate Smart Cities Assessment Framework for 100 identified Smart Cities under Smart City Mission.¹⁷ Out of 100 Smart Cities, 54 smart cities are also identified as non-attainment cities (see Table 2). This assessment framework is aimed at helping smart cities to take actions to tackle climate change and be more responsive and less vulnerable to climate change. The Framework has 30 indicators across five sectors: (i) energy and green buildings; (ii) urban planning and biodiversity and green cover; (iii) mobility and air; (iv) water resource management; and (v) waste management. It addresses both mitigation and adaptation.

¹³ Government of India (2019) National Action Clean Air Programme. New Delhi, India.
¹⁴ The Times of India (2019) 20 more cities added to CPCB’s ‘polluted list’. 18 August 2019.

¹⁵ Government of India (2008) National Action Plan on Climate Change. New Delhi, India.
¹⁶ UNFCCC (n.d.) What is the Paris Agreement? United Nations Framework Convention on Climate Change, Berlin, Germany.
¹⁷ See: <https://smartnet.niua.org/csc/assessment-overview.html>

1.4 City Development And Air Pollution

India is a vast country with an emerging economy. With its burgeoning population and widespread poverty, India faces enormous challenges in meeting commitments associated with poverty reduction, and eradication of hunger under the UN Sustainable Development Goals (SDGs) (see Box 4).

The 17 SDGs aim to end extreme poverty and create a healthy, sustainable world by the year 2030.

Health and wellbeing of people and the planet are at the heart of the SDGs. However, the deaths and disabilities caused by air pollution and its close links to climate change means it is a threat to delivering on the SDG vision of a better world.¹⁸

The environmental risk to human health changes as a city develops, moving from the household to community and global scale. Air pollution becomes a public health concern, GHG emissions increase while the severity of the household water quality and sanitation problems decline.¹⁹

As a country develops further, environmental controls are tightened and community-level risks (urban air pollution) tend to decline. In wealthy cities, strict regulation and the implementation of abatement technology reduce polluting emissions to ensure they meet health guidelines.

Policies and investments supporting cleaner transport, energy-efficient housing, power generation, industry and better municipal waste management can effectively reduce key sources of urban air pollution.

This decline in community risk leads to the richest countries contributing to global risks such as climate change due to the higher per capita GHG emissions.²⁰

In recent years, medium and small towns and cities in India have witnessed a rise in air pollution. The NCAP sets out an approach to better air quality in India's cities, by reducing PM concentrations in 122 non-attainment cities with the implementation of clean air action plans.

Box 4. Air Pollution and the Sustainable Development Goals

SDG 3, 7, 11 and 13 and relevant targets are closely linked to air pollution. The targets include reduction in pollution, reducing related deaths and disabilities, change in fuels for reducing air pollution and other actions to combat climate change.



Good health and well-being are a basic building block for people to achieve their potential in school, at work and at home. Every step taken to reduce air pollution is a step towards achieving this goal.

Access to clean and affordable energy is key to getting people out of poverty and enabling sustainable economic development. Three billion people cook and heat their homes with dirty fuels. This results in air pollution that kills almost four million people each year, mainly women and children. Clean and renewable energy can save lives and boost economic development.



Sustainable cities and communities are crucial in an urbanised world. In 2016, more than half of urban dwellers were exposed to outdoor air pollution levels at least 2.5 times above World Health Organization safe levels. Policies that make cities smart, resilient and green-through urban planning, technology and citizen participation-can provide better air quality and transform the urban landscape.

Many of the air pollutants that affect human health also contribute to heating the atmosphere. Actions to improve air quality-such as switching to cleaner energy, cooking and transport solutions-will also address the climate emergency.



2. Air Pollution: The Silent Killer



Air pollution is the contamination of the air we breathe with harmful substances, such as gases, dust, fumes and odour. The use of fossil fuels (coal, oil and gas), changes in land use and industrial activities all produce polluting air emissions. When emissions

of these air pollutants exceed the capacity of natural processes to convert or disperse them, they can cause damage to human health and the environment (see Figure 2).²¹

18 UNEP (2019) Air Pollution and the Sustainable Development Goals. United Nations Environment Programme, Nairobi, Kenya.
19 McGranahan, G. Jacobi, P. Songsore, J. Surjadi, C., Kjellen, M. (2001) The Citizens at Risk: From Urban Sanitation to Sustainable Cities, Earthscan, London.

20 Schwela, D. et al. (2008) Urban Air Pollution in Asian Cities, Earthscan, London.
21 EEA (2003) EEA Signals 2003. European Environment Agency, Copenhagen, Denmark.

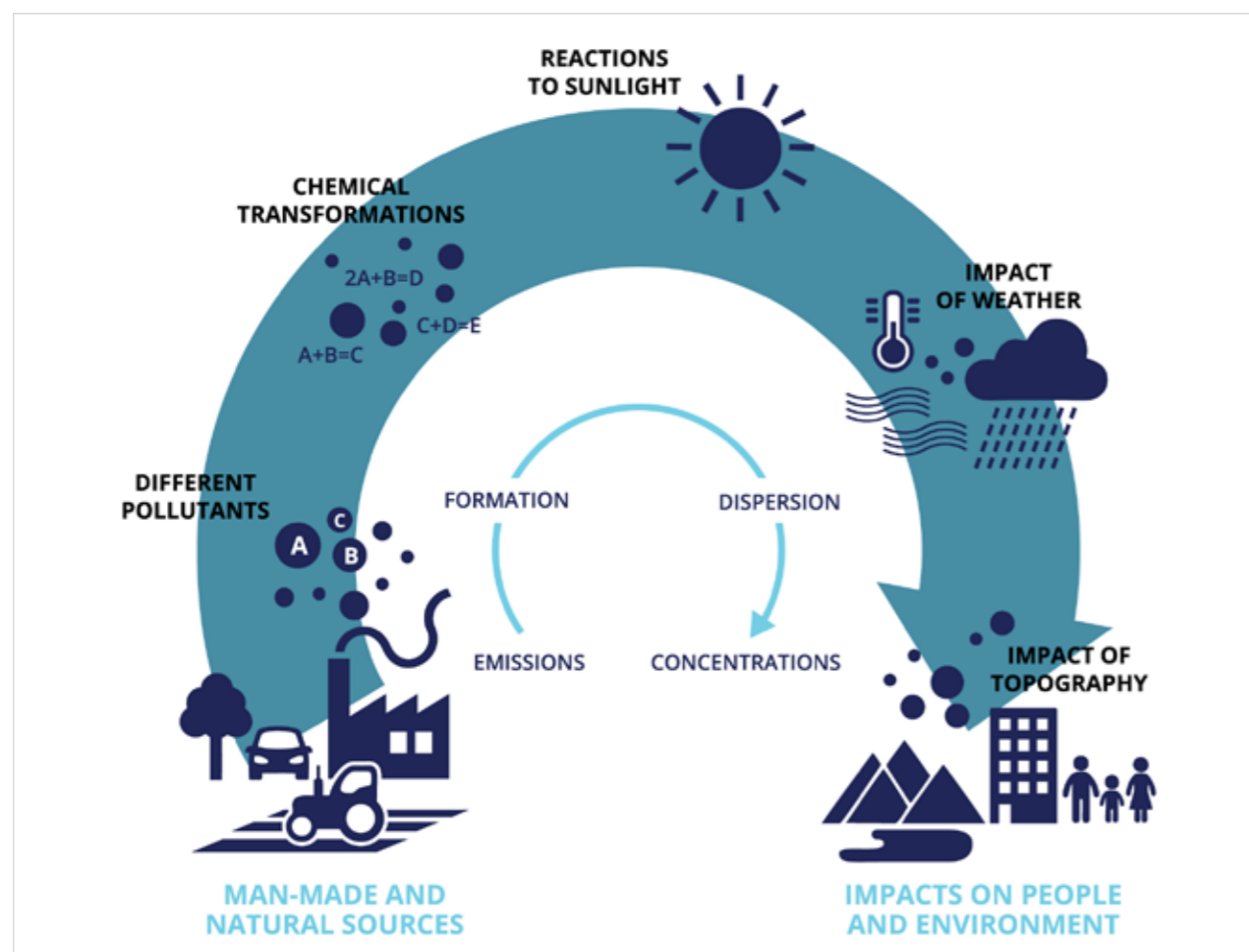


Figure 2: Air pollution from emissions to exposure²²

Air pollution occurs both indoors and outdoors. Indoor air pollution is caused mainly by the household burning of solid fuels such as wood, dung, agricultural residues, coal, and charcoal for cooking and heating. Outdoor air pollution, also called ambient air pollution, is due to polluting emissions from human activities such as use of motor vehicles, and natural sources such as dust storms.

India has some of the worst urban air pollution levels in the world.²³ Main sources of air pollution include road transport, construction, biomass burning, diesel generators, commercial and domestic fuel use.

Data from NAMP has shown that PM concentrations exceeded NAAS across the country. Other pollutants such as sulphur oxides (SO_x), nitrogen oxides (NO_x) and ozone (O₃) mostly meet national standards.

Urban areas in the Indo-Gangetic plain are at a particular disadvantage due to their geographical

location and soil composition. The Indo-Gangetic plain is essentially landlocked with the Himalayas preventing polluted air from escaping to the north, and dry alluvial soil further contributing to wind-blown dust.

Evidence suggests that poor air quality is threatening the health and wellbeing of Indian citizens.²⁴ Air pollution is now the second largest risk factor contributing to disease in India after malnutrition.

In 2015, India recorded 268,000 deaths caused by biomass fuel burning with 169,000 deaths caused by coal combustion from both thermal electric power plants and industry. Anthropogenic PM_{2.5} contributed to 100,000 deaths while agricultural burning contributed to 66,000 deaths; and transport, diesel, and kilns contributed to over 65,000 deaths.²⁵

²² EEA (2003) *ibid*.

²³ India State-Level Disease Burden Initiative Air Pollution Collaborators (2019) *Lancet Planet Health*, 3: e26–39 [http://dx.doi.org/10.1016/S2542-5196\(18\)30261-4](http://dx.doi.org/10.1016/S2542-5196(18)30261-4)

²⁴ India State Level Disease Burden Initiative Collaborators. Nations within a nation: variations in epidemiological transition across the states of India, 1990–2016 in the *Global Burden of Disease Study*. *Lancet* 2017; 390: 2437–60.

²⁵ HEI (2018) Air pollution from many sources creates significant health burden in India. Health Effects Institute, USA.

2.1 From The Local To Global Scale

Apart from the physical state of pollutants (such as gaseous or particulate matter) it is important to consider the geographical location and distribution of the emission sources. Air pollution can occur

at the household, urban, peri-urban, regional and global scale (see Figure 3). Where and how long gases remain in the atmosphere determines the type of pollution they cause. Moderately long-lived gases contribute to urban and regional air pollution, such as smog over a city or acid rain impact over a region. Long-lived pollutants such as GHG contribute to global heating and represent global scale air pollution.



Figure 3: Air pollution from the local to the global level

2.1.1 Household

Indoor air pollutants can be grouped into four categories:

1. **Combustion contaminants** comprise a large group of gaseous and particulate pollutants that may be emitted from all types of combustion. The composition and magnitude of the combustion contaminants emissions depend on the combustion efficiency. Smoke from combustion processes may contain thousands of substances, many of which damage human health.
2. **Volatile organic compounds (VOC)** may be emitted to indoor air from many sources. These include building materials, household products

and paints, or from contaminated soil.

3. **Biological agents** include mildew, moulds, fungi, or bacteria. Furthermore, biological allergens such as dust mites may cause an allergic reaction in vulnerable people.
4. **Other contaminants** are specific groups of chemicals such as pesticides or asbestos.

On a global scale, indoor air pollution is responsible for the premature death of 3.8 million people due to exposure to household air pollution from inefficient cooking practices using polluting stoves together with solid fuels and kerosene.²⁶ Around 3 billion people worldwide cook using polluting open fires or simple stoves fuelled by kerosene, biomass (wood, animal dung and crop waste) and coal.

²⁶ WHO (2018) Household air pollution and health, World Health Organization, Geneva.

Smoke from biomass fuels and coal contains a range of health-damaging pollutants including PM_{2.5} that penetrate deep into the lungs. In poorly ventilated dwellings, indoor smoke can be a hundred times higher than acceptable levels for small particles, which are set for outdoor air. Exposure is particularly high among women and children in rural areas, who spend more time indoors.

Although household air pollution is common it is also preventable. Replacement of solid cooking fuels with clean fuels such as liquid petroleum gas (LPG) gas was exemplified by the Pradhan Mantri Ujjwala Yojana, which intended to provide 80 million 'below poverty level' households with LPG by 2019. As per the state-wise PMUY connections record, by September 2019 the total registered connections were 80,339,993. This Indian programme is likely to have been the most effective intervention to reduce emissions of household air pollutants.²⁷

2.1.2 Urban

Over the last five decades, there has been unprecedented growth in Indian cities. The urban population of India has grown nearly fivefold from 60 million in 1947 to around 400 million people today. There are currently three Indian megacities with a population of more than 10 million people (Mumbai, New Delhi, and Kolkata).²⁸

As Indian cities are increasing in size and population, there is a steady demand for motorised vehicles, which places pressure on the city's infrastructure and environment, including poor urban air quality.

Urban air pollution not only has immediate localised impacts on human health and wellbeing but also contributes to regional and global air pollution. For example, regional acidification is increasingly experienced in East Asia and Southeast Asia. The use of fossil fuels in the industrial and transport sectors, not only contribute to climate change but also the haze in South Asia known as the 'Atmospheric Brown Cloud', which is a mass of ash, acids, aerosols and other particulates.

Smog

Smog is a combination of smoke and fog and has a high content of air pollutants. Smoke is an aerosol originating from combustion. Its noxious mixture of air pollutants that can be seen as a haze in the air. It often stays for an extended period of time over densely populated cities or urban areas, such as London, New York, Los Angeles, Mexico City, Houston, Toronto, Athens, Beijing and Hong Kong.

Normally, the ambient temperature decreases with altitude. During a temperature inversion, air close to the earth is cooler than the air above it. This prevents the air near the ground to rise because it is heavier than the air above it. The pollutants present in the air cannot be dispersed and remain trapped near the ground. Cities surrounded by mountains may also experience the trapping of air pollutants within the valley. Night-time temperature inversions are typical, when the air cools down in the absence of sunlight but at a rate slower than the cooling of the ground. Temperature inversion can occur in any season.

Winter inversions are likely to cause particulate and carbon monoxide (CO) pollution. In London, smog was frequently observed during winter due to additional emissions from domestic space heating and the special urban meteorological conditions during this time of the year. It is also known as winter smog. Summer inversions are more likely to create smog. Smog can make breathing more difficult (even for healthy people) and it can make people susceptible to cardio-respiratory diseases. Even healthy young adults breathe less efficiently on days when the air is heavily polluted, especially if exercising outdoors.

On the 7 November 2017, the Indian Medical Association declared a public health emergency in and around New Delhi. The air quality index (AQI) uses a scale of 0–500, with higher values (>100) associated with increasing public health hazards. The peak AQI for New Delhi was 486/500 on 9 November 2017 which falls within the severe category. This would have had an adverse respiratory impact on the whole population.²⁹

2.1.3 Peri-urban

It is often assumed that ambient air quality in rural areas is better than that in towns and cities. While this may be true for some primary gaseous air pollutants emitted directly from urban sources, it is not necessarily true for PM_{2.5}. For ground level O₃ (a secondary air pollutant that is formed in the atmosphere through photochemical reactions) the levels are often lower in urban areas than in suburban areas and the surrounding countryside.

The burning of agricultural crop residue to clear fields is a major contributor to air pollution. When rice farmers in north-western India burn their fields, PM_{2.5} concentrations in the highly populated city of New Delhi spike to about 20 times beyond the World Health Organization's (WHO) air quality guidelines. Living in areas where crop burning is common is associated with a three-fold higher risk of acute respiratory infection with children being particularly susceptible to the health effects of crop burning.³⁰

2.1.4 Regional and transboundary

The transboundary movement of air pollution across borders may cause adverse effects in countries other than the country of origin. Regional and transboundary air pollution has been a topic of scientific research for several decades but with advanced monitoring and modelling technology there is more evidence that pollution emitted in one part of the world can create adverse effects in other parts.

Pollutants with a potential for regional and intercontinental transport include: PM, acidifying substances such as SO₂, CO, O₃ and its precursors such as VOC and NO_x; heavy metals (mercury); and persistent organic pollutants.



27 Jindal, S. K, Aggarwal, A. N., Jindal, A. (2020) directions. Current Opinion in Pulmonary Medicine, 16:2, p128-134.

28 Shrivastava, M., Ghosh, A., Bhattacharyya, R., and Singh, S.D. (2019) Urban Pollution in India. Urban Pollution: Science and Management, First Edition. Edited by Susanne M. Charlesworth and Colin A. Booth. John Wiley & Sons Ltd.

29 Mishra, M (2019) Poison in the air: Declining air quality in India. Lung India. Mar-Apr; 36(2): 160–161.

30 Chakrabarti, A, Khan, M. T., Kishore, A, Roy, D and Scott, S. P. (2019) Risk of acute respiratory infection from crop burning in India: estimating disease burden and economic welfare from satellite and national health survey data for 250 000 persons. International Journal of Epidemiology, 2019, 1113–1124.



Regional haze from forest fires

Haze is the suspension of extremely small (dry) particles in the atmosphere which are invisible to the naked eye. However, they are numerous enough to reduce visibility. Small particles scatter and absorb sunlight which affects cloud formation and may introduce a range of effects from visibility reduction to climate change.

Uncontrolled forest fires in Southeast Asia cause haze almost every year. Transboundary haze pollution from forest fires is one of the most severe air pollution problems in the ASEAN region. The haze from forest fire causes deleterious effects to human health, nature, and material property. The incomplete combustion nature of forest fires emits smoke containing large amounts of toxic gases (e.g. CO and Hydrocarbons), and fine particles, which can be transported over a great distance.

In India, 5% of the biomass fires are from the irrigated croplands whereas 14% is from semi-deciduous forest fires. The maximum forest fire counts are reported during pre-monsoon (March to May) whereas the crop residue burning occurs in a dual phase season pre-monsoon (April and May)

and post monsoon (October and November). Open burning of agricultural residue contributes a large amount of air pollutants and spreads over the Indo-Gangetic plains during post-monsoon to winter.³¹

Exposure to haze air pollution can be substantial as it involves a large number of people over a large region. Haze also can cause transport disruption and accidents due to visibility reduction, which may result in life and economic losses.

Acid Rain

Acid rain was one of the first transboundary issues of concern. It was observed in 1960-1970s in North America, Canada and Europe. Nowadays, most industrialised countries have reduced SO₂ emissions. However, NO_x emissions have remained constant or are rising due to increasing emissions from mobile sources. Acid deposition includes both dry and wet deposition. The term 'acid rain' is normally used to address the wet acid deposition though it is sometimes used interchangeably with 'acid deposition'. The acidity of "pure" rain is pH 5.6-5.7. A wide-range of pollutants in the atmosphere such as SO₂, NO_x, ammonia (NH₃), organic compounds, and windblown dust, can lower pH and make

rainwater more acidic. Acid rain refers to all types of precipitation that has a pH below 5.6 (see Figure 4). Major human-made precursors of acid rain are SO₂ and NO_x. These are emitted primarily from fossil fuel combustion in stationary (e.g. smelters) and mobile sources (e.g. motor vehicles). These gases may remain

in the atmosphere for several days, during which they can travel over large distances, beyond 500-1000 km. In the atmosphere they are transformed into acidic compounds by a complex series of chemical reactions and deposited on the Earth's surface (see Figure 5.)

The pH Scale

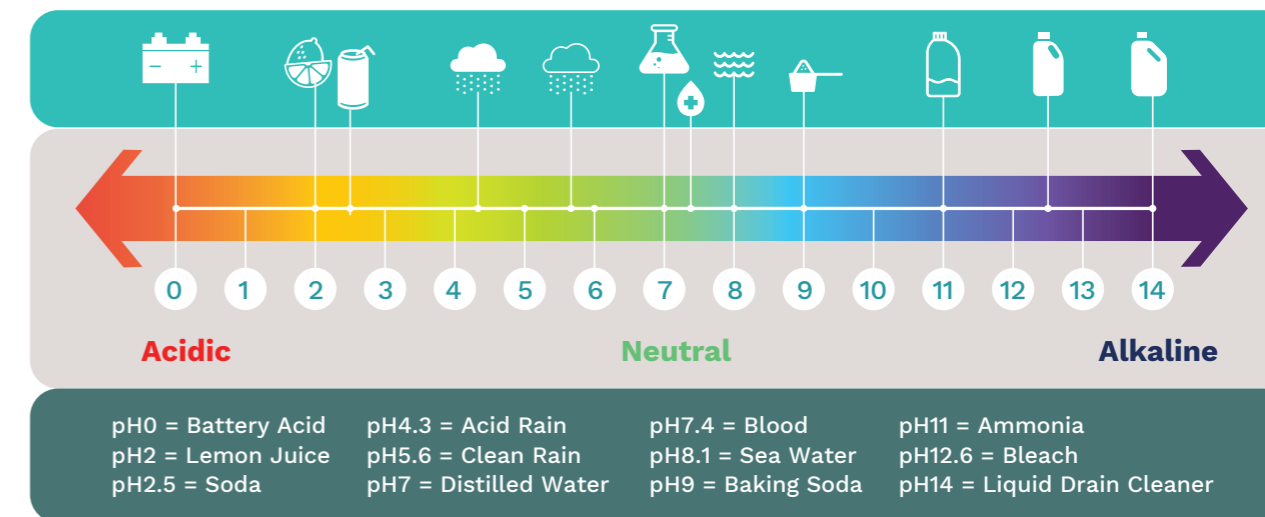


Figure 4: The pH scale³²

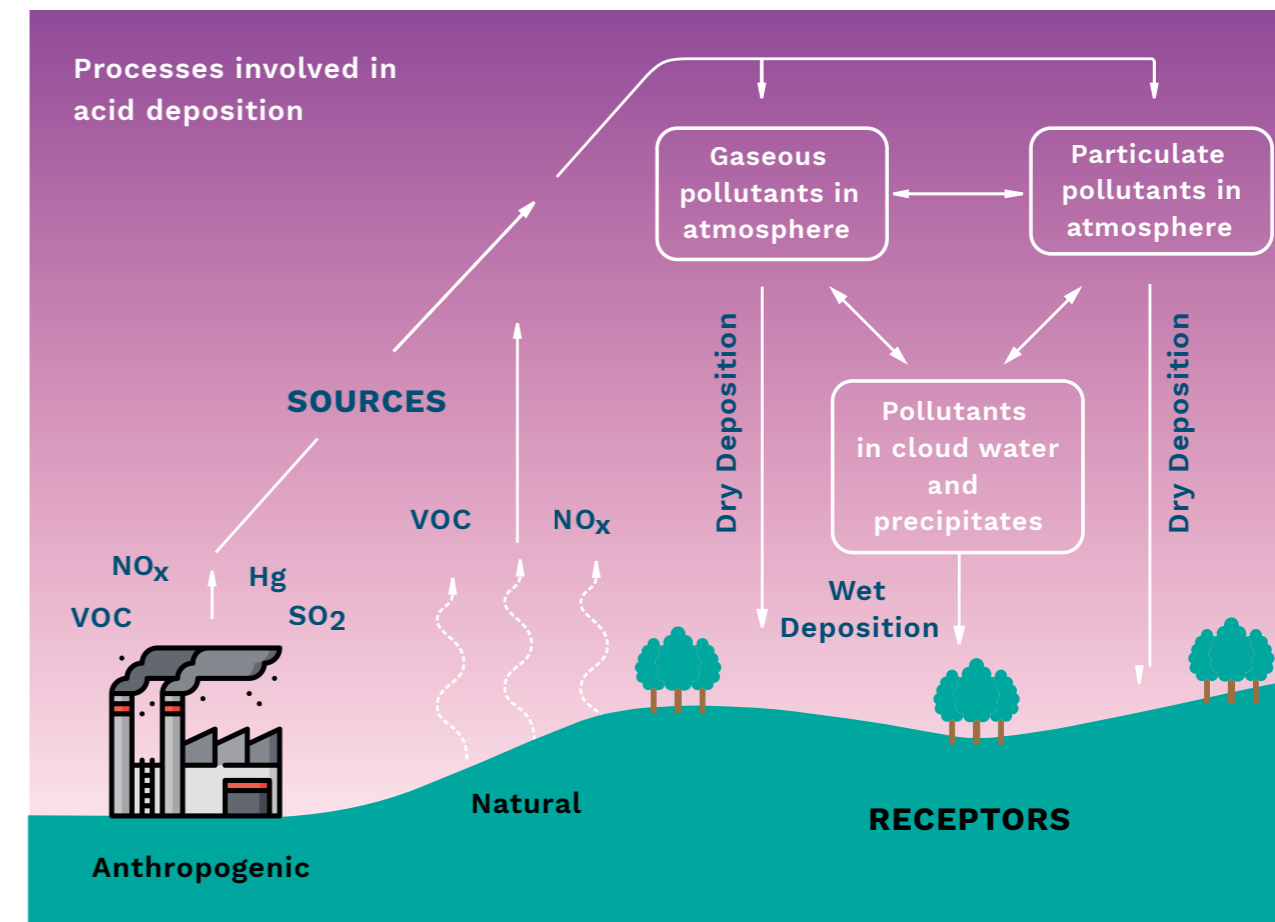


Figure 5: Acid deposition process

31 Shaik, D. S. (2019) Impact of biomass burning on regional aerosol optical properties: A case study over northern India. Journal of Environmental Management, 244:328-343.

32 USEPA (2020) What is Acid Rain? United States Environmental Protection Agency, Washington DS, USA.

Acid deposition is a serious environmental threat. The resulting effects depend on the amount of acid compounds deposited to particular receptor surfaces and on the sensitivity of these surfaces to acid deposition.

Acid rain can kill aquatic life, damage trees, crops, vegetation, buildings and monuments. It can corrode metals, reduce soil fertility and can cause toxic metals to leach into underground drinking water resources. In addition, SO₂ and NO_x and fine sulphate and nitrate particles may cause a reduction in visibility reduction and adverse health effects.

In Asia and the Pacific region, increased energy consumption and the use of sulphur-rich coal as a cheap fuel and oil are rapidly increasing.³³ East Asia contributes 36% and 29% to global emissions, which is much more than the United States and Europe. Oxidized S (SO₂ and sulphate) and oxidised N (NO_x

and nitrate) pollutants produced in East Asia can be transported not only to neighbouring countries but also distant countries that are in downwind regions or continents, affecting air quality.

Climate Change

Climate change is considered to be one of the greatest challenges we face today with the climate-related extreme weather events (e.g. heat waves, flooding, drought and tropical cyclones) becoming ever more evident (see Figure 6). Human activities are estimated to have caused approximately 1.0°C of global heating above pre-industrial levels.

Global heating due to the greenhouse effect is likely to reach 1.5°C between 2030 and 2052 if it continues to increase at the current rate (see Figure 7). This will result in higher climate-related risks for natural and human systems than at present, but lower than at 2°C.³⁴

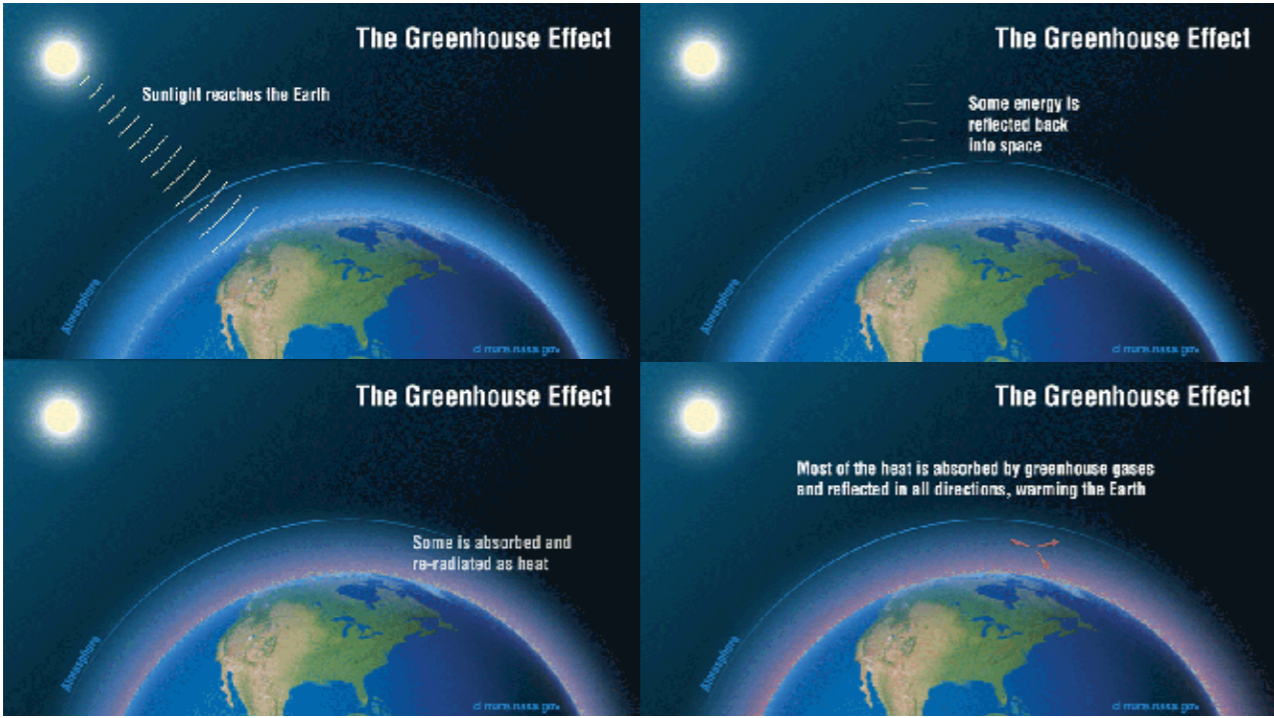
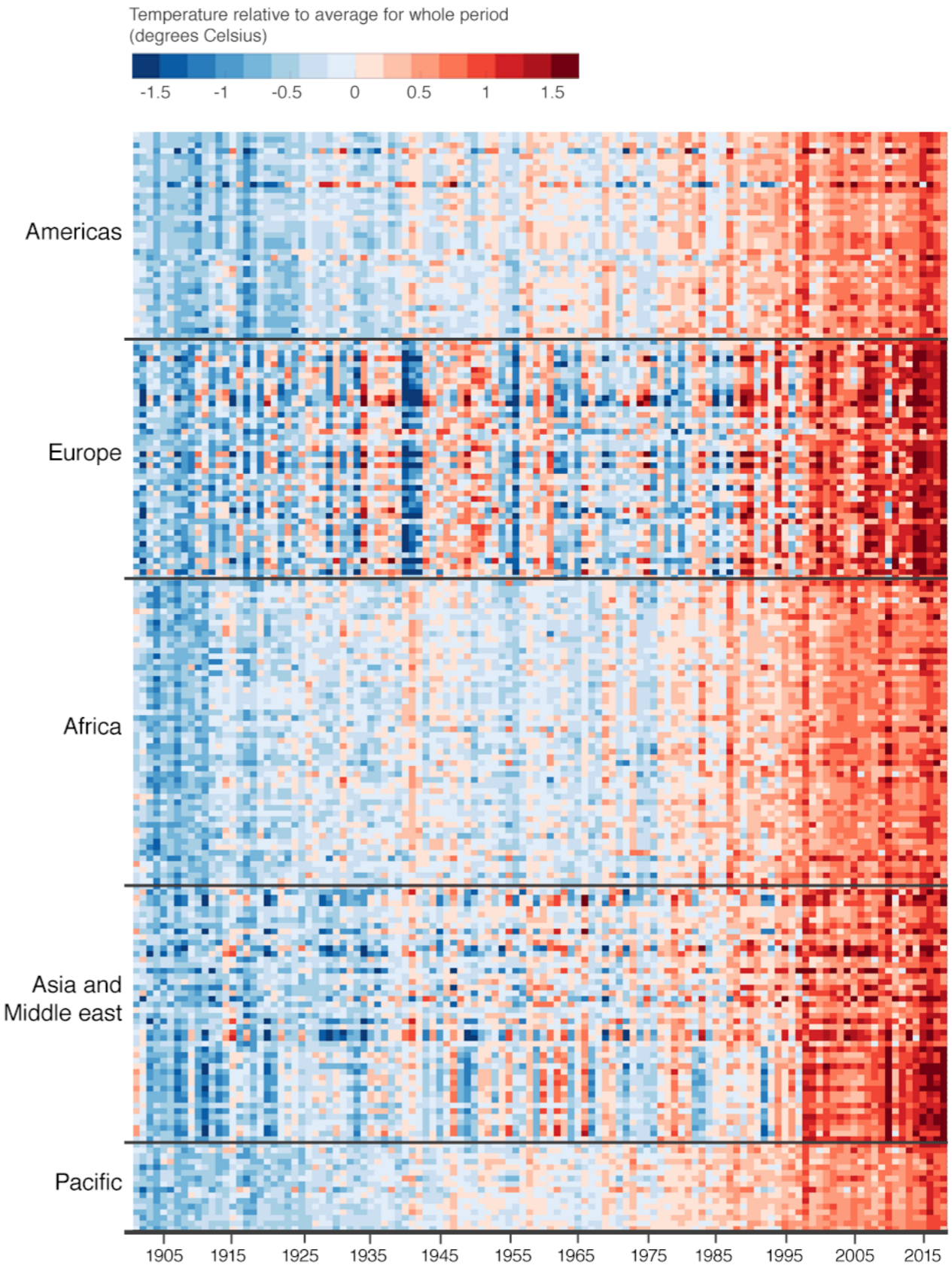


Figure 6: The Greenhouse Effect³⁵

Many urban air pollutants not only affect air quality but also contribute to climate change. Polluting air emissions from transport, power generation, industry, and domestic sectors contain both noxious pollutants and are GHGs. Carbon dioxide (CO₂),

methane (CH₄), nitrous oxide (N₂O) and three groups of fluorinated gases (sulphur hexafluoride (SF₆), hydrofluorocarbons (HFCs) and perfluorocarbons (PFCs) are major GHGs.

Temperature changes around the world (1901-2018)



Source: Ed Hawkins/Reading University

BBC

Figure 7: Temperature changes around the world (1901-2018)³⁶

³⁶ BBC (2019) The chart defines our warming world.

³³ Duan, L. et al. (2016) Acid deposition in Asia: Emissions, deposition, and ecosystem effects. Atmospheric Environment. 146:55-69.

³⁴ IPCC (2018) Summary for Policymakers. In: Global Warming of 1.5°C. An IPCC Special Report on the impacts of global warming of 1.5°C above pre-industrial levels and related global greenhouse gas emission pathways, in the context of strengthening the global response to. Intergovernmental Panel on Climate Change, Bonn, Germany.

³⁵ IPCC The Greenhouse Effect

3. Types of Air Pollution



3.1 Types Of Air Pollutants

Air pollutants can be classified as primary pollutants and secondary pollutants, according to their origin.

Primary pollutants are emitted directly into the atmosphere from the pollution source. Secondary pollutants are produced when primary pollutants interact with other substances in the air (see Table 1).

Table 1: General classification of gaseous air pollutants

Class	Primary Pollutants	Secondary Pollutants
Sulphur containing compounds	Sulphur dioxide (SO ₂) Hydrogen sulphide (H ₂ S)	Sulphur trioxide (SO ₃) Sulphuric acid (H ₂ SO ₄)
Organic compounds	Volatile organic compounds	Ozone (O ₃) Ketones, aldehydes, acids,
Nitrogen containing compounds	Nitrogen oxide (NO) Ammonia (NH ₃)	Nitrogen dioxide (NO ₂) Manganese oxide (MnO ₃)
Halogen	Hydrochloric acid (HCL) Hydrogen fluoride (HF)	-

Air pollutants in urban air can be divided into two groups: criteria air pollutants for which national air quality standards exist, and hazardous air pollutants. In India, NAAQs exist for eight key criteria pollutants: PM₁₀, PM_{2.5}, SO₂, CO, NO₂, O₃, Lead (Pb) and NH₃.³⁷

Hazardous air pollutants consist of chemical, physical and biological agents of different types such as hydrocarbons (HC) (e.g. benzene, toluene and xylenes and other toxic organic pollutants (e.g. polycyclic aromatic hydrocarbons (PAHs), pesticides and polychlorinated biphenyls (PCBs)). Hazardous

pollutants are present in the atmosphere in much smaller concentrations than criteria pollutants and often appear more localised.

3.2 Criteria Air Pollutants

3.2.1 Particulate matter

PM is a common proxy indicator for air pollution as it affects more people than any other pollutant. Airborne PM is a complex mixture of particles with components having diverse chemical and physical characteristics. Particles are generally classified by their aerodynamic diameters since size is a critical determinant of site of deposition within the respiratory tract.³⁸

PM particles are any solid or liquid particles suspended in the air. Fine particles are emitted from burning fuel for energy such as wood and charcoal in fireplaces and barbeques, motor vehicles and industries.

The major components of PM are sulphate, nitrates, ammonia, sodium chloride, black carbon, mineral dust and water. It consists of a complex mixture of solid and liquid particles of organic and inorganic substances suspended in the air.

PM₁₀ are particles less than 10 microns (µm) in aerodynamic diameter. They can further be divided into coarse particles (from 2.5 to 10 µm), fine particles (PM_{2.5}, less than 2.5 µm) and ultrafine (UF) particles (PM_{0.1}, particles of diameter less than 0.1 µm).

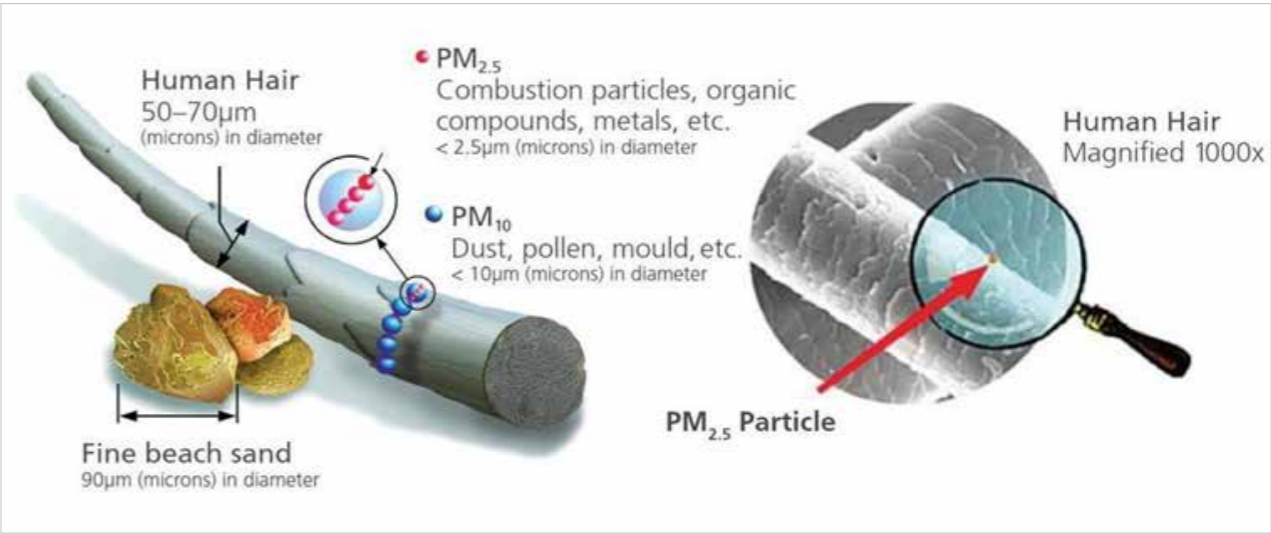


Figure 8: Size comparison particulate matter particles³⁹

PM₁₀ include inhalable particles (PM_{4.0}), which can enter the thoracic region. Fine particles (PM_{2.5}) penetrate deep into the lung and into the air sacs. These particles can damage cells in the airways and affect the lung causing exacerbation of asthma and chronic obstructive pulmonary disease. PM_{2.5} can also cause cardiovascular impacts and damage the heart and circulatory system.

3.2.2 Sulphur dioxide

SO₂ is used as the indicator for the larger group of gaseous sulphur oxides (SO_x). Other gaseous SO_x (such as SO₃) are found in the atmosphere at concentrations much lower than SO₂.

SO₂ is an acidic gaseous pollutant. It is a colourless gas with a pungent, suffocating odour. SO₂ is

corrosive to organic materials and it irritates the eyes, nose and lungs. The principal source of SO₂ is the combustion of sulphur-containing fossil fuels in industry and power stations, and for domestic heating. When large industries and power stations with tall stacks are located away from urban areas, SO₂ emissions may still affect air quality in both rural and urban areas.

SO₂ in ambient air can affect human health, particularly in those suffering from asthma and chronic lung diseases even at levels well below 100 µg/m₃. SO₂ is known to be associated with increased daily mortality and hospital admissions from respiratory and cardiovascular disease. SO₂ is considered more harmful when particles and other pollution concentrations are high. In the atmosphere,

37 CPCB (2009) NATIONAL AMBIENT AIR QUALITY STANDARDS. New Delhi, India.

38 WHO (2005) WHO Air quality guidelines for particulate matter, ozone, nitrogen dioxide and sulphur dioxide. World Health Organization, Geneva, Switzerland.
39 USEPA Basics. United States Environmental Protection Agency, Washington DC, USA.

SO₂ is transformed into sulphuric acid and sulphate particles.

SO₂ emissions can be successfully reduced using fuels with low sulphur content (e.g. natural gas or oil instead of coal). The flue gas desulphurisation technique, which uses a basic solution to scrub flue gas, can also reduce SO₂ from emissions.

In India, the ceramic industry has been identified as an important source of SO₂ emissions. An increase in the population and rural to urban migration is creating more demand for ceramic products, which is providing an additional growth opportunity for ceramic industries.

3.2.3 Nitrogen oxides

NO_x is a mixture of NO and NO₂. The majority of NO_x emissions are in the form of nitrogen oxide (NO), which is oxidised in the atmosphere to the secondary pollutant NO₂. NO₂ is the major form of NO_x in the atmosphere. NO is a colourless gas while NO₂ is a gas of reddish-brown colour with a distinct sharp, biting odour.⁴⁰

Besides methane (CH₄), NO₂ is a major source of tropospheric ozone in the presence of hydrocarbons and ultraviolet light and therefore plays an important role in determining ambient O₃ concentrations. NO₂ is also a key precursor of nitrate particles, which form an important fraction of the ambient air PM_{2.5} mass. NO_x reacts with NH₃, moisture, and other

compounds to form small particles such as PM_{2.5} and/or ultrafine particles.

The principal source of NO_x is road traffic, power stations, heating plants and industrial processes. NO_x emissions can be reduced by optimisation of the combustion process (e.g. low NO_x burners in power plants). Three-way catalytic converters for mobile sources remove NO_x from the exhaust gas by transforming it into nitrogen gas.

NO₂ can irritate the lungs and lower resistance to respiratory infections such as influenza. Continued or frequent exposure to high concentrations may cause increased incidence of acute respiratory illness in children.

An analysis of NO₂ satellite data⁴¹ showed that transport and industrial clusters are the cause of the worst NO_x hotspots in India.⁴² NO₂ satellite data from the Tropospheric Monitoring Instrument (TROPOMI) (February 2018 - May 2019) showed the most polluted hotspots such as the cities of New Delhi - National Regional Capital (NCR), Bengaluru, Kolkata, Chennai and Hyderabad. These cities have high vehicle populations and diesel/oil consumption. However, coal consumption and industrial clusters such as Sonbhadra (Madhya Pradesh), Singrauli (Uttar Pradesh), Korba (Chattisgarh), Talcher (Odisha), Chandrapur (Maharashtra), Mundra (Gujarat) and Durgapur (West Bengal) were equally polluting with regard to NO_x emissions.

3.2.4 Ozone

O₃ is the main component of the photochemical smog. Tropospheric or ground-level O₃ is the toxic pollutant which we breathe in contrast to stratospheric O₃, which protects the earth harmful ultraviolet radiation.

Ground-level O₃ is formed from the photochemical reactions of VOC and NO_x in the presence of sunlight. This results in higher ambient O₃ concentrations in summer months. CH₄ is the dominant anthropogenic VOC contributing to O₃ formation in the global troposphere (See Figure 9). In the lowest part of the atmosphere, in regions where NO_x concentrations are sufficiently high, reactions of OH radicals with CH₄ and other substances leads to the production of O₃.⁴³

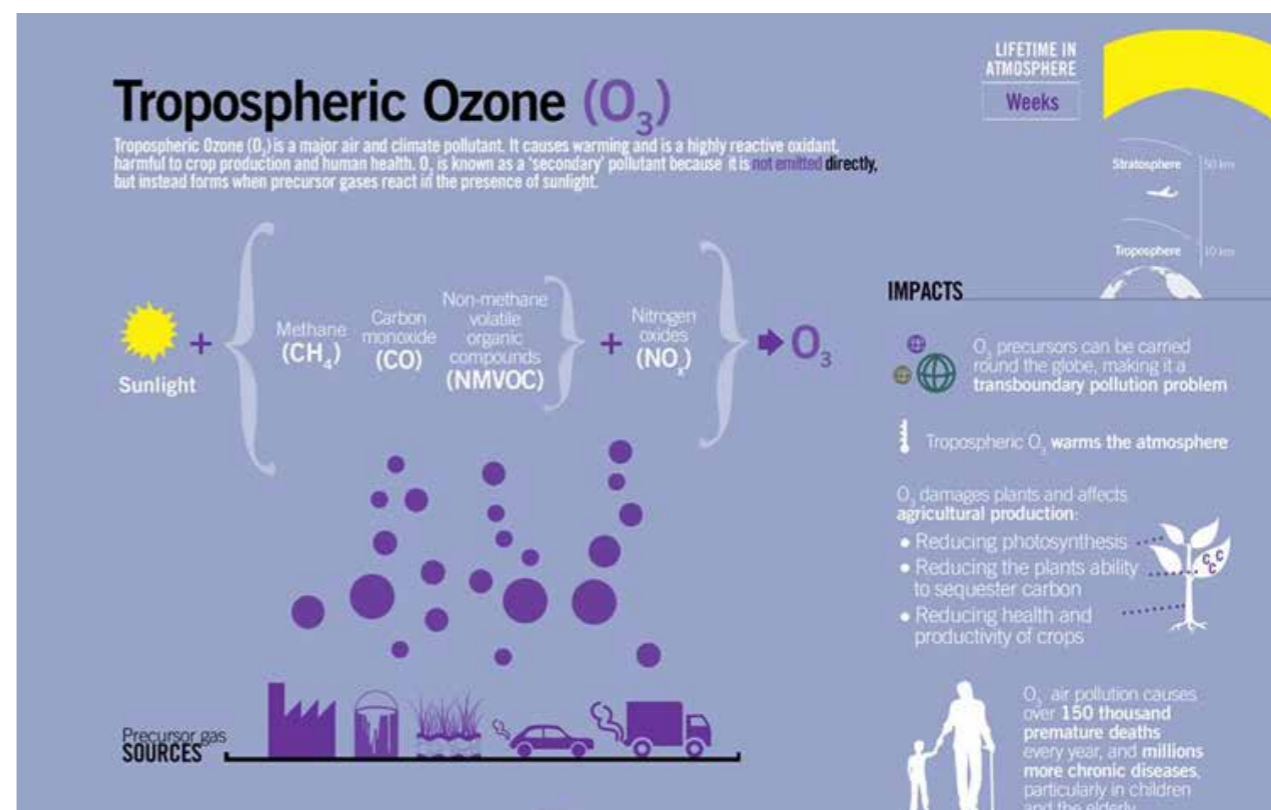


Figure 9: Formation of tropospheric ozone⁴⁴

Ground-level O₃ is a colourless gas that irritates the airways of the lungs, increasing the symptoms of those suffering from asthma and lung diseases. It may increase the lung's reaction to allergens and other pollutants. O₃ not only affects human health but also damages vegetation and decreases the productivity of some crops. It can also injure flowers and shrubs and may contribute to forest decline. O₃ can also damage synthetic materials, cause cracks in rubber, accelerate fading of dyes, and speed deterioration of some paints and coatings. Likewise, it damages cotton, acetate, nylon, polyester and other textiles. O₃ contributes to global heating as one of the most important GHG.

Ground-level O₃ is a secondary pollutant because it is not directly emitted from sources but rather, produced when the primary pollutants react in presence of sunlight. These two primary pollutants are NO_x and VOCs which come from natural sources as well as human activities. NO_x are nitrogen-oxygen compounds that include the gases NO and NO₂ and are produced by the burning of fossil fuels. VOC are carbon-containing gases (excluding CO₂, CO, CH₄, and chlorofluorocarbons) and vapours such as gasoline fumes.

Once formed, O₃ is destroyed by NO which is high at traffic sites, and therefore O₃ is normally higher at

a distance from busy traffic areas such as rural suburb areas than in the city centres.

3.2.5 Carbon monoxide

CO is a toxic gas which is produced as a result of incomplete combustion. Once emitted, CO can remain in the atmosphere for a few months and is eventually oxidised to CO₂.

CO interferes with the oxygen-carrying capacity of blood because of its high affinity for red blood cells, which is more than 200 times higher than that of oxygen. This gas therefore can lead to a significant reduction in the supply of oxygen to the heart, particularly in people suffering from heart disease. A range of symptoms can be expected from CO exposure, such as headaches, dizziness, weakness, nausea, confusion, disorientation, and fatigue in healthy people, and episodes of increased chest pain in people with chronic heart diseases. Exposure to high CO levels is lethal, but the normal concentrations found in the urban area are much lower than the lethal level.

In urban areas, CO is produced almost entirely (~90%) from road traffic emissions. Other sources of CO such as open fires may be significant in local areas. The emissions can be reduced by optimising the combustion conditions to burn more completely,

40 Brusseau, M. L. and Musil, S. A. (2019) Atmospheric Pollution in Environmental and Pollution Science.

41 NO₂ pollution (India) (2019), Google Maps.

42 Greenpeace (2019) New satellite data shows top polluting NO_x hotspots in India range from cities to industrial clusters. Press Release, Greenpeace, India.

43 Van Dingenen R. et al. (2018) Global trends of methane emissions and their impacts on ozone concentrations. JRC Science for Policy Report, EC Joint Research Centre, Ispra, Italy.

44 CCAC (2020) Tropospheric Ozone Climate and Clean Air Coalition, Paris, France.

but with the risk of increasing the formation of NO_x. Most effective reductions are achieved by catalytic converters which oxidise CO to CO₂.

3.2.6 Lead

Lead (Pb) is a toxic heavy metal that normally exists as fine particles in the air. It is a neurotoxin or nerve poison and could reduce the intelligence level and brain function of children.

Even small amounts of lead can be harmful, especially to infants and young children. Exposure has also been linked to impaired mental function and neurological damage in children. In addition, lead taken in by the mother can interfere with the health of the unborn child. For adults, lead could cause high blood pressure, anaemia, infertility or even death.

Sources of lead pollution include mining, smelting, manufacturing and recycling activities, and, in some countries, the continued use of leaded paint, leaded gasoline, and leaded aviation fuel. More than three quarters of global lead consumption is for the manufacture of lead-acid batteries for motor vehicles.⁴⁵

Tetraethyl lead has been used for many years as an additive in gasoline to reduce knock and to boost the octane number. Most airborne emissions of lead therefore originated from gasoline-powered vehicles. Lead is also emitted from metal processing industries, battery manufacturing, painted surfaces, and waste incineration.

Leaded gasoline has been phased out rapidly in almost all countries which has resulted in a drastic reduction in lead emissions and ambient air concentrations of lead. However, in India, population-wide Blood Lead level (BLL) remains elevated despite regulatory action to reduce the most significant lead sources. The attributable disease burden may be larger than previously calculated, particularly with regard to intellectual disability in children.⁴⁶

Despite efforts to reduce the lead content of fuel and other products, lead has not completely disappeared. This is due to the widespread use of lead and its extensive environmental contamination.

3.2.7 Ammonia

NH₃ is a colourless, pungent, hazardous caustic gas composed of nitrogen and hydrogen. NH₃ emissions are also grouped as NH_y which is a sum of NH₃ and NH₄. Human activities have increased the production and emissions of atmospheric NH₃ and other reactive nitrogen worldwide. The increase in reactive nitrogen emissions can cause environmental impacts such as photochemical air pollution, reduced visibility, formation of fine particulates, changes in biodiversity, and climate change.⁴⁷

Agriculture is the largest source of NH₃ emissions. However, motor vehicles, drainage and fertilizer industries urban areas can also contribute to atmospheric NH₃. In India, fertiliser use and livestock farming account for the biggest percentage of total ammonia emissions which are due to the decomposition of urea from large animal wastes and uric acid from poultry wastes.

3.2.8 Other pollutants

Volatile Organic Compounds

VOC are any compound of carbon (organic) (e.g. excluding CO, CO₂, carbonic acid, metallic carbides or carbonates and ammonium carbonate), which participates in atmospheric photochemical reactions.⁴⁸

VOC easily evaporate and enter the atmosphere. VOC may include a wide range of organic air pollutants, from pure HC to partially oxidised HC to organic compounds containing chlorine, sulphur, or nitrogen. Historically, the definition of VOC did not include methane compounds (non-methane VOCs: NMVOC) since the atmospheric concentration of CH₄ was considered to be a stable natural background. However, it has since been recognised that CH₄ is also a human made air pollutant that comes from intensive animal and rice production. Though some of these compounds can have direct toxic effects, they have been grouped together because of their role in O₃ formation.

WHO categorises indoor organic pollutants by the case they will be emitted (see Table 2):

- Very volatile organic compounds (VVOC)
- Volatile organic compounds (VOC)
- Semi-volatile organic compounds (SVOC)

Table 2: Classification of Inorganic Organic Pollutants (adapted from WHO)⁴⁹

Description	Abbreviation	Boiling Point Range (°C)	Example Compounds
Very volatile (gaseous) organic compounds	VVOC	<0 to 50-100	Propane, butane, methyl chloride
Volatile organic compounds	VOC	50-100 to 240-260	Formaldehyde, d-Limonene, toluene, acetone, ethanol (ethyl alcohol) 2-propanol (isopropyl alcohol), hexanal
Semi volatile organic compounds	SVOC	240-260 to 380-400	Pesticides (DDT, chlordane, plasticizers (phthalates), fire retardants (PCBs, PBB))

The higher the volatility (lower the boiling point), the more likely the compound will be emitted from a product or surface into the air. VOC are so volatile that they are difficult to measure and are found almost entirely as gases in the air rather than in materials or on surfaces.

VOC are released from fuel combustion as the product of incomplete combustion or fuel evaporation, typically from vehicles. They are also emitted by the evaporation of solvents used in industry and motor fuels from gasoline stations.

As emissions from transport-related sources of VOC are reduced, other VOC emissions are becoming more apparent (e.g. solvents or other volatile chemical products). Programmes to target multiple VOC sources are needed such as regulations aimed at traffic, solvents or other sources.⁵⁰

In order to reduce ground-level O₃, all VOC mitigation efforts should consider the complex interplay between VOC, NO_x and O₃. In addition to emission reduction measures, robust air quality monitoring is an essential component of air pollution management.

3.3 Factors Affecting Air Quality

Ambient air quality and pollutant concentrations are affected by a number of factors such as meteorological conditions, level of emissions topography, and the stack height of particular fixed sources.

3.3.1 How did it get there?

Meteorological conditions have a significant impact on air quality. Low winds tend to disperse the pollutants over a short distance hence resulting in high ambient concentration, while high winds can dilute the pollutants by distributing them over a long distance and therefore lowering low ambient concentrations.

3.3.2 How much pollutants are there?

The level of emissions coming from different sources determines how much air pollutants are present in the air. Meteorology may reduce this level due to high winds but may also increase its concentration due to temperature inversion. The emission level or mass loading of pollutants can be tracked through an emissions inventory.

3.3.3 Topography

Air pollutant concentrations are expressed as air pollutant mass per unit volume of atmospheric air (e.g., mg/m³, µg/m³, etc.). Air pollutant concentrations at sea level will decrease with increasing altitude. This concentration decrease is directly proportional to the reduction in pressure at higher altitudes.

Some cities are located in areas that are more prone to air pollution issues. A city at a higher elevation, will have a lower atmospheric pressure than a city located at sea level. New Delhi is a classic example of a landlocked area where pollutants are trapped due to its location. In contrast, Mumbai has the luxury of cleaner air than Delhi because of its coastal location.

45 WHO (2019) Lead poisoning and health. World Health Organization, Geneva, Switzerland.
46 Ericson, B. et al. (2018) A meta-analysis of blood lead levels in India and the attributable burden of disease. Environment International 121 (2018) 461–470.
47 Sharma, S. K., Kotnala, G. and Mandal, T. K. (2020) Spatial variability and sources of atmospheric ammonia in India: a review. Aerosol Science and Engineering, 4:1-8.
48 USEPA (2009) Technical overview of volatile organic compounds. United States Environmental Protection Agency, Washington DC, USA.

49 WHO (1989) Indoor air quality: organic pollutants. Report on a WHO Meeting, Berlin, 23-27 August 1987. EURO Reports and Studies 111. Copenhagen, World Health Organization Regional Office for Europe, Geneva, Switzerland.
50 Simpson, I. and Volosciuk, C. (2019) Changing volatile organic compound emissions in urban environment: many paths to cleaner air. World Meteorological Organization, Geneva, Switzerland.

3.3.4 Stack height

The height of a stack can determine the distance from the source where the impact of the emissions can occur. Tall stacks tend to influence the distribution of pollutants in the wider area and can affect those downwind from the source. In contrast, short stacks result in lower ambient concentrations, similar to the effect of high winds. The higher the ambient concentrations of pollutants, the worse the impact on human health and the environment.

3.4 Emission Sources

Major sources of air pollution in India include coal fired power stations, industry, construction activity, and brick kilns, transport vehicles, road dust, residential and commercial biomass burning, waste burning, agricultural stubble burning, and diesel generators.

Polluting air emissions can be identified on the basis of their source:

- **Stationary** (point) sources such as major industrial sites.
- **Area** (non-point) sources such as domestic

emissions and emissions from light industry and commercial areas.

- **Mobile** (line) sources such as motor vehicles.
- **Natural** (biogenic) sources such as dust storms, forest fires, and volcanic eruptions.

3.4.1 Stationary sources

A stationary source is a fixed-site emitter of pollution which usually involves industrial combustion processes. Emissions may be from large or small sources or several single sources over a small area (e.g. several smokestacks in a copper smelter). Emissions may also be released from material transfers, equipment leaks, stacks or vents. Point source emissions can be further divided into various sub-categories, depending on the industrial process such as fugitive emissions, process emissions, combustion emissions, various solvent usage emissions, and storage tank emissions.

In India, coal use is a key component of the energy system, accounting for two thirds in electricity generation and a quarter in industries. The efficiency and environmental performance of the coal sector is critical to reducing stationary emissions polluting air emissions such as SO_x, PM and NO_x.⁵¹

3.4.2 Area sources

Area sources refer to any source of air pollution emitted over an area, which cannot be classified as a point source. Area sources can be a large number of similar small stack point sources (e.g. household emissions) which can be difficult to estimate individually.

Area sources include emissions from household activities such as cooking, space- and water- heating, and kerosene used for lighting. Relatively small amounts of coal are used in households nationally in India and in recent years the use of kerosene for cooking has declined. This is mostly attributed to the Government of India's Ujwala LPG distribution programme.

Other area sources include small business activities, agricultural residue burning, waste combustion fugitive dust from deposits and roads, forest fires, small activities from gasoline service stations, small paint shops, consumer use of solvents and biogenic (natural) sources. Waste deposits can also be a large area source of emissions.

In India, large cities are often surrounded by agricultural land. The open burning of agricultural waste contributes directly to urban air pollution. In poorer cities, backyard burning of refuse (garbage and biomass) is another source of air pollution as well as street cooking in many urban areas. In the absence of properly monitored urban waste management facilities, garbage burning is also a major issue in cities and is being recognised as a major source of air pollution.

Diffuse sources are sources that are not clearly delimited such as open windows, gates, doors, tube connections and flanges in a plant. The combined impact of areas sources could be significant given the challenge of collecting data for each individual source.

Emissions from diffuse sources include evaporative emissions from motor vehicles and non-road mobile sources (e.g. hot soak emissions, running and diurnal losses) and emissions from areas with light industry, domestic and wood burning as well as emissions from natural sources. Area sources can be difficult and time-intensive to inventory and various screening techniques are often used to estimate their emissions.

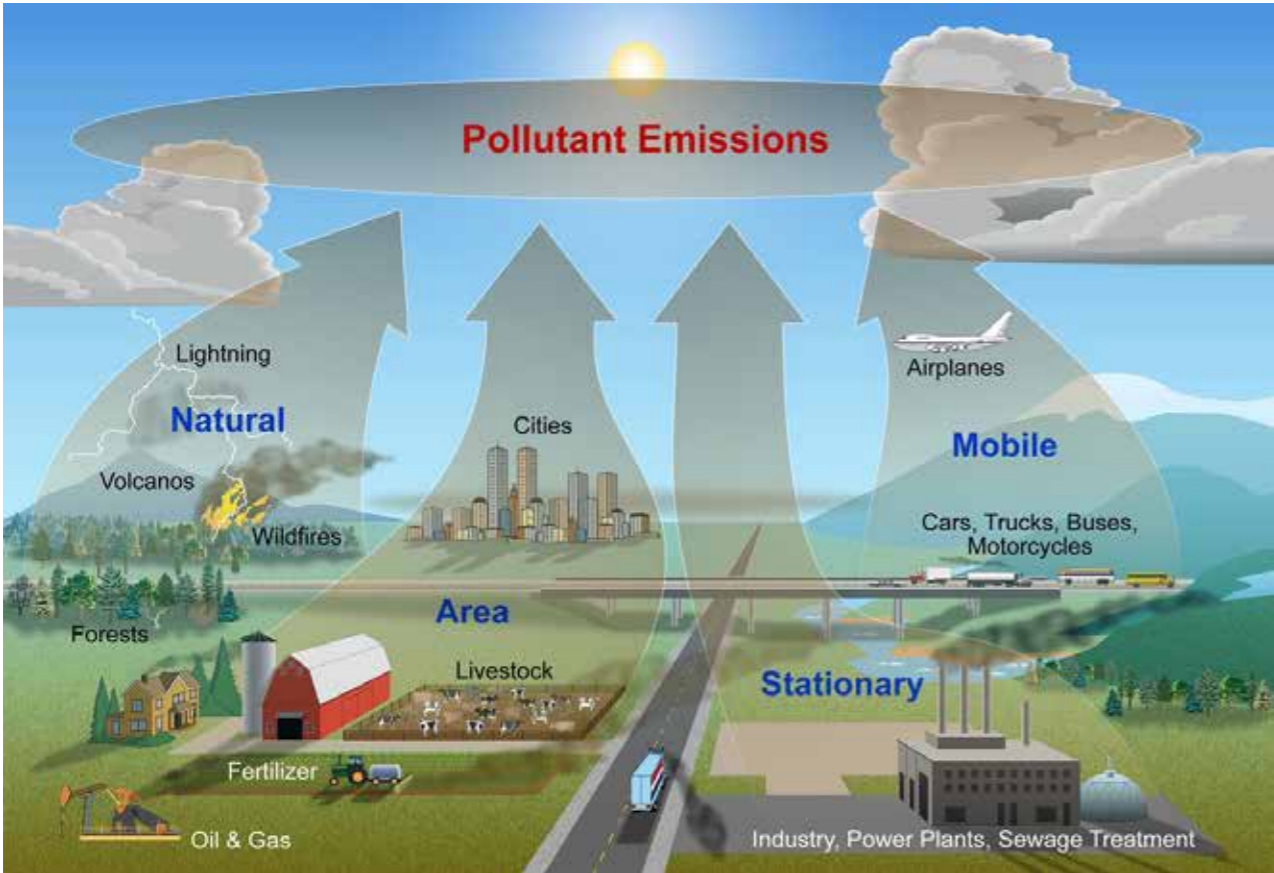


Figure 10: Sources of pollutant air emissions⁵²



51 IEA (2020) India's Energy Policy: key findings of the IEA in-depth Review 2020. International Energy Agency, Paris, France.
52 Anon.

3.4.3 Mobile sources

Mobile sources are road and non-road vehicles, ships and aircraft. Emissions from vehicles can be distributed over a large urban area and are normally near to where people live. In addition, the tail-pipe emissions are close to the level of the individual (e.g. breathing zone of children); therefore, exposure and impact of vehicle source emissions on human health may be higher than from stationary sources with elevated emission outlets.

Mobile road sources include all vehicles which move on roads. On-road sources include passenger cars; light duty vehicles; heavy duty vehicles; urban buses and coaches; and two- and three-wheelers.

Non-road sources include a large number of different emission sources such as construction machines and equipment, tractors, lawn mowers, oil field equipment, boats, ships, aircraft, etc. Emissions from these sources are similar to those from road vehicles but difficult to estimate due to the fact that for most of the categories, no registration and activity rates are available.

Ships and aircraft Emissions from ships are important in harbours and on shipping routes close to ports. Aircraft emissions are important for starting, landing and taxiing activities on airports.

The main pollutant categories associated with motorised vehicles are HCs which contain a number of different hydrocarbon species including carcinogenic substances such as benzene and PAH. Other pollutants emitted from motor vehicles include PM, NO_x, CO, and NH₃. PM includes black carbon, metal oxides, sulphates, nitrates, and other chemicals.

3.4.4 Natural sources

Natural sources of air pollution include sand and dust storms, volcanic activity and forest fires (e.g. caused by lightening). However, human activity can contribute to these natural sources, for example, deforestation.

Many pollutants are emitted into the atmosphere from naturally occurring sources, such as SO₂ from volcanic eruption. Volcanic eruptions generate gaseous, liquid or solid products that also deteriorate air quality.

Sand and dust storms occur during dry periods. They are a meteorological hazard, which is related to the process of wind erosion of surface soil and the mineral dust aerosol emission to the atmosphere.⁵³

A large variety of natural VOC and inorganic gases (NO_x, NH₃ and sulphur compounds) are emitted in the troposphere from terrestrial and water sources. It is now recognised that these volatile emissions affect the quality of the atmosphere at local, continental and global scales, by producing secondary volatile pollutants (O₃, carbonyl and carboxyl compounds, peroxyacynitrates, peroxyakil nitrates, nitric and nitrous acids) and aerosols (sulphuric acid, sulphate and nitrate salts and organic particles) through photochemical processes.

Although the contribution of natural sources to air pollution is widely recognised, a precise assessment is difficult. This is due to the uncertainties that exist in the emission, reactivity, transport and deposition of biogenic compounds in the atmosphere, and the ability of mathematical models to describe these processes.



4. Air Pollution Impacts



The impact of air pollution has a range of direct and indirect effects on human health, ecosystems, vegetation and material assets. The severity of impact is dependent upon the concentration and mixture of the pollutants, the duration of exposure and the susceptibility of the sensitive receptor (i.e. human, flora, etc.). The spatial scale of air pollution impacts ranges from the street level to urban, peri-urban and regional and global. The time-scale of effects also varies ranging from hours to years (see Table 3).⁵⁴

The focus of attention in many air quality standards is for the protection of human health. Nevertheless, consideration should also be given to all receptors whether they are ecological, the built environment or human health.

Air pollutants are causing changes in the ecosystem and are indirectly affecting wildlife as well as directly affecting animal populations that are exposed to harmful air pollutants. The impact of air pollution is not limited to human health but extends to agriculture and the human wellbeing, flora and fauna population.

Extensive experimental studies to assess the potential threat from O₃ to agriculture conducted in Europe

and North America have demonstrated crop losses due to O₃ impacts amounts to billions of dollars.⁵⁵

Air pollution can impact cultural heritage materials and lead to the loss of important historical and cultural monuments. The Taj Mahal has been affected by air pollution which has caused the marble structure to corrode and turn yellow due to the reaction and deposition of pollutants such as SO₂.

The Government of India created the Trapezium Zone (TTZ) to protect the monument from pollution. The TTZ is a defined area of 10,400 sq. km around the Taj Mahal. Three World Heritage Sites (Taj Mahal, Agra Fort and Fatehpur Sikri) are located in the TTZ, which gets its name from the trapezoid like shaped area.

On 30 December 1996, the Indian Supreme Court delivered a ruling regarding industries in the TTZ and banned the use of coal/coke. There was a requirement for industry to switch from coal/coke to natural gas, to relocate outside the TTZ, or closedown altogether.⁵⁶

53 WMO (2019) WMO Airborne dust bulletin. World Meteorological Organization, Geneva, Switzerland.

54 EEA (2003) Air Pollution in Europe 1990–2000, European Environment Agency, Copenhagen, Denmark.

55 Murphy, J. J. (1999) Cost of crop damage caused by ozone pollution from motor vehicles. Journal of Environmental Management, 55:4, 273-289.

56 1987 AIR 1086, 1987 SCR (1) 819

Table 3: Impacts of air pollution

Issue	Spatial scale	Effects-related timescale
Human health-related impacts due to exposure to ozone and particles (and a lesser extent to NO ₂ , SO ₂ , lead and benzene)	Urban areas, streets Ozone: also rural areas	Hours, days, years
Acidification and eutrophication of water, soils and ecosystems	Range: 100–1,000 km	Years
Damage to vegetation and crops due to exposure to ground-level ozone	Range: 100–1,000 km	Hours, growing season
Damage to materials and cultural heritage due to exposure to acidifying compounds and ozone	Urban, rural areas	Years

4.1 Human Health Impacts

A healthy adult human breathes about 16 kilograms of air every day. Ambient air pollution has significant impacts on human health. Many air pollutants have been classified as carcinogenic, and cause a variety of respiratory, cardiovascular diseases and physiological disorders in humans (see Figure 11).

As an emerging economy, India, is accelerating its growth rate to reduce its widespread poverty, the

country faces the challenge of air pollution. Ironically, air pollution affects the health, employability and coping capabilities of those living in poverty the most.

The greatest impacts on human health tend to be focused on the effects of criteria pollutants such as PM_{2.5}, O₃, NO₂ and SO₂ as well as toxic air pollutants, secondary pollutants, VOC and heavy metals (see Table 4).

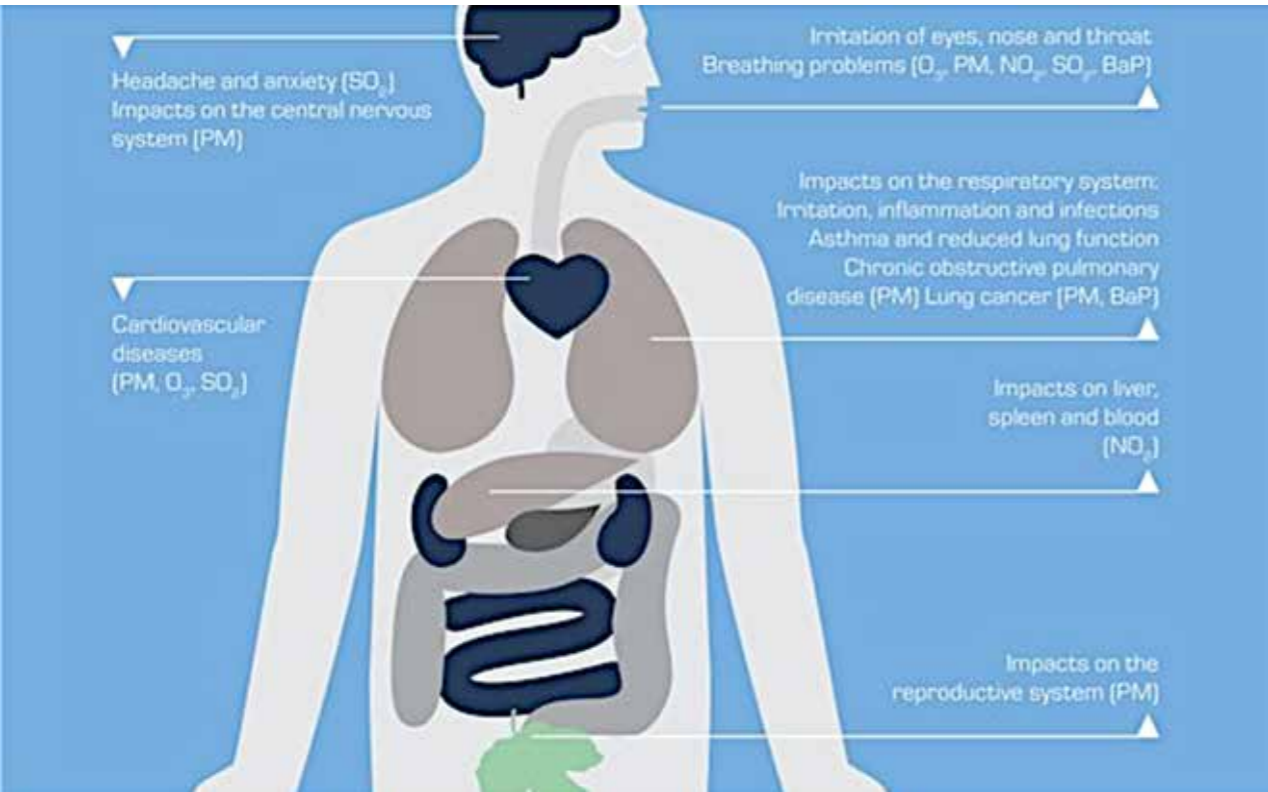


Figure 11: Air pollution and health⁵⁷

57 EEA (2014) Health impact of air pollution. European Environmental Agency, Copenhagen, Denmark.

In Indian cities, poor air quality is emerging as a serious concern because of its impact on human health. Long-term exposure to air pollution has shown that people living in more polluted locations die prematurely, compared with those living in areas with lower levels of pollution.

The WHO estimate 4.2 million premature deaths globally are linked to ambient air pollution, mainly from heart disease, stroke, chronic obstructive pulmonary disease (COPD), lung cancer, and acute respiratory infections in children. Research indicates that cities worldwide show that when air pollution levels increase, so do the number of deaths.

In India, WHO estimates that exposure to ambient air pollution, particularly PM_{2.5}, have caused 6.73 lakh

premature deaths nationwide (2017). Over 38 million years⁵⁸ of healthy life were lost due to air pollution in 2017. The Global Burden of Disease (GBD) study⁵⁹ ranks air pollution as the fifth most important risk of premature death worldwide. In India, COPD is estimated to rank second with 9.58 lakh deaths for all ages and sexes (2017).⁶⁰

The GBD study shows that India has the second largest share of the ambient PM_{2.5} related deaths worldwide with an estimated 6.73 lakh deaths in 2017. Approximately 23% of these cases are in India. This is also the case with premature deaths worldwide due to ground-level O₃ exposure, with India accounting for approximately 31% of such deaths or 1.45 lakh cases (2017).

Table 4: Health impacts of air pollutants⁶¹

Pollutant	Potential Health Impact
Particulate matter (PM ₁₀)	Exposure to particles of aerodynamic diameter less than 10 µm can pose a variety of problems, including: <ul style="list-style-type: none">• Decreased lung function• Increased respiratory symptoms, such as irritation of the airways, coughing or difficulty in breathing• Irregular heartbeat• Nonfatal heart attacks• Aggravated asthma• Emergency department visits• Hospital admissions for cardiovascular or respiratory diseases• Premature death in people with heart or lung disease. People with heart or lung diseases, children, and older adults are the most likely to be affected by particle pollution exposure.
Sulphur dioxide (SO ₂)	Short-term exposures to SO ₂ can affect the human respiratory system and make breathing difficult. Children, the elderly, and asthmatics are particularly sensitive to effects of SO ₂ .
Ozone (O ₃)	Short-term inhalation exposure to O ₃ can cause the following impacts: <ul style="list-style-type: none">• Difficulty to breathe deeply and vigorously.• Shortness of breath, and pain when taking a deep breath.• Coughing and sore or scratchy throat.• Inflammation and damage the airways.• Aggravate lung diseases such as asthma, emphysema, and chronic bronchitis• Make the lungs more susceptible to infection.• Continue to damage the lungs even when the symptoms have disappeared.• Chronic obstructive pulmonary disease• Increased school absences• Increased medication use, visits to doctors and emergency rooms, and hospital admissions• Increased mortality.

58 The disability-adjusted life year (DALY) is a measure of overall disease burden, expressed as the number of years lost due to ill-health, disability or early death. It was developed in the 1990s as a way of comparing the overall health and life expectancy of different countries.
59 The Global Burden of Diseases, Injuries, and Risk Factors Study (GBD) is the single largest and most detailed scientific effort ever conducted to quantify levels and trends in health.
60 IHE (2019) Global Burden of Disease Compare. Institute of Health Metrics, Seattle, USA.
61 Clean Air Asia (2018) Mainstreaming air quality in urban development in Asia. Clean Air Asia, Manila, the Philippines.

	Long-term exposure to O ₃ can aggravate asthma and is likely to be one of many causes of asthma development. Long-term exposures to higher concentrations of O ₃ causes asthma development and may also be linked to permanent lung damage, such as abnormal lung development in children, as well as increasing the risk of death from respiratory causes.
Nitrogen dioxide (NO ₂)	Short-term inhalation exposure due to a high concentration of NO can irritate human airways and aggravate respiratory diseases, particularly asthma, leading to respiratory symptoms (such as coughing, wheezing or difficulty breathing), hospital admissions and visits to emergency departments. Long-term exposures to elevated concentrations of NO may contribute to the development of asthma and potentially increase susceptibility to respiratory infections. Asthmatics, as well as children and older people, are generally at a greater risk for the health effects of NO ₂ . Older people are more vulnerable to the negative health effects of NO ₂ .
Carbon monoxide	Inhalation exposure to high concentration of CO reduces the amount of oxygen that can be transported in the blood stream to critical organs like the heart and brain. It can also cause dizziness, confusion, chest pain, unconsciousness, and death. Such levels can be of particular concern for people with some types of heart disease, reduced ability for getting oxygenated blood to their hearts in situations when exercising or under increased stress.
Benzene (C ₆ H ₆)	Short-term inhalation exposure of humans to C ₆ H ₆ may cause drowsiness, dizziness, headaches, as well as eye, skin, and respiratory tract irritation. At high levels, C ₆ H ₆ can cause unconsciousness. Long-term inhalation exposure can cause various disorders in the blood such as reduced numbers of red blood cells, and leukaemia (cancer of the tissue that form white blood cells) in humans occupationally exposed to C ₆ H ₆ .
Arsenic (As)	Short-term inhalation exposure to high levels of As dust or fumes can cause gastrointestinal effects such as nausea, diarrhea and abdominal pain. Inorganic As compounds can cause peripheral nervous system disorders in occupationally exposed humans. Long-term inhalation exposure to inorganic arsenic compounds can lead to irritation of the skin and mucous membranes, effects in the brain and gastrointestinal system, anaemia, peripheral neuropathy, skin lesions, hyperpigmentation, liver or kidney damage, and lung cancer. Ingestion of inorganic As compounds can cause skin, bladder, liver, and lung cancer.
Cadmium (Cd)	Short-term inhalation exposure to Cd compounds may cause pulmonary irritation. Long-term inhalation or oral exposure can cause kidney disease ³⁴ .
Chromium (Cr)	Short-term inhalation exposure to CrVI compounds can cause shortness of breath, coughing, and wheezing. Long-term inhalation exposure to CrVI compounds can cause perforations and ulcerations of the septum, bronchitis, decreased pulmonary function, pneumonia, and lung cancer.
Lead (Pb)	Inhalation and ingestion exposure of Pb compounds can cause effects on the blood, as well as the nervous, immune, renal and cardiovascular systems. Early childhood and prenatal exposures are associated with slow cognitive development and learning deficits. Ingestion exposure to high amounts of lead can cause gastrointestinal symptoms, severely damage the brain and kidneys, and may cause reproductive effects.
Mercury (Hg)	Short-term exposure to high levels of elemental Hg can result in central nervous system (CNS) effects such as tremor, mood changes, and slowed sensory and motor nerve function. Long-term exposure to elemental Hg can affect the CNS, with effects such as increased irritability, excessive shyness, and tremors. Short-term ingestion exposure to inorganic Hg compounds may result in effects such as nausea, vomiting, and severe abdominal pain. Long-term exposure to inorganic Hg compounds can cause kidney damage. Short-term exposure to methyl mercury can cause CNS effects such as blindness, deafness, and impaired level of consciousness. Long-term exposure to methyl mercury can affect the CNS with symptoms such as a sensation of pricking on the skin, blurred vision, malaise, speech difficulties, and constriction of the visual field. Ingestion exposure of methyl mercury of pregnant women to high levels of methyl mercury can cause mental retardation, ataxia, and constriction of the visual field, blindness, and cerebral palsy in new born children.
Nickel (Ni)	Short-term inhalation exposure to Ni can cause respiratory effects. Long-term inhalation exposure to Ni compounds (Ni refinery dust and Ni subsulfide) may result in an increased risk of lung and nasal cancers.

4.1.1 Particulate matter

The long-term exposure to ambient PM_{2.5} is linked to deaths from COPD, ischemic heart disease, stroke, lung cancer and Lower Respiratory Infections (LRIs). Of these deaths attributable to PM_{2.5}, most were caused by ischemic heart disease and stroke.⁶²

Evidence suggests that there is a close correlation between exposure to high concentrations of small particles and increased death or disease, both in the short and long term. When fine PM in the air is inhaled, it penetrates deep into the lungs and the air sacs. The particles damage cells in the airways and affect the lung; this is associated with the exacerbation of asthma and COPD. The fine PM cause further damage as they impact the heart and circulatory system.⁶³

PM_{2.5} related deaths occur due to:

- Ischemic heart disease
- Cerebrovascular disease (ischemic stroke and haemorrhagic stroke)

- Type II diabetes
- COPD
- Acute LRI.

Non-fatal health impacts of exposure to PM_{2.5} include:

- Non-fatal heart attacks irregular heartbeat, aggravated asthma
- Decreased lung function, acute bronchitis
- Increased respiratory symptoms.

These can lead to absence from work and reduced school attendance as well as increased hospital admissions and doctor's visits.

Figure 12 shows the number of deaths attributable to PM_{2.5} pollutions in India by source. The highest proportion of deaths is due to residential biomass burning.

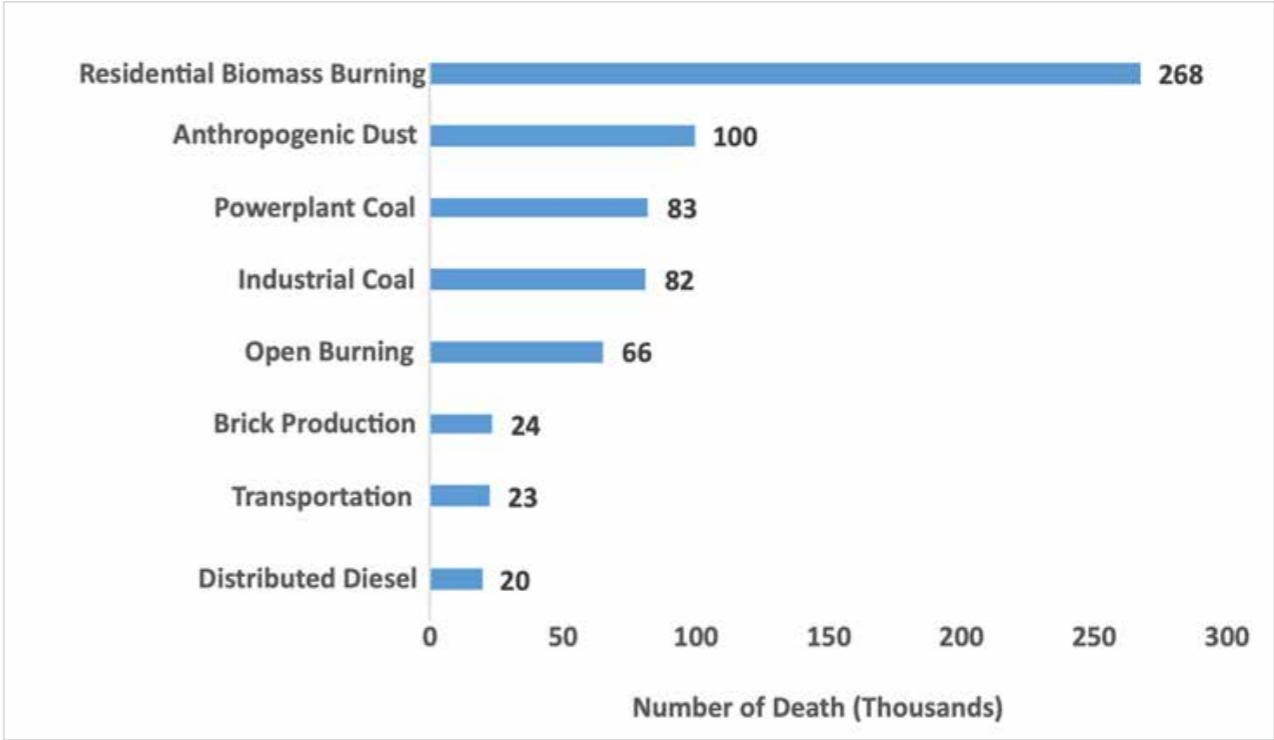


Figure 12: Attributable deaths to PM_{2.5} pollution in India (2015) by source⁶⁴

62 HEI/IHMC (2018) State of Global Air. Health Effects Institute/Institute for Health Metrics.

63 WHO (2005) WHO Air quality guidelines for particulate matter, ozone, nitrogen dioxide and sulfur dioxide. World Health Organization, Geneva, Switzerland.

64 HEI/IHMC (2019) State of Global Air. Health Effects Institute/Institute for Health Metrics.

A number of studies on the health impacts of air pollution have been conducted in Indian cities. One study of air pollution in New Delhi reported that 32.1% of children have suffered from respiratory problems. Furthermore, other studies have also linked the increase in number of deaths and hospital admissions to air pollution in Delhi. Other studies undertaken in the megacities of Kanpur, Chennai, Bangalore, Mumbai, Delhi showed the high influence of PM and air pollution on the health of urban residents (see Table 5).

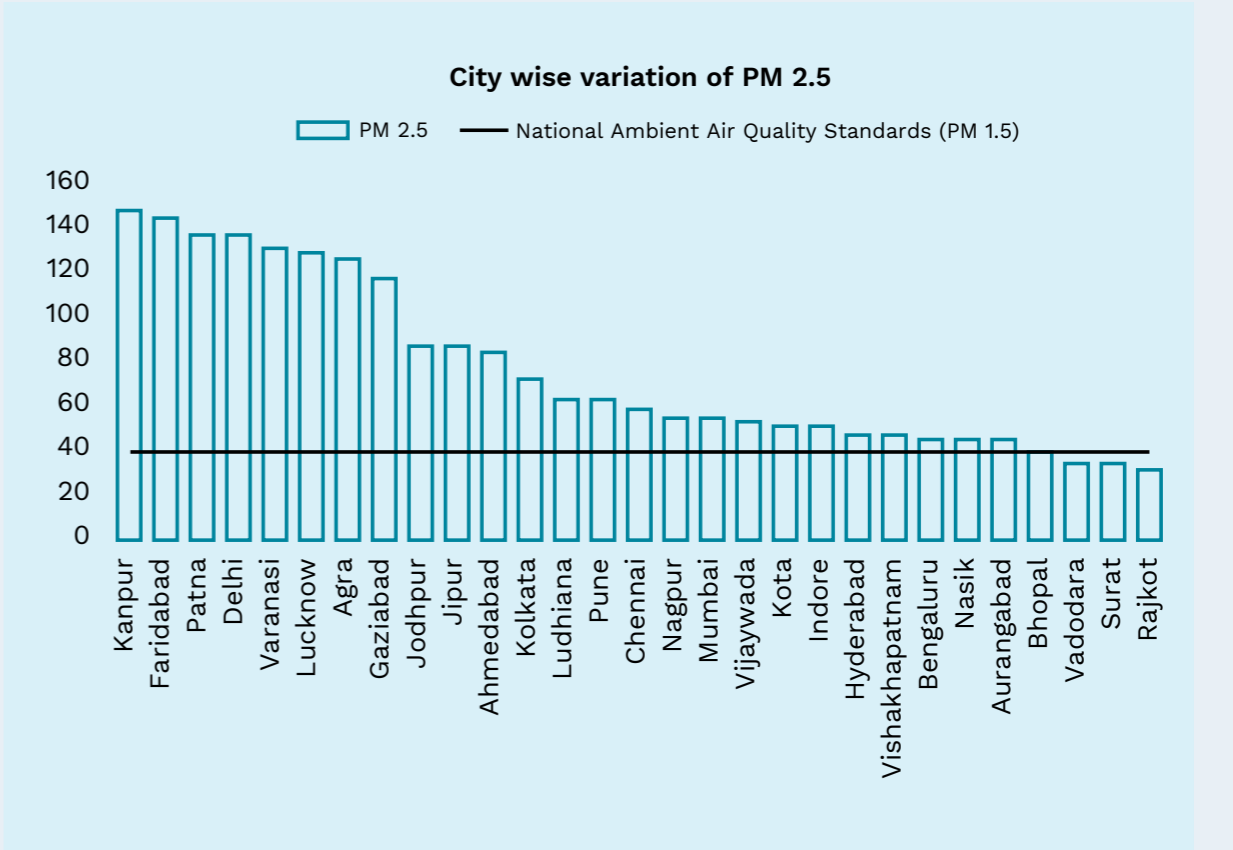
Table 5: Mortality count due to air pollution

Location	Year	Pollutant	Count	Source ⁶⁵
All India	1990	PM10	438000	IHME (2013)
Delhi	1990	Total PM	5070	(Cropper et al. 1997)
Mumbai	1991	PM10	2800	Shah and Nagpal (1997)
Delhi	1993	PM10	3800-6200	Kandlikar and Ramachandran (2000)
Mumbai	1993	PM10	5000-8000	Kandlikar and Ramachandran (2000)
Delhi	2001	PM10	5000	(Talaiekhosani et al. 2018)
Kolkata	2001	PM10	4300	Nema and Goyal (2010)
Mumbai	2001	PM10	2000	Nema and Goyal (2010)
Chennai	2001	PM10	1300	Nema and Goyal (2010)
Ahmedabad	2001	PM10	4300	Nema and Goyal (2010)
Kanpur	2001	PM10	3200	Nema and Goyal (2010)
Surat	2001	PM10	1900	Nema and Goyal (2010)
Pune	2001	PM10	1400	Nema and Goyal (2010)
Bhopal	2001	PM10	1800	Nema and Goyal (2010)
Pune	2010	PM10	3600	(Guttikunda and Jawahar 2012)
Chennai	2010	PM10	3950	(Guttikunda and Jawahar 2012)
Indore	2010	PM10	1800	(Guttikunda and Jawahar 2012)
Ahmedabad	2010	PM10	4950	(Guttikunda and Jawahar 2012)
Surat	2010	PM10	1250	(Guttikunda and Jawahar 2012)
Rajkot	2010	PM10	300	(Guttikunda and Jawahar 2012)
All India	2010	PM2.5 + ozone	695000	IHME (2013)
Delhi	2010	PM2.5	7350-16200	(Guttikunda and Goel 2013)
Delhi	2030	PM2.5	22000	Dholakia et al. (2013)
China	2016	Air Pollution	950000	(Landrigan et al. 2017)
Global	2014	Air pollution	7 million	(World Health Organization 2014b)
Global	2016	Air pollution	6.5 million	(Landrigan et al. 2017)

Box 5: Air Pollution Deaths in Indian Cities

In India, the majority of the population is exposed to high levels of ambient PM_{2.5} resulting in a negative effect on human health and wellbeing. Heart and lung disease (i.e. Ischemic Heart Disease (IHD), Cerebrovascular Disease (Stroke), Chronic Obstructive Pulmonary Disease (COPD), Lower Respiratory Infection (LRI), and Lung Cancer (LNC)) have been associated with long-term PM_{2.5} exposure resulting in early death.

A study (Saini and Sharma, 2020)⁶⁶ estimated the premature deaths (2016) in 29 Indian cities with a population of more than a million people. The city-specific registered deaths data together with information on percentage share of cause-specific deaths in the total deaths and measured ambient PM_{2.5} concentrations were used to estimate cause-specific baseline deaths for each city. Early death due to PM_{2.5} exposure is estimated from this baseline assessment.

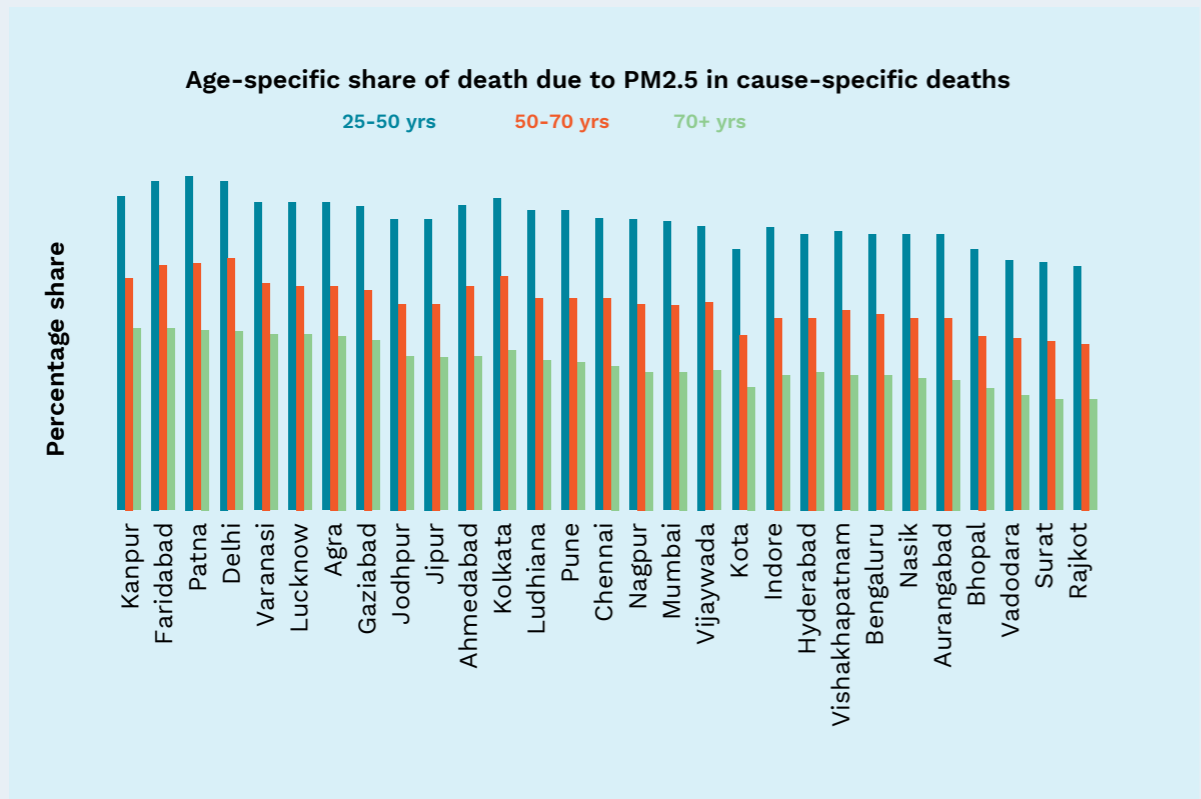


The study found heart disease (IHD) is the leading cause of death accounting for 58% of PM_{2.5} related premature deaths, followed by Stroke (22%), COPD (14%), LRI (4%), and LNC (2%) in these 29 cities. The estimated number of PM_{2.5} related deaths in productive age group (25 – 50 years) is low compared to older people, but the percentage share of these deaths in the cumulative cause-specific baseline deaths is higher for productive age group.

The productive population is therefore at a higher risk of death due to PM_{2.5} exposure. There is approximately 18% and 70% reduction in premature deaths if these cities can attain National Ambient Air Quality Standards (NAAQS) (40 µg/m³) and the WHO guidelines (10 µg/m³) of annual PM_{2.5}, respectively. The estimates of air pollution related deaths at the city level could assist in city-specific policy formulation for better air pollution prevention and control measures.

65

66 Saini, P. and Sharma, M. (2020) Cause and Age-specific premature mortality attributable to PM2.5 Exposure: An analysis for Million-Plus Indian cities. Science of the Total Environment 710 (2020) 135230



4.1.2 Ground-level ozone

Ground-level O_3 is less soluble in water. It is therefore not scrubbed in the upper respiratory tract and reaches the lower respiratory tract where it dissolves in the fluid of the thin surface layer of lung cells. Free radicals and other oxidants in the fluid are assumed to react rapidly with the cell molecules and mediate the effects of O_3 exposure of the human lung. O_3 exposure is a major factor in asthma morbidity and mortality. Even short-term exposure can aggravate existing lung diseases and make the lungs more susceptible to infection.⁶⁷

Health effects of short-term exposure to O_3 include:

- Increased all-cause mortality
- Increased cardiovascular mortality in adults younger than 75 years
- Increased hospital admission for heart diseases in adults older than 65 years
- Increased hospital admissions for respiratory diseases in adults older than 65 years Increased hospital admissions for chronic obstructive pulmonary disease

- Potentially increased hospital admissions for asthma
- Increased school absences.

4.1.3 Nitrogen dioxide

The human respiratory tract can absorb between 70-90% of the NO_2 on inhalation. Even greater levels are absorbed when breathing with the mouth (e.g., during exercise). NO_2 is increasingly deposited in the lower respiratory tract and can remain in the lung for prolonged periods. Short-term exposure to NO_2 can aggravate people with asthma and other lung diseases. Above safe levels, NO_2 exposure can cause inflammation of the airways.

4.1.4 Sulphur dioxide

The main human made source of SO_2 is the burning of sulphur containing fossil fuels by power plants and other industrial facilities. Smaller sources of SO_2 emissions include industrial processes such as extracting metal from ore; natural sources such as volcanoes; and locomotives, ships and other vehicles and heavy equipment that burn fuel with a high sulphur content.

Being highly soluble in water, inhaled SO_2 is readily absorbed in the human respiratory tract, in particular, while breathing from the mouth. Inhaled SO_2 can cause inflammation of the respiratory tract.⁶⁸

Health studies have linked SO_2 long-term exposure to:

- Changes in lung function
- Exacerbation of existing heart diseases
- Increased number of asthma attacks

4.1.5 Hazardous air pollutants

Hazardous air pollutants, also known as toxic air pollutants or air toxics, are those pollutants that are known or suspected to cause cancer or other serious health effects, such as reproductive effects or birth defects, or adverse environmental effects. They can be gases (e.g. hydrogen chloride), or compounds (e.g. asbestos), or elements (e.g. cadmium, mercury, and chromium).⁶⁹

Hazardous air pollutants include hydrocarbons, VOC, heavy metals and secondary pollutants. Examples are benzene (in petrol/gasoline), benzo- α -pyrene (in tar and asphalt fumes and diesel engine emissions), perchloroethylene (in dry cleaning chemicals), methylene chloride (in solvents and paint strippers), asbestos, toluene, PAH, arsenic and heavy metals such as lead, cadmium, mercury, chromium, nickel and zinc compounds.

Benzene, ethylbenzene, toluene, and xylenes collectively known as the BTEX group. BTEX is an important fraction of non-methane hydrocarbons (NMHC) and has been commonly found in urban air. BTEX are known to be toxic and genotoxic and they also actively participate in the photochemical reactions.

BTEX are emitted from a number of sources such as power plants, industrial enterprises, and construction works are the main sources of atmospheric BTEX. In particular, motor vehicles are a key source when benzene-rich additives are used as the anti-knock agents to replace the alkyl lead compounds.⁷⁰ Chronic exposure to BTEX as a negative impact on the human respiratory, cardiovascular and endocrine systems.

An assessment of BTEX levels in various green spaces in New Delhi found the average

concentrations were higher for toluene and xylene among BTEX compounds. The cancer risks for benzene exceeded the benchmark limits of USEPA and WHO. The study suggested that the vegetative areas in New Delhi are not safe for public health and regulatory bodies need to initiate action to reduce BTEX emissions.⁷¹

Health Impacts of Air Pollution: Key Questions

To understand the impact of air pollution on human health a number of questions can be posed:

What is a health hazard due to air pollution?

A health hazard is a source of danger or an agent that can harm human health (qualitative notion).

What is a health risk due to air pollution?

The health risk is the probability that health impact will occur.

Which information do we need to assess health risks presented by hazards?

- Hazards as they occur in a particular environment
- Population groups which are exposed
- Level to which they are exposed
- Duration of exposure
- Health impacts that these hazards could cause or do have caused, i.e. Dose- (exposure) response relationships

Which environments do we have to consider in the assessment of risks due to air pollution?

- Home environment
- Workplace environment
- Community environment
- Larger-scale environment

67 WHO (2005) WHO Air quality guidelines for particulate matter, ozone, nitrogen dioxide and sulfur dioxide. World Health Organization, Geneva, Switzerland.

68 USEPA Sulfur Dioxide Basics. United States Environmental Protection Agency, Washington DC, USA.

69 ALA <https://www.lung.org/clean-air/outdoors/what-makes-air-unhealthy/toxic-air-pollutants>

70 Truc, V. T., Kim Oanh, N. T. (2007) Roadside BTEX and other gaseous air pollutants in relation to emission sources. Atmospheric Environment, 41:7685-7697

71 Kashap, P., Kumar, A. and Kumar, K. (2019) BTEX concentrations of associated risks at urban vegetative sites in Delhi, India. Environmental Claims Journal, 31:4, 349-365.

4.2 Air Pollution Impacts On Ecosystems

Air pollutants such as sulphur may lead to excess amounts of acid in lakes and streams and can damage trees and forest soils. Nitrogen in the atmosphere can harm fish and other aquatic life when deposited on water surfaces. Ozone damages tree leaves and negatively affects scenic landscapes in protected natural areas. Mercury and other heavy metal compounds that are emitted into the air from fuel combustion and deposited on land and in water accumulates in plants and animals, some of which are consumed by people. Recent studies have documented the decline of insect populations across the world and reductions in habitat quality due to air pollution.

Adverse health impacts of air pollution affect a country's economy through a decline in productive days, revenues, and increased medical expenses. When air quality causes hospitalisation or absences from work, there is loss in productivity that entails some loss of revenues and additional medical costs. For example, despite overall improvements in air quality in China, illnesses resulting from O₃ and PM exposure in China is estimated to have cost USD 112 billion.⁷²

The costs of outdoor air pollution can be divided into costs to the economy (market) and welfare (non-market) costs (see Figure 13). Market costs are those that are associated with biophysical impacts that directly affect economic activity as measured in the national accounts GDP. For example, lower crop yields affect agricultural production. Non-market costs include the monetised welfare costs of mortality (premature deaths), and of the disutility of illness (e.g. pain and suffering). Market costs show the need to address air pollution policies in order to avoid negative effects on the economy, non-market costs show the potential social benefits of air pollution control policies.

4.3 Economic Impacts Of Air Pollution

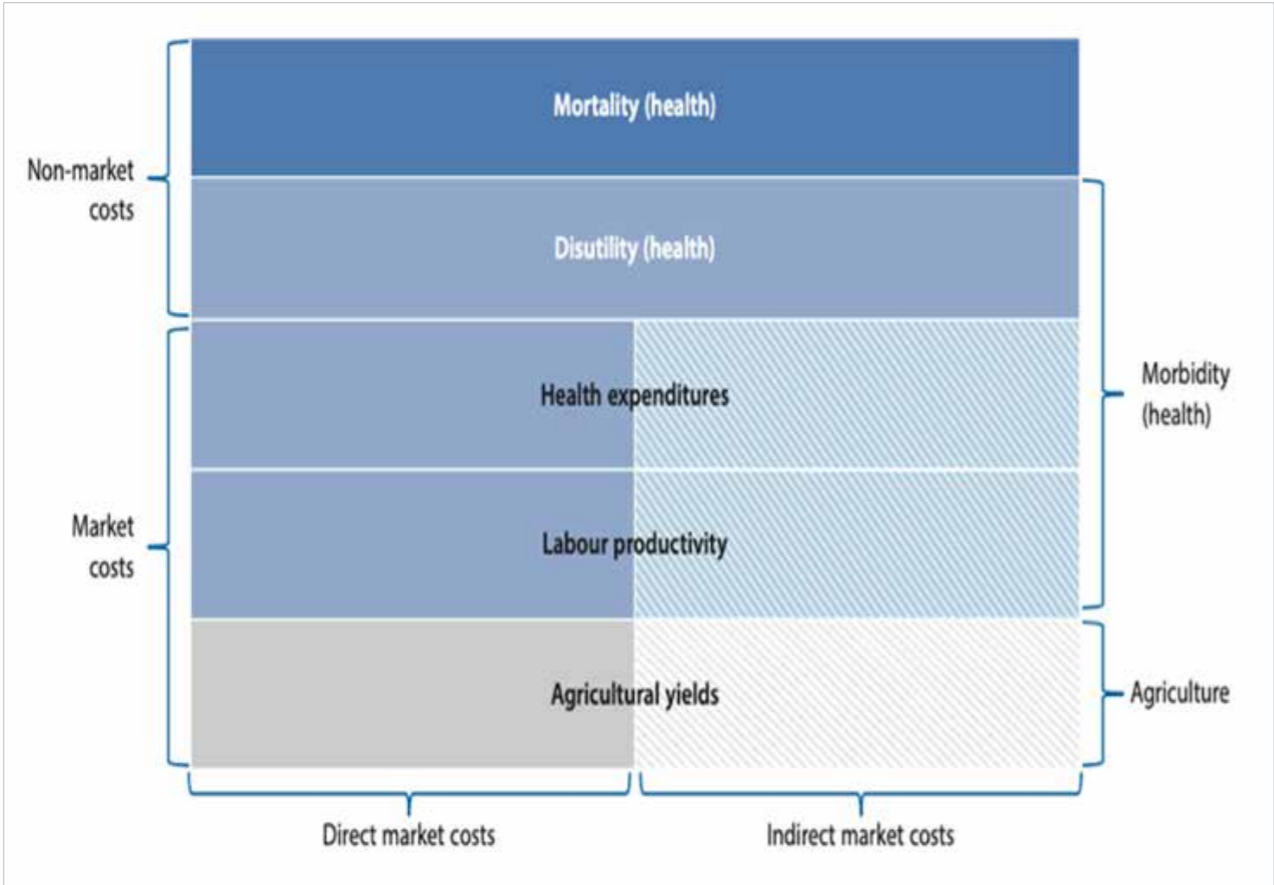


Figure 13: Direct and indirect market costs of outdoor air pollution⁷³

The cost-benefit analyses of air pollution control policies normally address non-market benefits such as avoided deaths. In contrast, market benefits – such as absenteeism at work are given less attention.

The OECD estimates that the total annual market costs of outdoor air pollution (including reduced agricultural yields, absenteeism at work and health expenditures) amounted to 0.3% of global GDP in 2015 while welfare from non-market impacts represented 6% of total income. The total annual market costs of outdoor air pollution are projected to rise from 0.3% in 2015 to 1.0% by 2060.

A 2020 Greenpeace study suggests air pollution from fossil fuels costs 1.8 billion lost working days worldwide per year through poor health. Combining health costs and work absences, the study estimate from fossil fuel-related air pollution has an economic cost equivalent to 3.3% of global GDP, or USD 8 billion per day. For India, this is equivalent to an annual cost of USD 100,000 – 190,000 million and

an estimated premature death rate of 715,000 – 1,300,000 people.⁷³

The USEPA estimates that the benefits of the 1990 Clean Air Act Amendments over the period 1990-2020 amounted to USD 2 trillion (in 2006 USD), with the majority of these benefits attributable to reductions in premature mortality. In contrast, the costs of public and private efforts to the Clean Air Act Amendment requirements is expected to reach an annual value of USD 65 billion by 2020.

In addition to premature deaths (non-market costs), air pollution has an impact on labour productivity as it causes absenteeism at work and reduces individuals' cognitive and physical capabilities.

Based on European evidence, the OECD demonstrates that air pollution affects economic activity. A 1µg/m³ increase in PM_{2.5} concentration causes a 0.8% reduction in real GDP per person that same year. This means reducing PM_{2.5} concentration by 1µg/m³ can boost GDP by 0.8%.

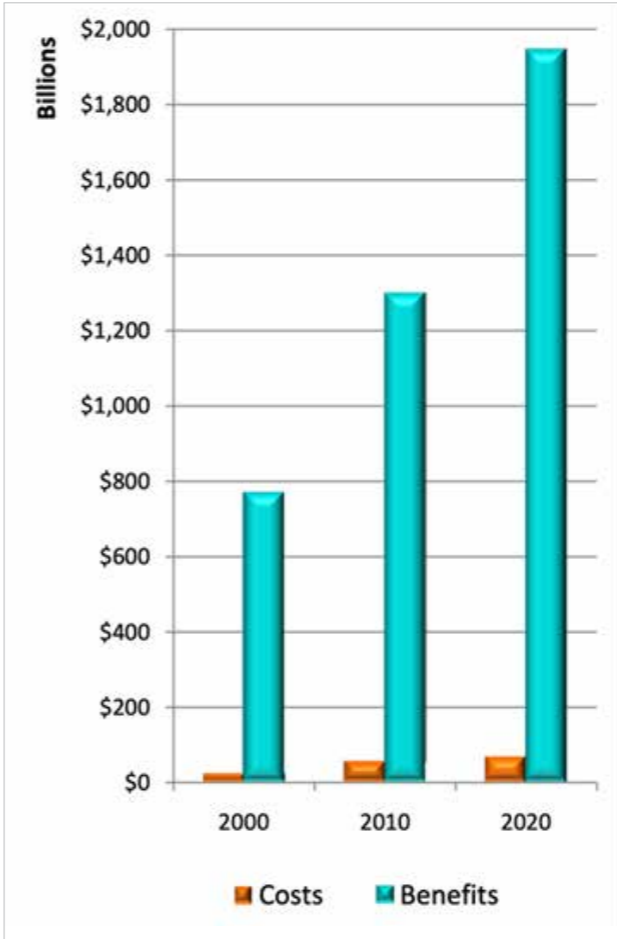


Figure 14: Costs and benefits of the US Clean Air Act⁷⁴

In 2013, exposure to ambient and household air pollution cost the world's economy USD 5.11 trillion in welfare losses. In terms of magnitude, welfare losses in South Asia and East Asia and the Pacific were the equivalent of 7.4% and 7.5% of the regional GDP, respectively.

When proposing control measures or policy and regulations to address air pollution, decision-makers usually consider the economic costs of control measures. If the cost were the only factor to consider in AQM, none of the regulations would have been implemented. Evidence suggests air pollution control measures have positive benefit for not only for health and wellbeing, but for the whole economy.

4.4 Health Impact Assessment

Health studies correlate air pollution with health impacts. However, these are not based on indigenous studies of dose response functions. As a consequence, they create unclear perception for the public and policy makers.

Attributing one to one correlation and the number of deaths and ailments due to air pollution needs

72 Matus, et.al. (2012) Health damages of air pollution in China. Global Environmental Change, 22:1, 55-66.

73 Greenpeace/ Centre for Research on Energy and Clean Air(2020) Toxic Air the Price of Fossil Fuels. Greenpeace South Asia.
74 USEPA(2011) The Benefits and Costs of the Clean Air Act from 1990 to 2020. United States Environmental Protection Agency, Washington DC, USA.

to be investigated and supported by local studies and strong evidence. Local data and studies may strengthen the efforts, public demand and confidence of policymakers in improving the air quality.

A city-specific AQM programme is a long-term plan of action intended to improve the air quality and public health of the city by identifying measures to reduce emissions from sectors such as transport, industries, construction, waste management and household burning, among others.

The health impact assessment (HIA) in a city AQM programme is a means of assessing the positive and negative health impacts of existing air pollution abatement policies, strategies, plans and projects.

HIA can be defined as a combination of procedures, methods and tools by which a policy, programme or project may be judged as to its potential effects on the health of a population and the distribution of those effects within a population, and the distribution of these effects within a population.⁷⁵

HIA will produce a set of evidence-based practical recommendations that will inform decision-makers on how best they can promote and protect the health and wellbeing of local communities. The HIA should maximise the positive impacts and minimise the negative impacts of the policy and address health inequalities.

HIA is a valuable tool within a city AQM programme to develop policies, strategies, programmes and projects for cleaner air by providing information for decision making and addressing policymaking requirements. One of the objectives of an HIA study is to assess whether or not air pollution has an effect on human health. This tool brings policies and people together and involves all stakeholders. It is a proactive process that can mitigate health impacts due to air pollution.

Figure 15 presents the HIA procedure within an AQM programme, which should be seen as an iterative process. Strengthening the capacity for HIA helps shape and define policies for improving air

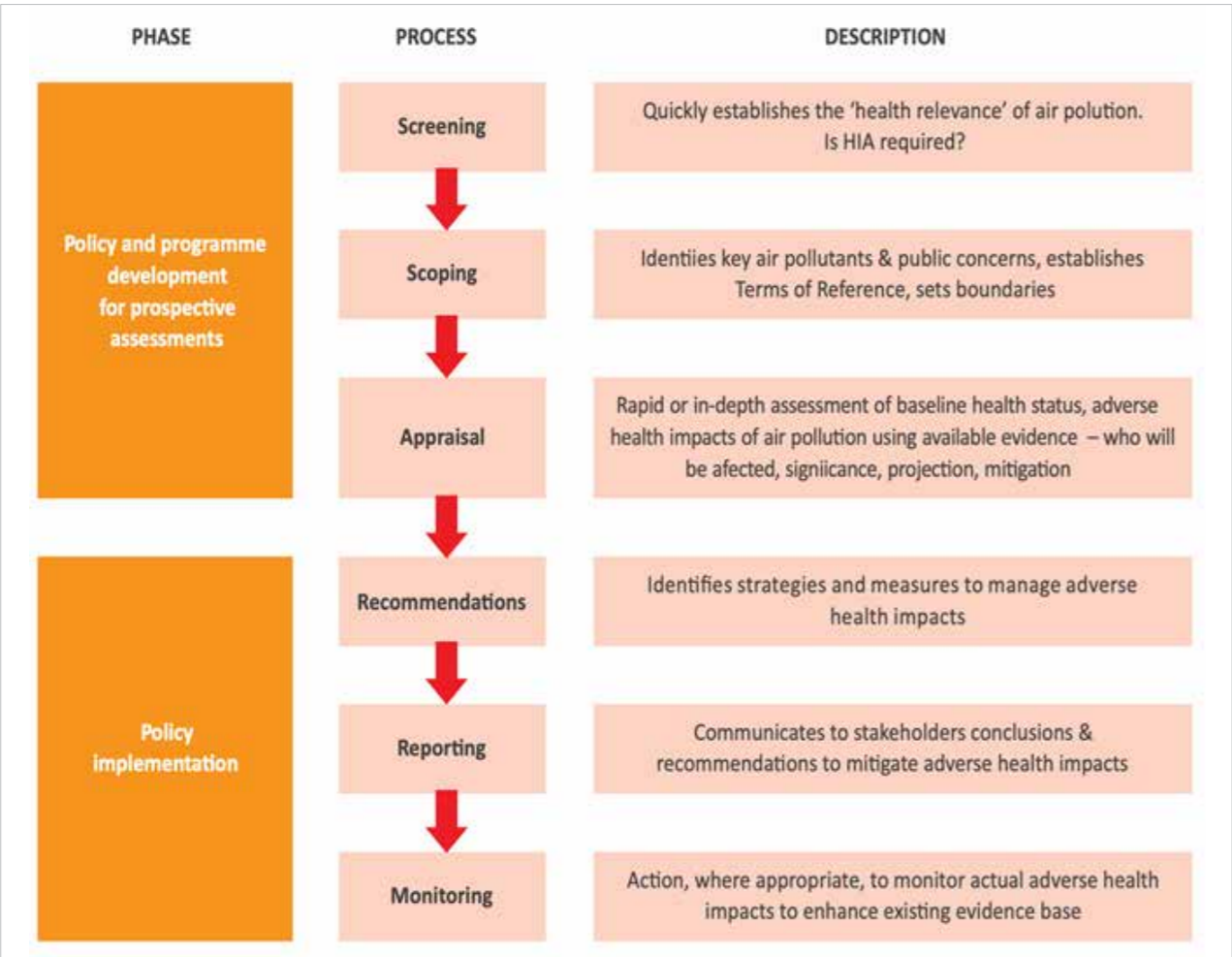


Figure 15: The health impact assessment procedure in air quality management⁷⁶

75 DoH (2010) Health Impact Assessment of Government Policy. Department of Health, UK Government, London, UK.
 76 Clean Air Asia/CEE (2019) National Module on Advancing Air Quality, Delhi, India.

quality. Such capacity also helps in the assessment of the effectiveness of measures to protect human health and the environment.

The following serve as key considerations in progressing through the health and environmental impact assessments:

- Availability of information for estimating health and other impacts
- Processes for estimating health impacts of air pollution
- Capacity for estimating health and other impacts of air pollution
- Presentation of results of health impacts assessment for policy development purposes

In India, cities are at the early stage with regard to air quality and HIA:

- Health surveillance system for monitoring impacts due to air quality unavailable in the majority of cities
- Required air quality databases are unavailable for many non-attainment cities. However, meteorological and air quality databases are being developed for emission-exposure-impact modelling.
- Initial observations on health impacts due to air pollution exposure exist.
- There is a lack of capacity for: air pollution monitoring, exposure assessment and health environmental impact.
- Local specific studies on the socio-economic cost of pollution and the benefits of pollution control are unavailable.
- Cost effectiveness/cost-benefit analysis is not conducted.

Reliable information health and environmental impacts is essential for AQM. Municipal, state and national governments should recognise the need to consider health and environmental impacts as an important ingredient of AQM. It is important to strengthen the political will and understanding of the social and economic costs of air pollution, which often surpass the costs of control measures.

A strong governmental response is needed to mitigate the health and environmental effects of air pollution. It is also important to strengthen the linkages among source inventory, emission, air quality monitoring, meteorological situation and health and environmental impacts due to air pollutant exposure.

To better understand these linkages, it is necessary to involve all relevant stakeholders in the development of action plans for health and environmental impact assessment as an integral part of city specific AQM programmes. Similarly, the collaboration, communication and coordination between environmental and health authorities at the municipal, state and national levels should be strengthened. Enhancing the institutional capability with respect to AQM issues through sustainable education and training and provision of sufficient human resources is also significant.

Sufficient financial resources should be allocated for the following health and environmental impact studies. If reliable emissions and meteorological data exist, models can be used to estimate exposure and with the application of established exposure-response relationships and corresponding health environmental impacts. This would be the low-cost option because appropriate models can be downloaded free of charge (e.g. the USEPA website). If a health surveillance system is in place, epidemiological studies can be performed but the cost of such studies can be high to very high depending on the type of study, the number of cases and the planned duration of the study.



5. Air Quality Management



The ultimate goal of air AQM is to ensure that air pollution concentrations do not exceed defined target levels (e.g. air quality standards), that are needed to protect human health and the environment.

The principles on which the AQM is based include the right to clean air for all, access to environmental information and an awareness of the air pollution situation.

AQM is also based on the polluter pays and precautionary principles and ensures adopting a cost-effective approach using best available technology. Yet, a number of economic, institutional and political constraints may hinder the full implementation of all these guiding principles.

AQM enables governmental authorities to achieve and maintain clean air with the support of numerous stakeholders from governmental institutions, research institutes, non-governmental organisations (NGOs), private organisations, the general public and the media. AQM takes into consideration local circumstances such as sources of air pollution, background air pollutant concentrations, technological feasibility; cultural and social conditions; and available financial and human resources.

Air Quality Management Goals

- Elimination or reduction to acceptable levels of ambient air pollutant concentrations
- Avoidance of adverse effects to human health and/or welfare
- Avoidance of deleterious effects on animal or plant life
- Avoidance of damage to materials

AQM is a dynamic and iterative process which involves a number of key components:⁷⁷

- Ambient air quality objectives/standards are defined to protect human health and the environment.
- Air quality monitoring is undertaken to provide information on the current status of air quality. It helps to evaluate existing policies and their effective implementation. A key component of an air quality monitoring programme is the planning, design and establishment of monitoring network based on the air quality objectives.⁷⁸
- Source apportionment studies are conducted to identify and quantify the impact of different

sources of air pollutants at receptor sites. This provides input on categories of sources that may contribute to ambient air pollution followed by their quantification.

- A comprehensive emission inventory is compiled to develop an emission control strategy for selected pollutants. A compilation of an accurate emission inventory is an integral part of AQM.
- Air quality modelling is undertaken to formulate air pollution control and management strategies by providing guidelines for efficient air quality planning. Its main objective is to predict ambient air pollutant concentrations of one and more species in space and time as related

to independent variables such as emission and meteorological parameters.

- Air pollution exposure and health assessments are undertaken to ensure the impact of air pollution on human health is minimal. These can involve studies to assess the effects of short- and long-term exposure to air pollution.
- Air pollution prevention and control strategies are adopted to maintain acceptable ambient air quality in key urban areas. For example, improved fuel quality in fuel quality, inspection and maintenance programme for vehicles or the banning the open burning of waste (see Figure 16).

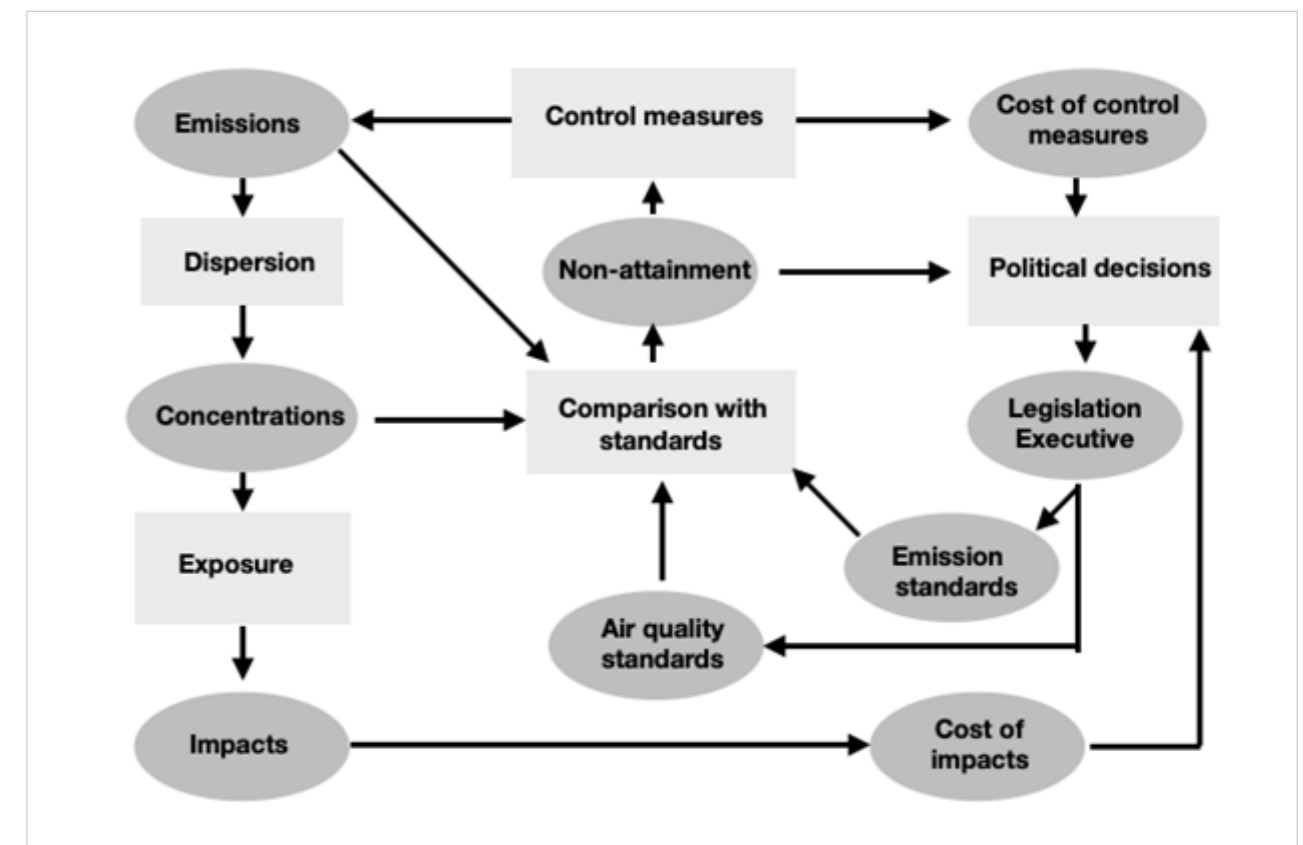


Figure 16: Key component of air quality management

The implementation of a co-ordinated, integrated AQM strategy requires strong commitment from all stakeholders, and not least, an empowered environmental authority to take the leadership in this process.

Clean Air Asia's approach to air quality management

Clean Air Asia's approach to strategic AQM begins with an assessment of cities using the Clean Air Scorecard Tool (CAST).⁷⁹ The Clean Air Scorecard Tool (CAST) is an Excel-based tool incorporating

three indices: (i) Air Pollution and Health, (ii) Clean Air Management Capacity, and (iii) Clean Air Policies and Actions. It was developed under the Sustainable Urban Mobility in Asia (SUMA) program with support from Asian Development Bank (ADB) and the Swedish International Development Cooperation Agency (SIDA) to help cities have a comprehensive understanding of the status of their AQM. The tool builds on experiences from past benchmarking studies and assessment tools and improved on these. This includes a 2006 benchmarking study on air quality management in 20 Asian cities conducted by Clean

⁷⁷ Gulia, S. et al. (2015) Urban air quality management: a review. Atmospheric Pollution Research, 6: 286-304.

⁷⁸ Sivertsen, B. (2008) Monitoring air quality, objectives and design. Chemical Industry & Chemical Engineering Quarterly 14: 167-171

⁷⁹ The tool can be accessed through: <https://cleanairasia.org/cast/>

Air Asia, Korea Environment Institute, Stockholm Environment Institute, and United National Environment Program (UNEP).

The assessment covered four components: air quality measurement capacity; data assessment and availability; emissions inventory; and AQM management enabling capacity. The study made use of a questionnaire survey developed in the early 1990s by the World Health Organization (WHO)/UNEP–GEMS Project. An assessment of 30 cities in India reveals that most cities are in the status of ‘emerging’ and there is a considerable process of capacity building for air quality management before the cities reach the ‘fully develop’ category. For cities such as New Delhi where monitoring systems are adequately placed and there is some source apportionment and emissions inventory, it still falls below the ‘fully

developed’ category and is in the ‘maturing’ status. This is due to the lack of capacity in New Delhi to undertaken health impact assessment. There is also a lack of city-specific data to define a city’s AQM status in the context of health impact assessments.

For a city to be considered as having a ‘developed’ AQM status, there is a need to have a high level of information and dissemination of air quality and health data. In terms of assessment, this involves the availability of data and information for estimating health impacts of air pollution, processes for estimating health impacts of air pollution, capacity for estimating impacts in relation to health data, and the results of health impacts assessment communicated to stakeholders, including policy makers for awareness raising and policy development purposes.



Figure 17 Clean Air Scorecard Tool

Planning and implementation require developing short-, mid- and long-term targets, aligning health impact assessment planning with city/regional environmental, development or other sectoral plans, ensuring multi-stakeholder participation and allocating financial resources. In addition, it includes institutional arrangements for conducting health impact assessments and developed capacity

for conducting such assessments. The Guidance Framework for Better Air Quality in Asian Cities (Guidance Framework), provides roadmaps with management, institutional, and technical recommendations to guide cities in building their capacity to progress through air quality management development stages.

5.1 Air Quality In Indian Cities

An assessment of twenty Indian cities (Agra, Amritsar, Bengaluru, Bhopal, Bhubaneswar, Chandigarh, Chennai, Coimbatore, Dehra Dun, Indore, Jaipur, Kanpur, Kochi, Ludhiana, Nagpur, Patna, Pune, Raipur, Ranchi, and Varanasi) found that all cities exceed the annual PM₁₀ standard (60 µg/m).⁸⁰

Major sources of PM₁₀ include combustion of coal, kerosene, petrol, diesel, biomass, cow dung, and waste as well as dust. Coimbatore reported just above the standard.

Six cities (Agra, Bengaluru, Jaipur, Kanpur, Ludhiana, and Raipur), recorded 4–6 times the annual standard. These are among the fastest growing Indian cities, traditionally known to be dusty due to a lot of construction activities and dust on the roads which is resuspended when vehicles pass.

All cities comply with the annual SO₂ standard (50 µg/m). Major sources of SO₂ include combustion of coal. The three most populated cities (Bengaluru, Chennai, and Pune) recorded the highest SO₂ concentrations.

Nine out of the twenty cities exceed the annual NO₂ standard (40 µg/m). Major sources of NO₂ include combustion of petrol, diesel, and gas (i.e., transport related emissions) and large industries. Bengaluru, Chennai, Jaipur, Nagpur, Kanpur, and Pune recorded the highest concentrations.

- The study made a number of recommendations to control pollution and develop management skills:
- Kochi and Chennai lie on the coast and host large commercial ports. Freight movement (i.e. ships and on roads heavy duty trucks) is a major source of PM_{2.5} and SO₂ pollution. This sector can benefit from a **freight management programme**. For example, movement of freight on rail, restrictions on vehicle types entering the port area, restrictions on the fuel quality used by ships anchored at the ports. The decision makers and other key officials can develop professional knowledge and skills by learning about how these measures operationalised and different measures taken to reduce the air pollution emissions through freight management programme in Kochi and Chennai.
 - All the cities need to **promote public transport systems** and non-motorised transport (walking



80 Guttikunda, S. K., Nishadh, K. A., Jawahar, P. (2019) Air Pollution Knowledge Assessment (Apna) for 20 Indian cities. Urban Climate, 27, 124–141

and cycling) to reduce vehicle use and associated emissions including on-road dust. By 2030, the vehicle exhaust emissions are expected to remain constant or tend lower, if Bharat 6 (equivalent of Euro-6) fuel standards are introduced nationally by 2020, as recommended by the Auto Fuel Policy. The decision makers can develop professional knowledge on the subject of public transport system and utilise these skills in air quality management.

- All the 20 cities lack a **comprehensive waste management system**. The practice of open waste burning which contributes to air pollution is hard to regulate and monitor. The decision makers and other key officials need to develop their professional knowledge on how to reduce waste generation, to collect waste more efficiently, and manage collected waste. This can be done by understanding the norms given in Solid Waste Management Rules, 2016.
- Coal-fired power plants and large industries with captive power plants should **meet stricter national emission standards** for all the criteria pollutants to reduce their contribution to urban air quality. The professional knowledge can be enhanced by decision makers by the strengthening of legal frameworks such as tightening of coal-fired power emission standards and recommendation to improve professional skills through strengthened capacity to implement the standards and related regulations.
- The study stated that air monitoring capacity and data fall very short of expectations, in all the cities. Chennai, Bengaluru, Kanpur, Agra and Nagpur monitor at 25-30% of the recommended capacity. The regulatory authorities can build on their core skills to improve addressing the air pollution. This can be done by enhancing the capacity building on data management.

5.2 Ambient Air Quality Guidelines And Standards

City development has resulted in an increase in the polluting air emission that has affected the health and wellbeing of its citizens and the natural and built environment. Regulations and emission and air quality standards are important tools to reduce emissions from both stationary and mobile sources. They provide a basis for public health protection, eliminating or reducing to as low as possible, those air contaminants of air that are known or likely to be hazardous to human health and wellbeing.

The WHO developed air quality guidelines (AQGs) to achieve air quality that protects public health in different contexts. AQGs are not the same as air quality standards but are recommendations that are not enforceable. Air quality standards, on the other hand, are set by a country to protect public health and as such are enforceable and an important component of national risk management and environmental policies.

5.2.1 WHO air quality guidelines

First produced in 1987 and updated in 1997, the WHO AQGs are based on expert evaluation of current scientific evidence. They offer guidance to reduce the health impacts of air pollution. The WHO AQG are intended to inform policy-makers and to provide appropriate targets for a broad range of policy options for AQM in different parts of the world.

In 2005, the WHO updated the AQGs which offer recommended exposure levels for PM₁₀ and PM_{2.5}, O₃, NO₂ and SO₂. The 2005 update lowered the recommended limits of many pollutants, including O₃ and SO₂, making them much more stringent than the national standards currently applied in many parts of the world (see Table 6).⁸¹

The update outlined interim targets are given for each pollutant. These are proposed as incremental steps in a progressive reduction of air pollution and are intended for use in areas where pollution is high. These targets promote a shift from high air pollutant concentrations, which have acute and serious health consequences, to lower air pollutant concentrations. If these targets were to be achieved, one could expect significant reductions in risks for acute and chronic health effects from air pollution. Progress towards the guideline values should be the ultimate objective of AQM and health risk reduction in all areas.

The WHO AQG values are based on the threshold limits for various air pollutants. These are derived from the concepts of lowest-observed- effect level, lowest-observed-adverse-effect level, or no-observed-adverse-effect level, by application of uncertainty factors (e.g. threshold of carcinogens).

If thresholds for the onset of health effects do not appear to exist, air quality guidelines are derived in the form of percentage-change-of-effect/concentration relationships (risk-concentration relationships).

WHO AQG are intended to provide background information and guidance to local authorities in making decisions for AQM. In general, the guidelines address single pollutants, whereas, in real-life, exposure of populations is to a mixture of chemicals. The effect of exposure from a mixture of pollutants can have additive, synergistic or antagonistic effects. Although AQG are considered to be protective of human health, they are by no means a “green light” for pollution and attempts should be made to keep air pollution levels as low as practically achievable.

However, WHO AQG are not standards per se although several countries have adopted these for setting their own standards after considering various factors such as prevailing exposure levels, natural background concentration, meteorological conditions and socio-economic considerations. The policy options in setting standards include questions on which proportion of the general population and which susceptible groups should be protected.

5.2.2 Ambient air quality standards

Air quality standards are an essential part of AQM. They differ according to exposure (i.e. ambient (outdoor) or household (indoor); and what they intend to protect – primary standards for human

health protection, and secondary standards for protection of animals, crops, vegetation and buildings (see Box 6).⁸²

Air quality standards are established by taking into account various factors: prevailing exposure levels, technical feasibility, source control measures, abatement strategies, and social, economic and cultural conditions. Air quality standards necessitate the setting up of a reliable AQ monitoring system that evaluates trends of air pollution and compliance with these standards. Sophistication and sustainability of AQ monitoring networks and systems are often also linked with the country’s economic conditions and commitment to environmental protection.

Box 6: Factors considered in setting air quality standards⁸³

- **Sensitive receptors** – members of the human population more vulnerable to air pollution than the general population such as children, elderly, and disabled persons; components of the environment or a specific stage in biological organisms’ development more sensitive than that of others
- **Pollutant behaviour in the atmosphere** – the reactions the pollutant undergoes and its residence time in the atmosphere
- **Pollutant behaviour in the environment** – the ability of a substance to bioaccumulate or biodegrade after entering the environment
- **Natural levels and fluctuations** – concentration levels and fluctuations of pollutants that occur naturally or enter the atmosphere from uncontrollable sources (e.g. volcanoes, deserts, forest fires)
- **Technological feasibility** – the cost and availability of technology to control or avoid emissions

National standards are enforceable by law. They vary according to the approach adopted for balancing health risks, technological feasibility, economic considerations and various other political, cultural, and social factors, which in turn will depend on, among other things, the level of development and national AQM capabilities.

Table 6: WHO air quality guidelines

Guideline/IT	PM ₁₀		PM _{2.5}		O ₃	NO ₂		SO ₂	
	Annual	24hr	Annual	24hr	Daily max 8hr mean	Annual	24hr	24hr	10min
WHO IT-1	70	150	35	75	160			125	
WHO IT-2	50	100	25	50				50	
WHO IT-3	30	75	15	37.5					
WHO AQG	20	50	10	25	100	40	200	20	500

Notes: AQG –air quality guideline; IT –interim target

81 WHO (2005) Air Quality Guidelines – global update. World Health Organization, Geneva, Switzerland.

82 Clean Air Asia (2016) Guidance Framework GA2 Emission Inventories and Modeling. Manila the Philippines.

83 Haq, G. and Schwela, D. (2008) Foundation Course on Air Quality Management. Stockholm Environment Institute, Sweden.

An outdoor air quality standard for a specific pollutant is a limit, which a certain statistical parameter of concentrations (for instance median, arithmetic mean, 98-percentile) should comply with. In situations with high “natural” background concentrations (for instance due to windblown aerosols from desert areas) the setting of standards may be difficult.

5.3 Air Pollution Legislation In India

The concentration of air pollutants depends not only on the quantities that are emitted from particular polluting sources but also on the ability of the atmosphere to either assimilate or disperse emissions. The air pollutant concentrations vary spatially and temporarily, causing the air pollution pattern to change with different locations and meteorological and topographical conditions. The presence of air pollutants in the ambient air adversely affects the human health and environment.

In 1981, the Government of India enacted the Air (Prevention and Control of Pollution) Act to prevent and control air pollution in India. The 1986 Environment (Protection) Act further emphasised need to reduce polluting emissions. During 1984-85, the CPCB initiated the National Ambient Air Quality Monitoring (NAAQM) Network to assess the present and anticipated air pollution impacts through air quality survey/monitoring programmes. Over the years, the number of stations has increased, and the programme was renamed the NAMP. In 1988, the motor vehicle act was enacted due to concern about road safety standards, and pollution control measures, standards for transport of hazardous and explosive materials.

The ambient air quality monitoring network measures a number of air pollutants at different locations in the country. This involves the selection of pollutants locations, frequency and duration of sampling, sampling techniques, infrastructural facilities, manpower and operation and maintenance. The areas selected for monitoring are based on traffic density, industrial activities, human population and its distribution, emission source, public complaints, and land use. Generally, the basis of a network design are the pollution source and the pollutants present. Air pollution emission issues are associated with many sectors, which inter-alia include power, transport, industry, residential, construction and agriculture. The pollutants measured include PM_{2.5} and PM₁₀, SO₂, NO_x and CO.

In 2009, the CPCB notified the third (1982, 1994, 2009) version of the NAAQS under the provisions of the 1981 Air (Prevention and Control of Pollution) Act. The revised NAAS aimed to provide uniform air quality for all, irrespective of the land use pattern, across the country.

In 2019, the Government of India launched the NCAP to tackle increasing air pollution and to address the emerging issues of air pollution in the cities of India. Its goal is to meet the prescribed annual average ambient air quality standards at all locations in the country in a stipulated timeframe.

5.4 National Ambient Air Quality Standards

After the 1972 Stockholm Conference on the Human Environment, it became clear that the nation was in need of a uniform environmental law. As a result, AA-1981 was passed by the Parliament in 1981. Agencies responsible for air quality standard creation and monitoring include CPCB and several State Pollution Control Boards (SPCBs). All of these entities are under the control of the Ministry of Environment, Forest and Climate Change (MoEFCC).

NAAQS objectives

The objective of the NAAQs are to:

- Indicate necessary air quality levels and appropriate margins required to ensure the protection of human, plant and animal lives and property
- Provide a uniform yardstick for the assessment of ambient air quality at the national level
- Indicate the extent and need of a monitoring programme. Annual standards are the annual arithmetic mean of a minimum of 104 measurements in a year at a particular site taken twice a week 24 hourly at a uniform interval and 24 hourly, 8 hourly or 1 hourly monitored values (time weighted average values), as applicable, which should be complied with 98% of the time in a year. About 2% of the time, they may exceed the limits but not on two consecutive days of monitoring.

The CPCB, working together with the SPCBs, provides technical advice to MoEFCC to fulfil the objectives outlined in the AA-1981.

NAAQS are set taking into consideration geographical conditions, pollutant background concentrations, available air pollution control technologies and the cost of treatment, international standards (WHO, USEPA, EU and Chinese) and the sensitivity/tolerance of the receptor (see Table 7). The SPCBs/PCCs can set more stringent standards than the existing national standards in their respective states but do not have the powers to relax these standards. Such a process is similar to the local divisions used within the USEPA with the goal of providing for the prevention, control and abatement of air pollution.

Regulatory authorities need to undertake concrete measures to ensure that the standards are implemented and met, taking into account the existing air quality in the particular region, number of complaints received, directions from the courts, based on the carrying capacity of the specific area, the cost of control strategies, etc. The process takes years or even decades, especially for pollutants where

the level of standards is not easily available. The air pollution areas can be identified and designated as attainment and non-attainment areas. Two types of State Implementation Plans (SIP) can then be developed— an attainment-maintenance SIP if the area is designated as attainment, and an attainment-demonstration.

5.4.1 Industry standards

In addition to the NAAQS, MoEFCC, through CPCB, adopted 113 emission/effluent standards for different sectors of industries. To strengthen the monitoring mechanism and ensure compliance with emission standards, CPCB has required 17 categories of highly polluting industries to install and provide connectivity to the CPCB server for Online Continuous Emission/Effluent Monitoring System (OCEMS). The CPCB has directed the State Pollution Control Boards/PCCs of the National Capital Region and other states to install online continuous emission monitoring systems by the red category air polluting industries located in 23 districts of the NCR and Delhi (2017). Out of 3,531 industries, 2,743 industries have installed OCEMS and closure directions are in force for 740 non-complying units.

Table 7: Different air quality standards

Sr. No.	Pollutant	Time weighted average	Indian AQS		Chinese AQS		USEPA AQS	EU AQS	WHO AQS
			Industrial, Residential, Rural area	Ecological sensitive area	Natural Protection Area	Residential, Commercial, Industrial and Rural Area			
1	Particulate Matter Pm10 (µg/m3)	Annual	60	60	40	70	-	40	20
		24 hours	100	100	50	150	150	50	50
2	Particulate Matter PM2.5 (µg/m3)	Annual	40	40	15	35	12	-	10
		24 hours	60	60	35	75	35	25	25
3	Sulphur Dioxide So2 (µg/m3)	Annual	50	20	20	60	75ppb (1 hour)	125	-
		24 hours	80	80	50	150	-	350	20
4	Nitrogen Dioxide No2 (µg/m3)	Annual	40	30	40	40	53 ppb	200	40
		24 hours	80	80	80	80	100ppb (1 hour)	-	-
5	Ozone O3 (µg/m3)	8 hours	100	100	100	160	0.070 ppm	-	100
		1 hour	180	180	160	200	-	-	-
6	Lead Pb (µg/m3)	Annual	0.5	0.5	-	-	-	-	-
		24 hours	1.0	1.0	-	-	0.15 (Rolling 3 month average)	-	-
7	Carbon Monoxide CO (mg/m3)	8 hours	2.0	2.0	-	-	9.0	10	-
		1 hour	4.0	4.0	10	10	35.0	-	30

8	Ammonia NH ₃ (µg/m ³)	Annual	100	100	-	-	-	-	-
		24 hours	400	400	-	-	-	-	-
9	Benzene C ₆ H ₆ (µg/m ³)	Annual	5	5	-	-	-	5	-
10	Benzo(a)pyrene BaP (µg/m ³)	Annual	1	1	-	-	-	-	-
11	Arsenic As (ng/m ³)	Annual	6	6	-	-	-	-	-
12	Nickel Ni (g/m ³)	Annual	20	20	-	-	-	-	-
13	Poly Aromatic Hydrocarbon PAH (1 ng/m ³)	Annual	-	-	-	-	-	1	-

5.4.2 National air quality index

In 2015, a national air quality index (AQI) was launched (see Figure 18). This was initially for 14 cities but was extended to 57 cities. AQI is an effective tool to communicate the air quality status to the public in an understandable way. It transforms ambient air quality data of various pollutants into a single number (index value), nomenclature and colour.

There are six AQI categories: Good, Satisfactory, Moderately Polluted, Poor, Very Poor and Severe.

Each category is based on the ambient concentration values of air pollutants and their likely health impacts (known as health breakpoints). The lower value of the range is known as a health breakpoint⁸⁴ (e.g. 51 is the minimum for the category ‘satisfactory’).

AQ sub-index and health breakpoints have been developed for eight pollutants (PM₁₀, PM_{2.5}, NO₂, SO₂, CO, O₃, NH₃ and Pb) for which short term (up to 24 hours) NAAQS exist.

AQI	Associated Health Impacts
Good (0-50)	Minimal Impact
Satisfactory (51-100)	May cause minor breathing discomfort to sensitive people
Moderate (101-200)	May cause breathing discomfort to the people with lung disease such as asthma and discomfort to people with heart disease, children and older adults
Poor (201-300)	May cause breathing discomfort to people on prolonged exposure and discomfort to people with heart disease with short exposure.
Very Poor	(301-400) May cause respiratory illness to the people on prolonged exposure. Effect may be more pronounced in people with lung and heart diseases
Severe (401-500)	May cause respiratory effects even on healthy people and serious health impacts on people with lung/heart diseases. The health impacts may be experienced even during light physical activity

Figure 18: Air quality index⁸⁵ Source: Control of Urban Pollution series CUPS/82/2014-15, Air Quality Index, CPCB

⁸⁴ USEPA (2012) Air Quality Index. United States Environmental Protection Agency, Washington DC, USA.

⁸⁵ MoEFCC (2019) Government launches National Clean Air Programme (NCAP). Ministry of Environment, Forests and Climate Change, New Delhi, India

The AQI is useful for: (i) the general public to know air quality in a simplified way; (ii) a politician to ensure quick actions; (iii) a decision maker to know the trend of events and to outline corrective pollution control strategies.

Taking into account the available international experiences and national studies, the tentative national level target of 20%–30% reduction of PM_{2.5} and PM₁₀ concentration by 2024 is proposed under the NCAP, keeping 2017 as the base year for the comparison of concentration.

Whenever there is an increase in the concentration of PM_{2.5} or PM₁₀ and the AQI achieve a poorer quality category, actions in the form of Graded Response Action Plan (GRAP) similar to the New Delhi-NCR region plan must be adopted.

5.4.3 Role and responsibilities of decision maker

Various institutions, at different levels, have roles within the AQM framework. These roles and responsibilities could be:

- National Government: establish laws, standards, taxes and prices; determine attainment status by comparing monitoring results with standards
- National or provinces: established environmental plans, control, and disclosure
- Municipalities/local government: action plans, investments, control, and disclosure
- Industry: awareness raising and cooperation in achieving national standards
- NGOs and media: awareness raising, public participation

Determination of attainment status requires constant monitoring for a long period of time. Many regulations allow for exceeding the ambient air quality guideline value or standard for a specified number of days. The rules for the determination of non-attainment status must be clearly stated in the regulation to avoid legal battles as the declaration of non-attainment status can be a potentially contentious issue. This is because the attainment (or non-attainment) status has implications on the clean air action plan as well as regulations and control measures that will be implemented in the city.

Box 7: Air quality enforcement procedure in the European Union⁸⁶

In the EU, Directive 2008/50/EC sets strict limit values on air pollutant concentrations for SO₂, NO₂, PM₁₀, PM_{2.5}, CO, C₆H₆, and Pb. A ‘limit value’ is defined as “a level fixed on the basis of scientific knowledge, with the aim of avoiding, preventing or reducing harmful effects on human health and/or the environment as a whole, to be attained within a given period and not to be exceeded once attained”. For O₃ the Directive sets a target value that has a more lenient definition.

EC Directive 2004/107/EC sets target values for arsenic, cadmium, mercury, nickel, and BaP. A ‘target value’ means “a concentration in the ambient air fixed with the aim of avoiding, preventing or reducing harmful effects on human health and/or the environment as a whole, to be attained where possible over a given period.”

Law enforcement relies on a monitoring and reporting system to inform the European Commission (EC) and the public. Due to air quality monitoring uncertainties, some air pollutant concentrations, notably PM_{2.5}, NO_x, O₃, and BaP temporarily do not comply with their respective limit or target values in the majority of Member States. However, only a few Member States exceed air quality limits (i.e., the lower 95% confidence levels are above the limit or target values in only a few countries). If an EU Member State exceeds a limit or target values, the EC can set a fine in order to enforce non-exceedance.

When the air pollution in a city requires control measures, the policy and regulation to be implemented must be carefully planned. Ideally, a cost-benefit analysis of the control measure proposed is conducted before being enforced. The cost of implementing the measure is compared with the benefits that will be reaped when it takes effect. Monetising both costs and benefits requires data on the population’s willingness to pay-as-well the value they put on health.

⁸⁶ Clean Air Asia (2018) Mainstreaming air quality in urban development in Asia. Clean Air Asia, Manila, the Philippines.

For decision-makers involved in AQM, the city’s emission inventory and air quality monitoring data are the minimum needed to assess the air quality status. However, additional socio-economic data are needed in drafting a clean air action plan for the city. These socio-economic data include but are not limited to economic indicators energy usage; population growth; cost estimate of control measures health endpoints (hospital visits, morbidity, mortality, etc.); and inventory of resources.

Box 8: Air Quality Enforcement Procedure in the USA

In the US, sanctions and consequences of failure to attain NAAQSs in a SIP are regulated in 42 U.S. Code § 7509 (Cornell Law School Legal Information Institute, 2017). If the US EPA:

- Finds that a State has failed, for a non-attainment area to submit a SIP or to submit one or more of the elements applicable to such an area, or has failed to make a submission for such an area that satisfies the minimum criteria established in relation to any such element, or
- Disapproves a SIP for an area designated nonattainment, based on the submission’s failure to meet one or more of the elements applicable to such an area, or
- Finds that any requirement of an approved SIP is not being implemented and enforced within a fixed time period

One of the following two sanctions are applied:

- Highway sanctions: The US EPA may impose a prohibition, applicable to a non-attainment area, of any projects or the awarding of any grants, except for projects related to the safety of or reduction of accidents on highways, capital programs for public transit, and other transportation-related programs specified in the code.
- Offset sanctions: In applying the emissions offset requirements to new or modified sources or emissions units for which a permit is required, the ratio of emission reductions to increased emissions shall be at least two to one. Within a year after the USEPA publishes the notice of failure to attain, each State containing a non- attainment area shall submit a revision to the SIP meeting the requirements prescribed by the law and as the USEPA may reasonably prescribe.

5.5 Emissions

An emissions inventory is generally defined as a comprehensive listing of sources and an estimation of the magnitude of air pollutant emissions in a geographic area during a specific time period. It can have different geographical scales ranging from global to individual plant level emissions. An inventory can be compiled at the national level, or emissions at the national level can be the sum of emissions compiled at smaller geographical scales (e.g. county, municipality or even facility level).

An inventory can be given for a single year only, but inventories for more years (time-series) are needed for most applications. Emissions inventories should, therefore, be annually compiled and updated.

An emissions inventory can be used in a variety of ways as part of an AQM programme. It can be used to:

- Estimate the magnitude of local, regional or national emissions
- Evaluate emissions tendencies
- Serve as input in air quality models
- Assure compliance with regulatory/legal decisions (emission standards) and actions relating to emissions and/or air quality
- Estimate the impact of new sources of pollution (e.g. Planning new industrial plants or changing processes in existing plants or allowing the use of different types of vehicles)
- Support the setting of emission fees for sources
- Establish emission trading programmes
- Help revise current air quality regulations, policies and strategies
- Initiate strategies and regulations for AQM

Emissions inventories can be approached in two ways: top-down or bottom-up. The key decision on which approach to take is generally based on available resources.

Although a city-level emission inventory provides the decision-maker with estimates of the magnitudes of emissions coming from various sources within the city. It does provide information on how these sources are distributed throughout the city and usually includes location of the source. Such information can be seen in an emission map. Emission maps can locate the percentage of the population exposed to certain levels of pollutants.

Area sources are more complex to map. The grid size is typically 500 metres by 500 metres. Total emissions

of pollutants are encoded for each grid. While primary data for stationary sources may be collected directly from the facilities, data needed for the emission estimates of area sources are collected from only a representative sample. Socio-economic data, such as population density, are used to calculate the emissions of grids without any survey data. The result is an emission map that shows where the highest magnitude of emissions of a pollutant can be found.

The emission map is a graphical representation of all emission sources (stationary, area and mobile) in the city. Actual hotspots where ambient pollutant levels are found will not be shown in the emission grid map. However, the data in the emission map can be used as input to a dispersion model to predict where the hotspot may be found under particular meteorological conditions. If the spatial distribution of the emission sources is available, the model predictions will have a higher degree of accuracy compared to the output when the citywide emission is assumed to be distributed homogeneously throughout the city. The assumption of homogeneity is the usual assumption when there is no data available on the spatial distribution of emissions.

5.6 Air Quality Monitoring

Another key component of effective AQM is a sustainable and efficient AQ monitoring system. Routine monitoring of AQ provides data that allows monitoring of compliance with NAAQS, assesses trends in air pollution levels and exposures, and evaluates progress and effectiveness of AQ policies and measures (See Table 8).

Robust and credible AQ data contribute to effective decision-making in AQM and this can be achieved only through an effective monitoring system (see Figure 13). Monitoring systems/programs also need to be cost-effective; have stable financial, operational and personnel resources; and adjusted to local needs and conditions.

The design of an AQ monitoring program is primarily defined by its purpose or objectives. The design will then determine: size and sophistication of the monitoring network (including equipment); location and number of sampling stations; duration and frequency of sampling; and, most importantly, the financial and manpower resources needed

Table 8: Common objectives for air quality monitoring⁸⁷

Basic Objectives	Specific Objectives
Timely public reporting	Assess short-term pollution levels
	Develop an air quality index (or other tools for data communication)
	Forecasting
Compliance	Determine compliance levels with standards
	Observe pollution trends
	Formulate pollution control strategies
	Examine the extent and causes of elevated concentrations
	Enhance understanding of chemical and physical properties of atmospheric pollution and pollution sources
	Evaluate the effectiveness of pollution control strategies
Research	Support national and international agreements and initiatives
	Identify pollutant generation and behavioral characteristics
	Assess impacts to different groups of populations
	Assess impacts to visibility impairment, climate change and ecosystems
	Validate models
	Discover new contaminants

87 Clean Air Asia (2016) Guidance Framework GA2 Emission Inventories and Modeling. Manila the Philippines.

to operate and sustain the network. Air quality monitoring activities can be grouped according to three broad types of objectives: timely public reporting, compliance, and research (Table 2.5).

Ambient air quality monitoring requires the measurement of the concentration of air pollutants at regular intervals. The sampling period depends on the averaging time of the guideline value or standard. The instrument used in the monitoring determines whether the sampling is done continuously or intermittently. Many 24-hour samples are collected on a one-in-six basis since this ensures that samples will be collected at all days of the week during the whole year. It also allows for determination of seasonal variation of pollutant levels. More frequent monitoring may be done but the costs will be higher. More frequent sampling schemes (1-in-3, daily) do not necessarily provide better information for trends analysis.

- Factors to be considered when designing environmental monitoring system are:
- Air quality objectives
 - Data quality objectives
 - Quality assurance/quality control plan
 - Site Selection

- Understanding Meteorological conditions
- Sensitive receptors
- Parameter Selection (Key Pollutants)
- Equipment Selection/Available Equipment
- Data Analysis

Ambient air monitoring is different from roadside or source monitoring. It assumes that emissions from local sources have been mixed in the atmosphere as a result of meteorological conditions (temperature, pressure, wind speed, wind direction, solar insolation, and relative humidity). It is meant to capture air that the majority of the population breathes, not air near a source that only a small fraction of the population breathes.

There are various technical guidelines for designing and operating an AQ monitoring program/network, including those from WHO, USEPA, and the EU (Table 9). Air pollution – and its drivers – is complex in nature; it requires an AQ monitoring program that is dynamic — one that needs to be periodically reviewed and improved to ensure that it is responsive to these factors. These guidelines present differences in prescribed specifications for the number of sampling points/stations and the probe height, among others.

Table 9: International Guidelines for air quality monitoring⁸⁸

Organization	Title/Link to Guidelines
WHO	Monitoring Ambient Air Quality for Health Impacts Assessment http://www.euro.who.int/__data/assets/pdf_file/0010/119674/E67902.pdf
USEPA	Air Planning and Standards http://www.epa.gov/airquality/montring.html Guidance for Network Design and Optimum Site Exposure for PM _{2.5} And PM ₁₀ http://www.epa.gov/ttn/amtic/files/ambient/pm25/network/r-99-022.pdf Guidance for Using Continuous Monitors in PM _{2.5} Monitoring Networks http://www.epa.gov/ttn/amtic/files/ambient/pm25/r-98-012.pdf
EU	Directives for Monitoring Atmospheric Pollution (Directive 2008/50/EC) http://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:32008L0050&from=EN
Stockholm Environment Institute (SEI)	Global Atmospheric Pollution Forum (GAPF) Air Pollution Monitoring Manual http://www.sei-international.org/rapidc/gapforum/html/projects.php
Environment Canada	National Air Pollution Surveillance Program http://www.ec.gc.ca/rnspa-naps/

Case Study: Air Quality Monitoring in Thailand
The Thailand PCD has monitored ambient air quality since 1983. Ambient air pollutants routinely measured include CO, NO_x, SO₂, O₃, Total TSP, PM₁₀ and Pb,

as well as meteorological parameters. As of October 2017, the air quality monitoring network consists of 63 monitoring stations, five meteorological stations, and nine mobile units spread throughout Thailand.

Monitoring stations are focused on Bangkok due to the concentration and magnitude of people affected.

Other government agencies, such as the Bangkok Metropolitan Authority (BMA), Electricity Generating Authority of Thailand (EGAT), and the Industrial Estate Authority of Thailand, also monitor air quality and coordinate with the PCD. The BMA operates and maintains its own stations that aim to cover all districts of Bangkok. Its network comprises of continuous automated ambient air quality stations and roadside continuous and short-term temporary air quality stations that monitor TSP, PM10, and PM_{2.5}. A temporary roadside monitoring program was conducted in 18 sites in Bangkok in 2017. The EGAT focuses on monitoring specific AQ parameters in areas where it operates. Air quality data generation and assessment are coordinated with and reported to PCD by the government agencies. In addition, some industrial groups also conduct monitoring but are not required to report to PCD.

The PCD received assistance from Japan and Sweden in the early stages of its air quality monitoring. The Swedish Government provided assistance in 1992 for the preparation of the design of a nationwide air quality monitoring network and a meteorological monitoring network.

Operating monitoring stations

Monitoring activities are determined by budget allocation, identified AQM issues in a particular jurisdiction, and other related development priorities. For example, due to air pollution episodes, the need to monitor haze was identified in North-eastern Thailand, and similarly actual pollutants monitored may differ every year depending on the area (i.e., if the pollutant exceeds standards or guideline values), budget, and priorities.

Continuous automated analysers monitor PM₁₀, PM_{2.5}, O₃, SO₂(subscript), hydrosulphuric acid (H₂S), NO_x, NO, NO₂, and VOCs all year round. Continuous sampling and measurement are conducted monthly for TSP, PM₁₀, PM_{2.5}, Pb, and VOCs. Meteorological parameters, such as temperature, wind direction, wind speed, relative humidity, solar radiation, net radiation, pressure, and rain are also tracked. Eighteen stations currently measure VOCs throughout the country, with seven stations located in the Bangkok Metropolitan area. Monitoring of PM_{2.5} was initiated with one station in the Samut Sakhon province in 2013, and with two stations in Bangkok since 2014. While some of the monitoring stations include H₂S in

the parameters observed, Thailand currently does not have standards for the pollutant.

Quality assurance/quality control

Thailand’s air quality monitoring system is equipped with data loggers and data is transmitted from remote sites to the central processing computer at PCD for storage and analysis. The PCD implements QA/QC procedures for all monitoring stations and ensures data quality checks for hourly SO₂, NO₂, CO, O₃, and PM₁₀ on a daily basis. Data analysis is based on Thailand’s NAAQS and system performance audits could be undertaken by a third party.

The PCD adopts USEPA QA/QC procedures, which in theory can be adopted by other agencies as well as the private sector to help facilitate data comparison and reiteration of methods for verification. However, there is no standard or common QA/QC protocol across agencies. Different agencies that undertake air quality monitoring activities do not adopt the same protocols that the PCD uses. While data across different stations operated by different agencies are not comparable, these are still useful to generate trends. Further, PCD confirmed that even without a common QA/QC protocol, assessment and comparison of AQ data may be undertaken, depending on the air quality objective set and budget allocated by concerned agencies.

Communicating data to the public

Monitoring data in AQI format is displayed on screens at certain locations. It can also be accessed through a mobile app and PCD’s website (www.air4thai.pcd.go.th).

Costs of air quality monitoring

Investment costs of air quality monitoring depend on the parameters to be monitored. Monitoring full parameters and setting up of a meteorological tower can cost THB7-8 million (\$220,000 to 250,000). Monitoring less parameters would entail less costs. Annual operating costs include maintenance, which are also dependent on location and parameters covered. Estimated annual operating costs are around THB400,000-900,000 (\$12,700-28,700). Regular audit is done annually, but this is also contingent on available funding.

Outsourcing air quality monitoring

Currently, the PCD outsources the technical and maintenance service of almost half of its air quality monitoring stations. Monitoring stations and system performance are audited by a third party and

88 Clean Air Asia (2016) Guidance Framework GA2 Emission Inventories and Modeling. Manila the Philippines.

occasionally put under service contracts depending on the budget of PCD. With sufficient funds, it puts all monitoring stations under service contracts and hires companies to operate the stations. If funds are limited, PCD puts some stations under service contracts and operates the rest themselves. The service contracts cover sampling/data acquisition system/ single point calibration/log book (every 15 days), multi-point calibration (every 3-4 months), maintenance of mass flow controller (every 6 months), maintenance of meteorological equipment (every 6 months), efficiency test of Molybdenum converter, accuracy test of zero-air scrubbers and ozone generator of the calibrator, air conditioning system test and cleaning, handling of emergency cases, and data reporting. In 2017, 23 stations were outsourced by PCD. PCD owns the monitoring stations and the air quality data collected but the land stations are owned by different government agencies and/ or local governments.

Third-party contractors are selected through competitive bidding. Terms of Reference are prepared by PCD and are posted on its website. Data quality and the procedures that need to be followed are included in the TOR. Monthly inspections are done by PCD staff and the payment for outsourced services is dependent on the quality of data generated. PCD requires at least 85 percent of good quality data. If data quality is deemed to be below this percentage, the contractor pays a fine. During haze episodes, contractors are fined if good quality PM_{2.5} data is not available.

Mobile monitoring units

Mobile monitoring units supplement operations of the AQ monitoring stations. These are typically placed at locations where budget is insufficient to have a fixed station. The mobile unit is sent to the identified location thrice a year. In Northern Thailand where the incidence of open burning is high, mobile monitoring units are used to gather information because the fixed stations don't cover this area.

5.7 Air Pollution Control Measures

A city-specific clean air action plan (CAAP) enables the government as well as the wider stakeholder groups to recognise the vision and goals for air quality improvement, set objectives, mobilise resources and collaborate effectively and efficiently to achieve improved air quality.

Under India's NCAP, 122 non-attainment cities are required to prepare city air action plans along with GRAPs, the cities need to adopt three tier mechanism by formations of steering, monitoring and implementation committees at state or city levels (see Box 8). A city-specific action plan intends to improve air quality and public health by identifying cost-effective measures to reduce emissions from sectors such as transport, industries, waste deposits and residential burning among others, and bring it to the level of NAAQS. Plans should be city-specific because the background conditions, sources of air pollution, mitigation measures and other factors such as population, density of population, geographical area, availability of pucca roads, common mass transport facilities, and traffic sense among the people will differ city to city.

Box 9: City-specific Air Quality Management Plans for 122 Non-attainment cities under NCAP

The National Clean Air Programme (NCAP) has identified 122 cities that do not meet the air quality standards, based on order by National Green Tribunal and data reported by Central Pollution Control Board and WHO. The NCAP recommends that city action plans and emergency action plans be prepared. The Actions suggested are:

Preliminary city-specific action plans to be formulated for 122 non-attainment cities.

City-specific actions plans to be taken up for implementation by State Government and city administration

City-based clean air actions plans are to be dynamic and evolved based on the available scientific evidence including the information available through source apportionment studies.

A separate emergency action plan in-line with notified GRAP of Delhi to be formulated for each city to address severe and emergency AQIs

Under the NCAP, source apportionment studies are to be taken up in all the non-attainment cities and towns in a phased manner. Studies for ten priority cities have been commissioned.

5.7.1 City-specific air quality management plan

The key features of a city CAAP plan may include:

- Measures to set-up or strengthen the air quality monitoring and analysis system
- Measures to communicate air quality status to the public, vulnerable groups and relevant stakeholders for reducing exposure
- Adoption and implementation of control measures
- Instruments and strategies to comply with air quality and emission standards and fixing the time bound accountability of all responsible agencies/ stakeholders.
- Regular review of the progress of the action plan at the level of the Chief Secretary of the state.
- Continuous improvement after compliance, including through public reporting
- A city CAAP is also a collection of regulations, policies and programmes for cleaner air.

City CAAP encompass short-term, medium-term, and long-term mitigation and control measures to reduce emissions from mobile (transport), stationary (industry), and area sources (Table 10) Several different types of measures for improving air quality can be broadly identified and categorised as follows:

- **Conservation:** reducing the use of resources through energy conservation
- **Efficiency:** carrying out the same activity, but doing so more efficiently, thus reducing resource use and emissions of air pollutants

- **Abatement:** applying a technological approach to reduce emissions
- **Fuel switching:** substituting lower emission fuel for a higher emission fuel
- **Demand management:** implementation of policies or measures which serve to control or influence the demand for a product or service
- **Behavioural change:** changing the habits of individual's organisations in such a way as to reduce emissions – e.g. travelling by bus instead of car.

These measures can be brought about in many different ways through legislation, economic instruments, voluntary agreements and available technologies. Specifically, measures to reduce air pollution from mobile and stationary sources – i.e. transport sector, industrial, and area sources. The Air Pollution in Asia and the Pacific: Science-based Solutions report identifies 25 clean air measures to positively impact human health, crop yields, climate change and socio-economic development, as well as contribute to the achievement of the SDGs.

It aims to support efforts to air pollution and mitigate climate change in Asia and the Pacific by proposing cost-effective options suited to the countries of the region (Clean Air Asia and UNEP, 2019). Cities may refer to this report as guidance in selecting the control measures.



Table 10: UNEP's 25 Clean Air Measures

Asia-wide application of conventional measures	
Post-combustion controls	State-of-the-art end-of-pipe stored ucesulphurdioxide, nitrogenoxides and PM emissions at power stations and industry
Industrial process missions	Advanced emission standards for e.g.iron and steel plants, cement factories, glass production, chemical industry etc.
Emissions standards for road vehicles	Strengthen all emissions standards; special focus on regulation of diesel light- and heavy-duty vehicles
Vehicle inspection and maintenance	Enforcement of mandatory checks and repairs for vehicles
Road dust	Road paving and cleaning
Next generation 'Asia-specific air quality measures that are not yet major components of clean air policies in many parts of the Asia Pacific	
Agricultural crop residues	Management of agricultural residues including strict enforcement of the burning ban
Residential waste burning	Strict enforcement of ban of open burning of household waste
Prevention of forest and peat fires	Prevention of forest and peat fires
Livestock manure management	Covered storage and efficient application of manure, Anaerobic digestion
Nitrogen fertilizer application	Efficient application, urea inhibitors, Use of ammonium nitrate
Brick kilns	Improving efficiency and introducing emission standards
International shipping	Low sulphur fuels and control of particulate matter emissions
Solvent use and refineries	Low solvent paints (both industrial and DIY applications), leak detection, incineration and recovery

Measures contributing to development priority goals with benefits for air quality	
Clean cooking	Clean fuels in cities (electricity, natural gas, liquefied petroleum gas[LPG]),LPG and advanced biomass cooking stoves in rural areas; substitution of coal by briquettes
Renewables for power generation	Incentive instruments to foster extended use of wind, solar And hydro power for electricity generation and phase-out of least efficient plants
Energy efficiency standards-households	Incentive instruments for household appliances, buildings, lighting, heating and cooling; roof-top solar
Energy efficiency standards-industry	Ambitious energy efficiency standards for industry
Electric cars	Promotion of electric cars
Improved public transport	Improved accessibility through public transport
Solid waste management	Centralized waste collection with source separation and treatment, gas utilization
Rice paddies	Intermittent aeration of continuously flooded rice fields
Wastewater treatment	Well-managed two-stage treatment with biogas recovery
Coal mining	Pre-mining recovery of coal mine gas
Oil and gas production	Recovery of associated petroleum gas; stop routine flaring; improve leakage control
*HFC refrigerant replacement	Full compliance with the Kigali Amendment
Source: UNEP, 2018	

5.7.2 Assessment of ten clean air action plans
Over 100 Indian cities across have developed a city CAAP. However, the city CAAP varies in terms of proposed mitigation actions. The National Resource Defence Council (NRDC) assessed the clean air actions plans of 10 Indian cities (Ahmedabad,

New Delhi, Hyderabad, Kanpur, Kolkata, Mumbai, Nagpur, Patna, Pune and Surat).⁸⁹ This included an analysis of transport, power plants and industries, construction, waste collection, industrial waste and diesel generator sets.

Figure 19 outlines the city CAAP actions to reduce transport emissions in the ten Indian cities. The study identified a number of gaps that needed to be strengthened. These included strengthening AQM regulatory frameworks and legal enforcement,

improving the collection of air pollution and health data, introducing road pricing to reduce motor vehicle use, lowering speed limits, reducing idling, upgrading bus fleets to use alternative fuels, and restricting vehicle access.

89 NRDC (2020) Clearing the air: a review of 10 city plans to fight air pollution in India. National Resource Defense Council.

Transportation										
Action	Ahmedabad	Pune	Delhi	Hyderabad	Kanpur	Nagpur	Patna	Surat	Kolkata	Mumbai
Restriction on older vehicles	Yes (Partial)	Yes (Partial)	Yes	Yes (Partial)	No	Yes (Partial)	Yes (Partial)	Yes (Partial)	Yes (Partial)	Yes (Partial)
Infrastructure for CNG and e-mobility	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Cleaner Fleets for public transport, TNC's and 1 st /last mile connectivity using clean fuel – CNG and EVs	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
In-use emission control, including installation of remote sensor-based PUC system	Yes	No	Yes	Yes	Yes	Yes	No	Yes	Yes	No
Intelligent traffic management systems	Yes	Yes	Yes	Yes	Yes	Yes	No	Yes	Yes	Yes
Vehicle demand management - parking policy, walking & NMT, and fiscal measures	Yes	Yes	Yes	No	Yes (Partial)	Yes (Partial)	Yes (Partial)	Yes	Yes	Yes

Stationary Sources – Power Plants and Industries										
Action	Ahmedabad	Pune	Delhi	Hyderabad	Kanpur	Nagpur	Patna	Surat	Kolkata	Mumbai
Regulation and closure of power plants within 300 km radius	No	No	Yes (Partial)	No	No	No	No	No	No	Yes (Partial)
Implementation of 2015 emission standards for PM, NOX and SOX for TPPs	No	No	No	No	No	No	No	No	No	Yes (Partial)
Clean Fuels - mandates, incentives and siting restrictions	No	No	Yes	Yes (Partial)	No	Yes (Partial)	Yes (Partial)	No	Yes (Partial)	Yes (Partial)
Conversion of brick kilns to induced draft zig-zag technology	Yes	No	Yes	No	Yes	Yes	Yes	No	Yes	No
Fiscal measures, including ETS schemes	No	No	No	No	No	No	No	Yes	No	No

Solid Waste, Construction & Demolition, and Diesel Generator Sets										
Action	Ahmedabad	Pune	Delhi	Hyderabad	Kanpur	Nagpur	Patna	Surat	Kolkata	Mumbai
Scientific management of landfill sites and complete implementation of MSW Rules, 2016	Yes (Partial)	No	Yes (Partial)	No	Yes (Partial)	No	No	Yes (Partial)	Yes (Partial)	Yes (Partial)
Limits on use of DG sets	No	No	Yes	No	No	Yes (Partial)	No	No	Yes (Partial)	No
C&D waste recycling	Yes (Partial)	Yes (Partial)	Yes (Partial)	Yes (Partial)	Yes (Partial)	Yes (Partial)	Yes (Partial)	Yes (Partial)	Yes (Partial)	Yes (Partial)
C&D dust control	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes

Figure 19. Actions in clean air action plans to reduce transport, stationary, and waste emissions⁹⁰

5.7.3 Construction and demolition

Road dust and dust arising from construction and demolition are the major contributors to air pollution in Indian cities. Dust is all airborne PM that is suspended in air or has settled out onto a surface after having been suspended in air. Three types of construction and demolition dust exist:

- **Silica dust** – created when working on silica-containing materials such as concrete, mortar and sandstone.
- **Wood dust** – created when working on softwood, hardwood and wood-based products such as mdf and plywood.
- **General dust** – created when working on other materials containing very little or no silica. The most common include gypsum (e.g. in plasterboard), limestone, marble and dolomite.

Construction works such as drilling and grinding undertaken in excavation, installation and demolition, emit an enormous quantity of particles into air.⁹¹ The level of dust pollution can exceed the maximum permissible concentrations.

Respirable crystalline silica (RCS) is a component in most of the materials used in construction activities

such as fine aggregates, coarse aggregates and limestone. Inhalation of RCS can cause severe health defects to human beings.⁹² Particles are inhaled into the lung, and consequently lead to physical diseases such as pneumoconiosis. This endangers both the construction workers and the individuals living in the neighbourhood. As the number of construction and demolition activities increase with city development so does construction dust pollution. It is therefore necessary to mitigate construction dust pollution and reduce its concentration to urban air pollution.⁹³

Both construction equipment and machinery such as a crane, pile machine, drilling machine, and dump truck, together with construction works are a source of PM pollution. In order to reduce dust pollution, developers should be required to implement appropriate dust pollution control measures to ensure the air quality impacts of construction and demolition are minimised and any mitigation measures employed are effective.

Developers should ensure that the site is responsibly managed during the demolition and construction phases of the development.

⁹⁰ NDRC (2020) Clearing the air: a review of 10 city plans to fight air pollution in India. National Resource Defense Council.

⁹¹ HSE (n.d.) Construction Dust: information sheet 36 (revision 3). Health and Safety Executive, London.

⁹² Cheriyan, D. and Choi, J. (2020) A review of research on particulate matter pollution in the construction industry. Journal of Cleaner Production 254:120077.

⁹³ Wu, Z et al. (2016) Mitigation construction dust pollution: state of the art and way forward. Journal of Cleaner Production 112 (2016) 1658e1666



Measures to control dust pollution from construction sites include:

- Erecting solid barriers around the site boundary
- Using water sprays or sprinklers to keep reduce dust during activities such as filling skips, breaking concrete and managing stockpiles
- Washing the wheels of vehicles leaving the site, if they are carrying mud or waste
- Covering lorries that leave the site carrying waste
- Cleaning the road and footpath near the site entrance when needed
- Using dust bags, spraying water or, when using disk cutters, making the working area wet before using the machinery
- Not burning waste materials
- Locating machinery and dust causing activities should be located away from sensitive receptors.
- Enclosing stockpiles or keep them securely sheeted.⁹⁴

Other potential city-wide control options include sweeping and watering of roads, better construction and maintenance, growing plants, grass, etc., to prevent re-suspension of dust.

The NRDC study of the CAAP of ten Indian cities found that city-level actions to reduce transport emissions included recycling construction and demolition waste and control dust from construction hotspots.⁹⁵

In 2016, the Government of India published Construction and Demolition Waste Management Rules (C&D rule) to tackle the issues of pollution and waste management. The basis of these rules is to recover, recycle, and reuse the waste generated through construction and demolition. Segregating construction and demolition waste and depositing it to the collection centres for processing to be the responsibility of every waste generator.

In 2018, MoEFCC issued a Dust Mitigation notification making mandatory dust mitigation measures in infrastructural projects and demolition activities in the country. This would help to keep the dust under control to reduce air pollution in metros and cities. The rules empower the ministry to issue notices against local authorities and state agencies for non-implementation of those actions.

The NCAP suggests a number of city-level actions aimed at road and construction dust. These are:

- Introducing mechanical sweepers on the basis of feasibility study in cities.
- Evolve standard operating procedure to addressing the disposal of collected dust from mechanical sweeping.
- Stringent implementation of the government Construction and Dust Rules (2016), and Dust Mitigation notification (2018).
- Wall-to-wall paving of roads to be mandated.
- Stringent control of dust from construction activities using enclosures, fogging machines, and barriers.
- Greening and landscaping of all the major arterial roads and national highways after identification of major polluting stretches.
- Maintenance and repair of priority roads.
- Sewage treatment plant-treated water sprinkling system along the roads and at intersecting road junctions and spraying of water twice a day before peak traffic hours.

5.7.4 Transport

Transport accounts for approximately 4% of PM_{2.5} emissions with emissions concentrated in urban centres.⁹⁶ For example, in Delhi, vehicle emissions contribute up to 40% of ambient PM_{2.5} pollution.⁹⁷

Air pollution from the transport sector has important health and environmental effects, especially road transport. India is one of the largest markets in the world for vehicle sales by volume.⁹⁸ Increasing vehicle ownership and use is a key challenge given that road transport is responsible for a significant proportion of NO₂ and PM (PM₁₀ and PM_{2.5}). These pollutants are most likely to exceed NAAQs. Therefore, reducing emissions from road transport is a key part of local AQM.

Box 10: Transport Control in Singapore⁹⁹

Since 1975, the Government of Singapore has introduced a series of traditional and experimental measures to slow down the growth of motor vehicle population and to control its usage. These include an area licensing system and general price restraints, a quota system on new cars, a weekend car scheme, and an electronic road pricing (ERP) system. The various policies adopted by the Singapore government to reduce traffic congestion and pollutant emissions have been largely successful because they are based on integrated city planning.

Other countries can profit from the Singapore experience through:

- Periodical adjustment of policies using feedback from the public and other stakeholders, made possible by transparency in policy formulation. Singapore has learned by doing. For example, ERP charges are subject to review every three months, and charge structures and times change depending on traffic and economic conditions.
- Investments in infrastructure. Demand-side management supplemented construction of additional road infrastructure, proper road maintenance, coordination of traffic-light systems, and building of expressways and mass rapid transit. The taxes and fees imposed on vehicles generated huge financial resources, which were not only invested in demand- and supply-side management but also applied to reducing less-desirable taxes.
- Technology factors play an important role. The ERP system, for example, depends on sophisticated technology that allows time-of-day pricing that reflects traffic conditions. A computerized traffic control system was already in place by 1986 in central business districts. It was replaced with a more advanced automated traffic signalling system called 'Green Link Determining System', a traffic-adaptive signal control system monitored centrally to adjust to changing traffic conditions.



94 <https://www.newham.gov.uk/Pages/Services/Pollution-control-construction-sites.aspx>

95 NDRC (2020) Clearing the air: a review of 10 city plans to fight air pollution in India. National Resource Defense Council.

96 Sharma, S., Kumar, A., Datta, A., Mohan, I., Das, S., Mahtha, R., Lakshmi, C. S., Pal, S., Malik, J., (2016). Air pollutant emissions scenario for India. Teri, New Delhi, India.

97 Council on Energy, Environment and Water (CEEW) (2019) What is Polluting Delhi's Air? Understanding Uncertainties in Emissions Inventory'.

98 Moneycontrol (2020) India is now world's 4th largest automobile market, outpaces Germany with 9.5% growth in sales, Mar 26, 2018, (January 5, 2020).

99 Clean Air Asia (2018) Mainstreaming air quality in urban development in Asia. Clean Air Asia, Manila, the Philippines

A number of measures can be adopted which address not only vehicle pollution control but demand management (see Table 10). Emissions from motor vehicles are determined by vehicle technology, fuel type and quality, land use, and use of vehicle. Hence, controlling emissions involves addressing each one of the following measures:

- Improved emissions standards and technologies
- Cleaner fuels
- Improved fuel efficiency
- Improved inspection and maintenance
- Improved transport planning and traffic demand management
- Shift to electric vehicles, public transport, promotion of non-motorised/active transport (i.e. cycling, walking)

The NRDC study of the CAAP of ten Indian cities found that city-level actions to reduce transport emissions included:¹⁰⁰

- Restrictions on older vehicles
- Increased infrastructure for CNG and electric mobility
- Cleaner fleets for public transport, transportation network company (TNC's), and 1st/last mile connectivity using electric vehicles or cleaner fuel, such as CNG
- In-use vehicles emissions control, including installation of remote sensor-based system pollution under check (PUC)
- Implementing intelligent traffic management systems
- Increased vehicle demand management, including parking policies, walking and non-motorized transport, and fiscal measures

The Indian smart cities programme includes actions to promote low emission mobility (see Box 11).

Box 11. Smart Cities Programme

The Indian smart cities programme is an urban renewal and retrofitting programme administered by the Union Ministry of Housing and Urban Affairs. It aims to develop 100 smart cities across the country, making them citizen friendly and sustainable. The programme is being implemented in collaboration with the state governments of the respective cities. Features of Smart cities include reducing congestion, air pollution

and resource depletion, boost local economy, promote interactions and ensure security. The road network is to be created or refurbished not only for vehicles and public transport, but also for pedestrians and cyclists, Promoting a variety of transport options - Transit Oriented Development (TOD), public transport and last mile para-transport connectivity. 43 of these smart cities fall in the list of 122 non-attainment cities.

Table 11 provides an overview of the policy instruments available to control emissions from the transport sector. To achieve an environmentally sustainable transport system, ensuring a minimal environmental impact both in the short- and long-term, measures will need to be taken to reduce the overall demand or travel, and to encourage the use of less polluting modes of transport. This requires the adoption of a combination of measures ranging from emission standards to land-use policies, in order to ensure that the overall need to travel and vehicle pollution are reduced.

Some of the measures can only be taken together with other specific interventions. For example, more stringent emissions standards cannot be achieved without imposing stricter fuel quality standards. However, none of these strategies alone will provide the optimum solution. Combinations of strategies applied progressively over a period of time and in an integrated manner will normally achieve the best results, although the details and optimum mix of strategies will vary according to local circumstances.

Green mobility

The Government of India has taken a number of actions to promote green mobility. In 2018, it approved the National Biofuel Policy to save on expensive oil imports and foreign exchange. The policy set a target blending 20% of ethanol in Petrol and 5% of biodiesel in diesel by 2030. Under this policy, the central government has expanded the scope of raw material for ethanol production by allowing use of various agro-waste products. In addition, GAIL Gas is facilitating the availability of CNG beyond city limits so that the clean fuel can be used for long distance journeys. It also enhances the CNG usage.

Ministry of Petroleum and Natural Gas piloting the use of CNG-retrofitted two wheelers and to reduce air pollution levels in cities, and support research and development of into hydrogen fuel which could substitute part of natural gas as transport fuel in future.

Electric vehicles

In 2018, the Ministry of Power launched the National E-mobility Programme which aims to provide an impetus to the entire e-mobility ecosystem, including vehicle manufacturers, charging infrastructure companies, fleet operators, service providers, etc.

The programme will be implemented by Energy Efficiency Services Limited (EESL), which will aggregate demand by procuring electric vehicles (EV) in bulk to achieve the economies of scale. The government is focusing on creating charging infrastructure and policy frameworks so that by 2030, more than 30% vehicles are EV. A number of Indian states have proposed or adopted EV policies. These include: Andhra Pradesh, Bihar, Karnataka, Kerala, Maharashtra, Madhya Pradesh, National Capital Territory (Delhi), Punjab, Tamil Nadu, Telangana, Uttar Pradesh, and Uttarakhand.

Table 11: Overview of policy measures to control transport emissions¹⁰¹

Control Issue	Governing Regulation	Economic
Emission standards, and technologies	Maximum emission standards for conventional emissions (CO, HC, NO _x , PM) and for toxic air pollutants (lead, 1,3-butadiene, halogenated organics, PAH, benzene/aromatics)	Tax differentials favouring abatement technology Vehicle taxes scaled for emission levels Incentives/disincentives Fiscal incentives for retiring old vehicles
Cleaner fuels	Certification and assembly line testing Fuel quality standards for gasoline (lead, volatility, benzene, aromatics) Fuel quality standards for diesel fuel (volatility sulphur aromatics cetane number polyaromatic hydrocarbons) limitations on fuel additives	Differentiated fuel pricing favouring cleaner fuels
Fuel efficiency	Fuel efficiency for vehicle fleets Maximum power/weight ratios Speed limits Various traffic management measures to increase share of anti-congestion measures, combined with measures controlling vehicle kilometres travelled	Broad based carbon tax on fuels/ emission charges Fuel-economy based vehicle taxes Research and development incentives (direct funding, tax credits, emissions test exemptions)
Inspection and maintenance	Mandatory inspection and maintenance, anti-tempering and enforcement programmes Diesel smoke control programmes	
Transport planning and traffic demand management: increase load factor of fleet; reduce travel demand times; reduce travel time.	Public transport system Parking control measures Individual ownership limitations Pedestrian-only zones in cities Car use restrictions Privileges (e.g. restricted highway lanes) for high-occupancy vehicles Improvement of biking/walking conditions “Park and ride” programmes Limitations and restrictions on freight transport	Road-broad carbon tax on fuel Emission-related vehicle taxes Road pricing or distance charges Parking charges Fiscal incentives for carpool programmes Insurance adjustment for distance Land use and physical planning instruments to reduce commuter travel and redistribute urban activities Redistribute mechanisms for financing more efficient transport modes

100 NDRC (2020) Clearing the air: a review of 10 city plans to fight air pollution in India. National Resource Defense Council.

101 Clean Air Asia/Centre for Environment Education (2019) National Module for Advancing Air Quality, New Delhi, India.

Other measures

A study¹⁰² of vehicle emissions in New Delhi found that stringent fuel emission norms and introduction of alternative public transport systems alone may not result in the modal shift and a reduction in exhaust emissions. Instead, a combination of these measures and management measures such as increased parking fees and regulated uniform speed of public transport result in reduced emissions. In addition, the inclusion of goods vehicle demand during transport policy formulation can help control air pollution in new urban centres in India.

During January 1 to 15 January and April 15 to 30 April 2016, the Government of New Delhi-NCR, implemented an odd–even vehicle rule. Under this rule, between 08:00 and 20:00, only cars with even-numbered plates were allowed to operate on even-numbered dates of the calendar and only cars with odd-numbered plates on odd-numbered dates. A study evaluated the effects of both phases of the odd–even policy on transport patterns and vehicle use in New Delhi.¹⁰³

However, during the experimental periods, car flow rates on roads were reduced by less than 20%, but rates increased for motorised two-wheelers, buses, and autorickshaws. There was an insignificant rise in car occupancy rates: most car owners did not opt for carsharing. Therefore, no improvements in PM_{2.5} levels detected. These experiments show that the odd–even rule was not that effective in reducing measurable PM_{2.5} pollution in New Delhi.

The old vehicles users in Indian continue the usage well beyond the expected life of the product. Such vehicles contribute higher emission content, lower fuel efficiencies and also have lower safety standards. The National Green Tribunal (NGT) and Supreme Court have taken action to stringent regulations, which have considerably reduced the number of years an automobile can be driven for. In Delhi/NCR, the maximum age of petrol and diesel vehicles has been brought down to 15 and 10 years, respectively.

While the performance of cars has improved due to technological developments and the introduction of alternative fuels, drivers have not changed their driving behaviours. Eco-driving is a generic term

used to describe an energy-efficient use of vehicles that is based on the decisions and behaviours adopted by drivers. When an adequate education about strategic, tactical and operational decisions is provided to drivers, eco-driving can reduce overall fuel consumption and CO₂ emissions. One study compared driving styles before and after eco-driving training, it revealed a reduction of unitary fuel consumption for heavy-duty vehicles (5.5%), while no significant variations were visible for light commercial vehicle.

Sustainable Urban Mobility Plans

Sustainable Urban Mobility Plans (SUMP) have been used to integrate air pollution issues into the transport sector. These plans have been applied in the EU to improve accessibility in urban areas while providing high quality and sustainable urban mobility and transport to meet the needs of a ‘functioning city’ rather than a municipal administrative region.¹⁰⁴

Plans such as SUMP have been credited with being able to address several objectives (e.g., reduced air pollution, improved safety and quality of life, and economic growth) as well as engaging citizens and changing the planning process. For example, large transport infrastructure schemes often provide lower value for money while smaller local schemes (e.g., traffic calming, local roads and cycle ways) can generate more jobs.¹⁰⁵

In cooperation with citizens and other stakeholders, SUMP are developed across different policy areas and sectors, and across different levels of government and administrations. They include measures such as integrated planning, urban logistics, collective transport, clean fuel and vehicles, intelligent transport systems, safety and security and mobility demand management. All these contribute to an integrated transport system, which improves quality of life and wellbeing.

Several tools are available to assist in developing urban mobility measures (e.g., clean fuels and vehicles, urban freight, demand management strategies, mobility management, collective passenger transport and transport telematics). For example, the Transport Emissions Evaluation Models for Projects (TEEMP) could be used to measure the emissions benefits of

different transport projects. The TEEMP is a suite of excel-based, free-of-charge, spreadsheet models and methods that can be used to evaluate the GHG, air pollution, and other impacts of many types of transportation projects.¹⁰⁶

The NCAP suggest a number of city-level actions aimed at transport. These are:

- Strengthen inspection of phase-out old vehicles, vehicle maintenance and certification
- Prepare action plan to check fuel adulteration and random checks at petrol stations
- Support fleet modernisation and retrofit to reduce tail pipe emissions
- Reduce emissions by congestion management
- Set up mass rapid transit systems, improve infrastructure for walking and cycling and establish measures for restricting or reducing growth of motorised trips by congestion charging and parking restraints
- Develop e-mobility actions plans at city level, including charging infrastructure and conversion of public buses, there wheelers to electric mode and/or CNG plan and conversion to CNG

ambient air without passing through an adequate stack, duct or chimney.

Open waste burning is a significant source of dangerous carcinogens such as dioxins and furans, and a short-lived climate pollutant, black carbon, that contributes to climate change, increased melting in Polar regions due to the deposition of soot and black carbon on snow and ice, and numerous human health issues (see Figure 20).

Open burning of municipal solid waste (MSW) on streets and landfill is a major concern in India. The materials openly burned include wood, biomass, forest waste, agricultural waste and MSW. It serves as a non-point source of various pollutants such as PM, CO, NO₂, SO₂, dioxin/furans, HC, benzene, ethyl benzene, toluene and 1-hexene. These emissions are associated short term (aggravation of asthma, shortness of breath, chest pains) and long-term (circulatory, respiratory and pulmonary diseases) health risks.

The type of emissions depends on the burning conditions such as temperature, environment, location and mostly on the composition of waste that is being burnt. Globally, human made open waste burning is responsible 24% of PM₁₀, 29% of PM_{2.5} and 43% of organic carbon emissions.¹⁰⁷

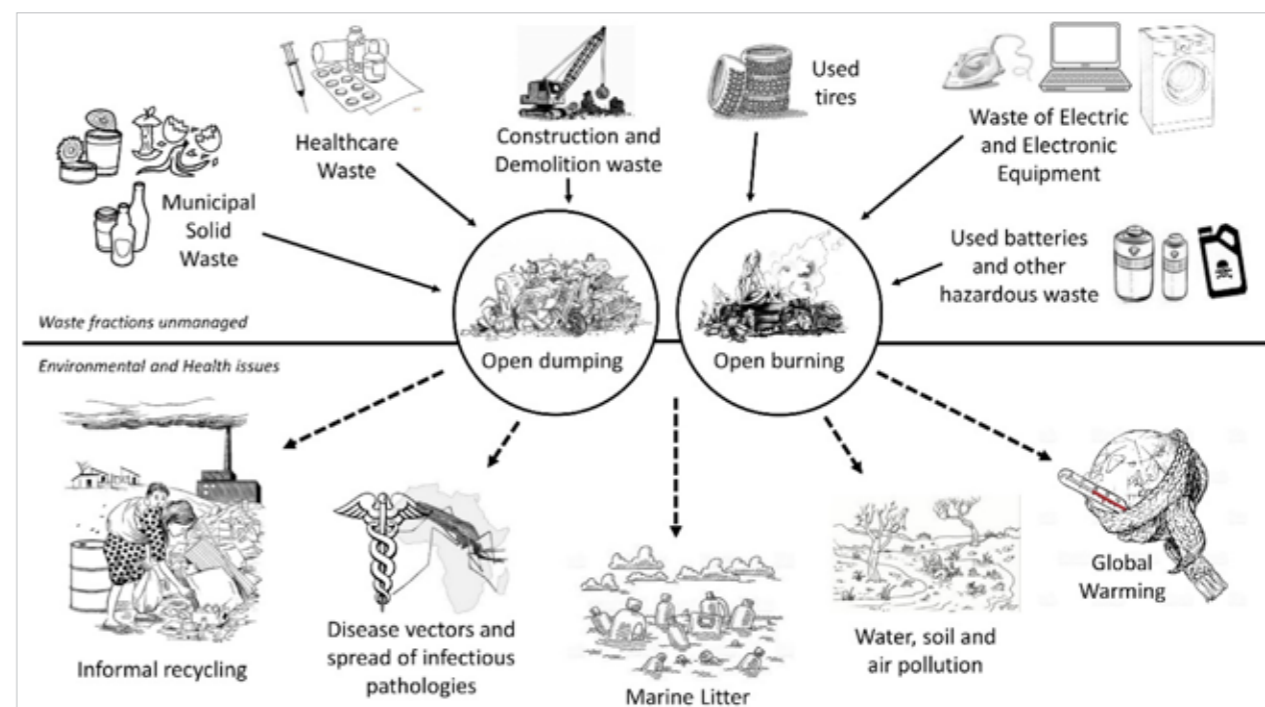


Figure 20: Source of contamination from solid waste mismanagement¹⁰⁸

102 Jain, S. et al. (2016) Vehicular exhaust emissions under current and Wiedinmyer, C. et al. (2004) Global Emissions of Trace Gases, Particulate Matter, and Hazardous Air Pollutants from Open Burning of Domestic Waste. Environmental Science & Technology, 48 (16), 9525. alternative future policy measures for megacity Delhi, India. Journal of Transport & Health 3 (2016) 404–412

103 Mohan, G., Tiwari, G. and Goel, R. (2017) Evaluation of Odd–Even Day Traffic Restriction Experiments in Delhi, India. Journal of the Transportation Research Board.

104 EC (2017) The Economic Benefits of Sustainable Urban Mobility Measures. European Commission, Brussels, Belgium.

105 EC (2017) The Economic Benefits of Sustainable Urban Mobility Measures. European Commission, Brussels, Belgium.

106 Clean Air Asia et al. (2015) Transport Emissions Evaluation Models for Projects.

107 Wiedinmyer, C. et al. (2004) Global Emissions of Trace Gases, Particulate Matter, and Hazardous Air Pollutants from Open Burning of Domestic Waste. Environmental Science & Technology, 48 (16), 9525.

108 Ferronato, N. and Toretta, V. (2019) Waste mismanagement in developing countries: a review of global issues. International Journal of Environmental Research and Public Health, 16: 1060.

The open burning of MSW is a major source of air pollution in Mumbai. It is reported that 2% of the total MSW generated is burnt on the streets and 10% is burned at landfill sites. This trend of open burning of MSW will have an adverse impact on the environment if the same trend prevails and continues throughout India.¹⁰⁹

Using observations of tracers of MSW burning (i.e. tin (Sn) and antimony (Sb) and lead (Pb)), a study found open burning emissions affecting urban aerosols in New Delhi. Open waste burning.¹¹⁰ Total carbon (TC) has also been reported as the most abundant component of PM_{2.5} and PM_{10-2.5} from MSW burning activities in the city of Raipur.

India has an average solid waste collection efficiency of 77% with a maximum of 100% in states of Bihar, Maharashtra and Lakshadweep and a minimum of 21% in Kerala.¹¹¹ In 2011, an average of 3750 MT/day of MSW was generated in India with a maximum value recorded in Maharashtra and a minimum in Lakshadweep. An increase of 43 million tonnes per year of MSW generation in the next 10 years was estimated. Such a steep increase in a decade will put stress on available natural, infrastructural and financial sources. This will add to improper waste management, eventually resulting in the public adopting unscientific waste disposal techniques like open waste burning.¹¹²

Open waste burning is a widespread practice caused, in part, by a lack of systematic waste collection. It occurs at major landfills, small or remote dumpsites, and individual households, which makes it a complex problem to address. Individuals may continue to burn waste out of habit or because other disposal options are not readily available. Raising awareness about the significant health impacts of waste burning is key to stopping it, as is capacity building for local waste managers to collect waste and prevent build-ups of landfill gas that ignite spontaneously.¹¹³

According to NGT, the burning of garbage and other material like plastic is contributing nearly 30% of the air pollution in the capital and its suburbs. In order to control air pollution in Delhi region, NGT imposed ban on burning of any kind of garbage in the open and will be fined who will violate this rule.

The NRDC study of the CAAP of ten Indian cities found that city-level actions to reduce waste emissions included better management of landfills and the implementation of 2016 MSW rules to address emissions from domestic waste.¹¹⁴

The NCAP suggest a number of city-level actions aimed at solid waste management. These are:

- Improve the implementation of all rules related waste management
- Ensure convergence of aq plans with swachh bharat mission
- Promote decentralised waste management, source segregation, zero waste and composting and address waste burning as a priority
- Strengthen training of municipality and rwas in decentralised waste management
- Set up plants for conversion of MSW to drop-in fuel, co-processing of MSW in cement plants
- Set up extended producer responsibility systems e-waste and plastics
- Regular monitoring of ambient air quality in and around solid waste disposal/dump sites and taking remedial action
- Plastic/hazardous waste should be sent to nearby cement/iron and steel or power plants co-processing

5.7.6 Households

Exposure to household air pollution from the combustion of solid fuels for daily cooking and heating is risk to human health. A large proportion of the world's low-income households still cook with solid fuels. Solid fuels are a low-cost and easily available alternative cooking fuel for many and the adoption and use of clean cooking technologies, particularly clean fuels, remains low.

Clean cooking fuels such as gas and electricity can reduce household air pollution exposure in households that depend on solid fuel combustion to meet daily energy needs. India has made ambitious effort for a large-scale transition from solid fuel combustion to clean cooking fuels. The widespread adoption of clean cooking fuels is a necessary step towards reducing household air pollution and improving population health.

A study¹¹⁵ of the Indian states of Kerala and Rajasthan examined how education and attitudes toward cooking associate with the adoption of liquefied petroleum gas (LPG). It found education is a strong predictor of LPG adoption. There are perceptions that LPG is good and affordable and progressive health-related perceptions are associated with LPG ownership. However, while education leads to LPG adoption it does not necessarily lead to positive attitudes towards clean cooking fuels.

If all Indian households transitioned to clean fuels, a study estimated 13% of premature mortality could be averted from the reduction in ambient air pollution, and the average ambient PM_{2.5} concentrations in the country would meet national PM_{2.5} standards.¹¹⁶

A number of measures can be taken to reduce household air pollution. These include:¹¹⁷

Public awareness: One of the most important steps in prevention of indoor air pollution is education by increasing awareness among people about the issue and the serious threat it poses to their health and wellbeing.

Change in pattern of fuel use: Fuel use depends on an individual's habit, its availability and affordability. The majority of low-income families rely on the use biomass fuels for their cooking needs as it is the cheapest and easiest option available. This could be rectified by promoting the use of cleaner energy sources such as gobar gas which utilises cow dung to produce gas for cooking.

Modification of design of cooking stove: traditional smoky and leaky cooking stoves should be modified to become more fuel efficient, smokeless and have an exit (e.g., chimney) for indoor pollutants.

Improvement in ventilation: During construction of a house, importance should be given to adequate ventilation; for poorly ventilated houses, measures such as a window above the cooking stove and cross ventilation through doors should be instituted.

Intersectoral coordination and global initiative: Indoor air pollution can only be controlled with coordinated and committed efforts between different



109 National Environmental Engineering Research Institute (NEERI). (2010) Air quality assessment, emissions inventory and source apportionment studies: Mumbai. Central Pollution Control Board (CPCB); New Delhi, India.

110 Kumar, S. et al. (2018) Understanding the influence of open-waste burning on urban aerosols using metal tracers and lead isotopic. Aerosol and Air Quality Research, 18:9, 2433-2446

111 CPCB (2011) Status report on municipal solid waste management. Central Pollution Control Board, New Delhi, India.

112 Kumari, K. et al. (2019) Emission from open burning of municipal solid waste in India. Environmental Technology, 40:17, 2201-2214

113 CCAC (2020) Open waste burning prevention. Climate and Clean Air Coalition, Paris, France.

114 NRDC (2020) Clearing the air: a review of 10 city plans to fight air pollution in India. National Resource Defense Council.

115 Gould, C. F. et al. (2020) The role of education and attitudes in cooking fuel choice: evidence from two states in India. Energy for Sustainable Development 54 (2020) 36e50

116 Chowdhury, S. et al. (2019) Indian annual ambient air quality standard is achievable by completely mitigating emissions from household sources. PNAS, 116:22, 10711-10716.

117 Kankaria, A. et al. (2014) Indoor Air Pollution in India: implications on health and its control. Indian Journal of Community Medicine, 39:4, 203-207.

sectors concerned with health, energy, environment, housing, and rural development.

The NCAP city-level actions aimed to reduce household air pollution is to enhance coverage of Pradhan Mantri Ujjwala Yojana.

5.7.7 Industry

Industrial pollution is a key contributor to the air pollution in India. Industries are growing at common centres/estates/parks to form industrial clusters such as medium- and small-scale industries. These industrial clusters are a major hub of pollution, indicating the lack of awareness and enforcement issues. In 2017-2018, the CPCB identified 100 prominent industrial clusters. The said number includes 38 critically polluted, 31 severely polluted and remaining 31 as other polluted areas.¹¹⁸

The Indian government has developed a total of 63 industry-specific emission standards. Ten emission standards (diesel and LPG/CNG gensets; petrol and LPG/CNG gensets; dedicated LPG/CNG gensets; industrial boiler; SO₂ and NO_x standards for glass, lime kiln, reheating furnaces, foundry, ceramic industry, and airport noise) have been developed and six emission standards (thermal power plant, sugar, man-made fibres, fertilizer, cement, and brick kiln) have been revised.

State Pollution Control Boards/Pollution Control Committees have adopted revised criteria for categorising industries in red/orange/green/white categories to strengthen the enforcement mechanism of environmental norms.

To implement strategies to reduce industrial emissions within the city, it is important to have adequate information on the type of emissions from these industries, emissions trends, effectiveness of actions to reduce these trends, and priorities. Most of this information should be available from emissions inventories.

The NRDC study of the CAAP of ten Indian cities found that city-level actions to reduce energy and industrial emissions included : the regulation and closure of older power plants within 300 km radius of the non-attainment city, implementation of the 2015 emission standards for PM, NO_x and SO_x for thermal power plants (TPPs), mandates, incentives, and siting restrictions for clean fuels; conversion

of brick kilns to induced draft zig-zag technology; and implementation of fiscal measures, including an emissions trading scheme.

The main strategies for addressing industrial pollution are the promotion of cleaner production and emissions reduction by industry, and land use planning and zoning.

1. Land use planning and zoning¹¹⁹

The main techniques used are:

- Use of planning regulations to restrict the location of new industries, for example to avoid proximity to residential zones or other sensitive land uses, and to establish suitably sited and serviced industrial areas
- Compulsory environmental impact assessment (EIA) for specified new major industries to require assessment of their potential for air pollution and to recommend improvement in location, processes, fuels, industry technology and emission limits. The most powerful and cost-effective AQM options occur during the planning stages for a new facility
- Relocation of existing industries away from residential and other sensitive land uses
- Control of visual appearance by planning guidelines and landscaping, etc.

The last two measures do not reduce emissions and can, therefore, be only considered as secondary actions, particularly in view of the spreading trends of urban areas.

2. Promoting cleaner production

Cleaner production and eco- efficiency aim to increase the efficiency of industrial processes and reduce consumption, prevent pollution, reduce waste at source and minimise risks to people and the environment. Cleaner production is a way to achieve both environmental protection and economic benefits by better managing the production process, often saving energy and materials. In the case of AQM, the main cleaner production successes have been achieved by improving the quality of fuels, for example by reducing the sulphur content or requiring cleaner fuels such as gas.

Although cleaner production is the most sustainable solution, some end-of-pipe solutions are still necessary to address industrial air pollution. However, prevention of pollution by use of clean fuels and the

adoption of new technologies that avoid emissions is generally less expensive than end-of-pipe techniques to reduce pollution, if the costs of the effects of pollution on health and the environment are included. Fuel taxes have been successfully used in many countries to provide economic incentives to use cleaner fuels and reduce the use of polluting fuels.

3. Promoting emissions reduction in industry

The promotion of the reduction of industrial emissions may involve:

- Setting priorities by focusing on emissions from the major emission sources
- Requirements for use of cleaner fuels
- Requiring the use of best available technology: policies need to focus on the implementation of best available technology for specific industrial processes. The industry must provide an action plan for how it will implement best available technology. Experiences show that this often results in a realistic action plan generating commitment from all stakeholders
- Compulsory notification of accidents
- Licensing of specified polluting processes
- Compulsory emission standards required under licence conditions: many developing countries have set emission standards for different types of industries. However, enforcement is often weak. An enforcement strategy should be addressed
- Setting strict fines for exceeding emission standards

5.8 Air Pollution Control Measures In Air Quality Management

5.8.1. Effectiveness of Indian air pollution control measures

Since 2015, the Government of India has enacted a wide range of pollution control policies and regulations. Initially, these mainly controlled primary PM (dust) at large stationary sources (power plants) and measures to reduce exhaust emissions from road vehicles. However, additional measures include stricter emission standards, adoption of new technologies (e.g. Zig-zag or vertical shaft kilns for new brick production) and the banning of open burning and certain fuels (e.g. coke and furnace oil industry).

Nevertheless, their impact on air quality will depend on how effectively pollution control measures are implemented and enforced. An assessment of pathways to achieve the NAAQS found that full compliance with new pollution control policies and regulations would enable NAAQS to be met by 2030 (see Figure 21). However, full compliance will be insufficient to deliver significant air quality improvements across India. By 2050, 40% more people (than today) will face pollution levels above the NAAQS. Implementation failure could further increase the number of people exposed to poor air quality.

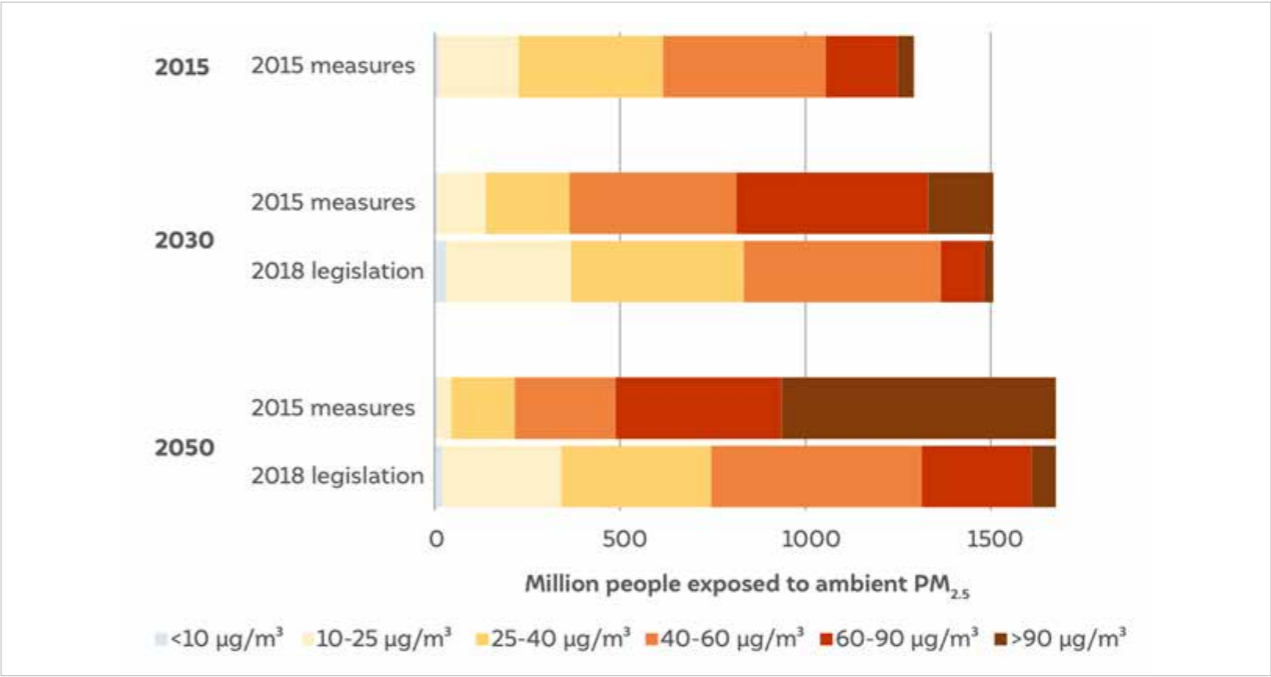


Figure 21: Distribution of population exposure to PM2.5 in 2015 and projected emissions for 2030 and 2050¹²⁰

118 NGT Order dated 10-07-2019.
119 ADB, Eco-Industrial Park Handbook for Asian Developing Nations, (2001) and UNIDO, IBRD and GIZ, An International Framework for Eco-Industrial Parks (2017)

120 IIASA/CEEW (2019) Pathways to achieve national ambient air quality standards in India. International Institute for Applied Systems Analysis/Council on Energy, Environment and Water, New Delhi, India.

The study suggested that effective solutions to reduce $PM_{2.5}$ will require regional cooperation between cities and states. Due to their small size and thermodynamic properties, $PM_{2.5}$ particles remain in the atmosphere for several days, during which they are typically transported over several hundred kilometres.

A large share of the particles found at any specific location originate from distant sources often outside the immediate jurisdiction and control of local

authorities. In many Indian states, emission sources that are outside of their immediate jurisdiction and contribute the largest share to (population-weighted) ambient pollution levels of $PM_{2.5}$ (see Figure 22). Mostly states cannot achieve significant improvements in their air quality and population exposure without emissions reductions in surrounding regions. Therefore, any cost-effective strategy to reduce pollution will require regionally coordinated approaches.

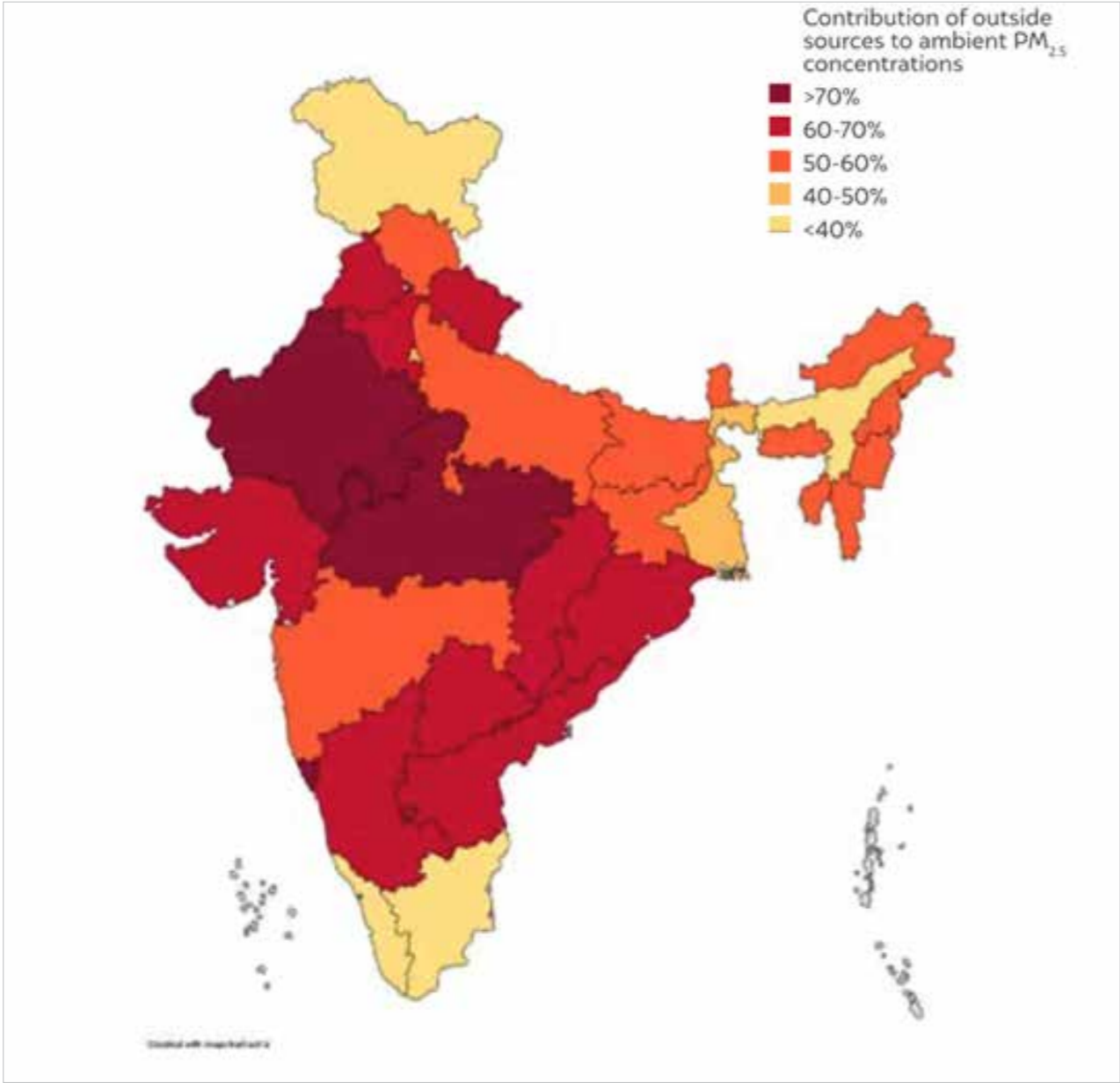


Figure 22: Contribution from outside sources to ambient $PM_{2.5}$ concentrations¹²¹

To reduce $PM_{2.5}$ in ambient and decrease in the health burden will need to balance emission controls across all these sectors and sources. A focus on a single source alone will not deliver effective improvements,

and it is likely to waste economic resources to the detriment of further economic and social development.

5.8.2 CNG in Delhi

On 19 January 1998, the Ministry of Environment and Forests (MoEF) established the Environmental Pollution (Prevention and Control) Authority (EPCA) for the National Capital Region (NCR) of Delhi. The EPCA was given the authority to control and tackle environmental pollution. This included taking the necessary steps to control vehicle pollution in the NCR. Based on various public interest litigation (PIL) and on the recommendation of EPCA, the Supreme Court on 28 July 1998 directed that all public transport vehicles comprising of taxis, three wheelers, and buses in Delhi were to run only on Compressed Natural Gas (CNG) after April 2001.¹²²

As assessment of the impact of the introduction CNG the air quality in Delhi highlighted the success of the policy measure as well as areas of concern.¹²³ The conversion of buses from diesel to CNG helped to reduce PM_{10} , CO , and SO_2 concentrations in the city. Targeting buses for conversion to CNG has been effective in part because buses, due to the number of kilometres travelled contribute more to the pollution load than other vehicles.

The reduction in the sulphur content of fuel helped reduce PM_{10} and SO_2 concentrations. However, the CNG-switching gains in buses were not being seen in three-wheelers. This may have been due to poorer technology for CNG three-wheelers which resulted in an increase, rather than a decrease, PM_{10} levels. CNG three-wheelers also are leading to an increase in NO_2 . A trend of increased levels in the proportion of diesel-fuelled cars at the time of the assessment appeared to have had a mixed impact on air quality. While diesel-fuelled cars have helped to reduce CO and SO_2 , the latter because these cars are running on cleaner diesel, diesel cars led to an increase in PM_{10} and NO_2 .

Overall, the study suggested that a number of the gains that have been made from fuel switching and other improvements in fuel quality and vehicle technology are being offset by the increase in the number of vehicles in Delhi.

5.8.3 Surat Emission Trading Scheme

In 2019, the Gujarat Pollution Control Board launched the emission trading system (ETS) claimed to be the first scheme address particulate pollution in the world. One hundred and fifty-eight plants in the

industrial hub have signed up for this “cap and trade” scheme.

Industrial clusters can set a limit on how much particulate pollution they can collectively emit. They can install equipment to cut their emissions, or purchase credits from those that do, to keep their collective emissions down. In this way, the system uses the power and flexibility of markets to deliver a win-win situation of simultaneously (i) reducing total cost of regulation, (ii) increasing firm profits, and (iii) protecting citizens from air pollution.

The ETS began live trading on 15 September 2019, after a two months large scale pilot programme in the Surat, Gujarat. An initial evaluation of the costs and benefits of the Surat ETS found that likely to reduce PM emissions by 29%, lower costs of reducing particulate emissions, increase average industry profits compared to the status.¹²⁴

5.8.4 A Smart Personal Air Quality Monitoring System in Chennai

In Chennai, India, a study was conducted to test the applicability of low-cost sensors for real time urban air quality monitoring and personal exposure assessment. A Smart Personal Air Quality Monitoring System (SPAMS) consists of commercially available low-cost sensors that can measure CO , NO_2 , O_3 , and PM , relative humidity and temperature was developed. The sensors exhibited good laboratory calibration and field validation results. Field measurements to obtain varying pedestrian exposure was obtained by walking on footpaths in three different locations (an urban background site, a busy traffic road, and a beach side road) and while travelling on three major bus routes.

Results show that $PM_{2.5}$ concentrations is highest in busy traffic site and lowest in urban background while CO concentration is lowest along beach road. Also, CO and NO_2 concentrations are higher in the morning and evening while travelling in buses due to the rush hours. This study was able to show that calibrated sensors can capture spatial and temporal variations of pollutant concentrations at different urban microenvironments. However, it was also recognised that the low-cost sensors used are sensitive to temperature and humidity. Hence, selection of low-cost monitors remains a challenge as their performance under diverse environmental conditions is varied and not well documented.

121 IIASA/CEEW (2019) Pathways to achieve national ambient air quality standards in India. International Institute for Applied Systems Analysis/Council on Energy, Environment and Water, New Delhi, India.

122 Singh, A. et al. (n.d.) Emission characteristics of in-use CNG vehicles in Delhi. Central Road Research Institute, New Delhi, India
123 Narain, U. and Krunpnick, A. (2007) The impact of Delhi's CNG Program on Air quality. Resources for the Future, Washington DC, USA.
124 EPIC India (2019) The Surat Emission Trading Scheme: a first look at the world's first particulate trading scheme. Energy Policy Institute of Chicago, New Delhi, India.



Figure 23 (A) Gas sensors calibration set up and (B) SPAMS.

5.8.5 Air quality monitoring during the 2015 Hong Kong marathon

During the 2015 Hong Kong marathon, a sensor-based air monitoring system was deployed along the route to detect immediate impacts of temporary traffic control on roadside air quality. Real-time pollutant concentrations of key pollutants (CO, NO₂, PM_{2.5}, and O₃) were used to calculate hourly Air Quality Health Index (AQHI) that was publicly

broadcasted. Sensor performance was assessed through laboratory and field tests and readings were corrected prior to deployment along the marathon route.¹²⁵ Field performance tests showed that sensor readings for CO, NO₂, and PM_{2.5} agrees well with air quality monitoring station data after correction ($R^2 > 0.90$) as shown below and measurement error is just within 5% of the pollutant concentrations.

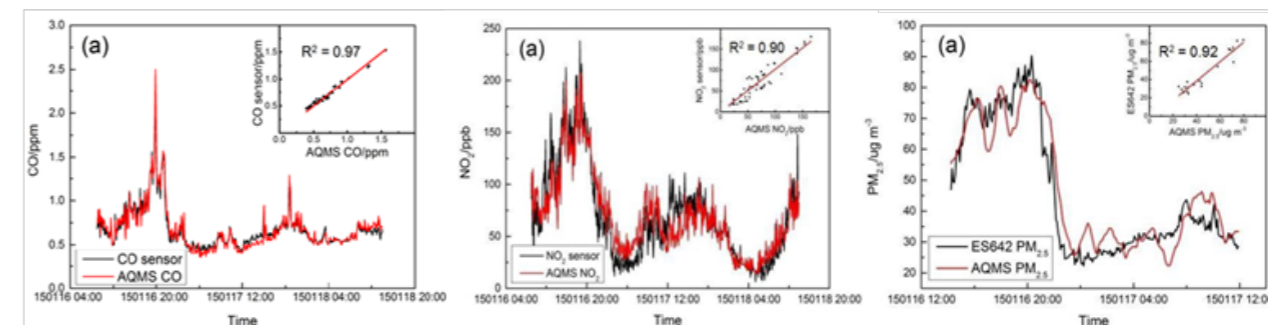


Figure 24 Sensor Field Performance Test

The study demonstrated the potential of low-cost sensors in supplementing existing air quality monitoring stations with high spatial and temporal resolution air pollution measurements. However, the study emphasised the need to: (i) characterise performance of sensors in response to ambient environmental conditions; (ii) understand sensor limitations; and (iii) undergo quality control and assurance protocols to ensure reliability of results.¹²⁶

5.8.6 A Simple Interactive Model for Better Air Quality

The Simple Interactive Model for Better Air Quality (SIM-air) is a family of tools to examine emissions, ambient air quality, health and control measures in a scenario approach (Guttikunda, 2015). While it relies on some of the basic approaches and emission factors contained in AP-42, CORINAIR, and RIAS, it is based on an integrated AQM approach such as AirQUIS and provides a user-friendly visualisation of rapid assessment of pollution data and control options. The family of tools includes:

- The SIM-air model – an integrated tool for air pollution analysis. The model starts from emissions and calculates multiple air pollutant concentrations, their potential health impacts and the costs and benefits of control measures;
- The Vehicular Air Pollution Information System (VAPIS) – a calculator for vehicle emission estimates using a repository of emission factors (www.urbanemissions.info/tools/vapis);
- A calculator for carbon analysis of road transport (smart-CART);
- A calculator for air quality indices;
- The Atmospheric Transport Modelling System (ATMoS) – a simplified dispersion model to generate transfer matrices for multiple pollutants from multiple sources;
- An easy-to-use calculator for fugitive dusts emissions from roads (V-Dust).

The SIM-air integrated approach has a number of advantages:

- Allows definition of all major types of urban emission sources, such as point, mobile, and area
- Provides default emission factors where available (users can change these factors based on local context, or use CORINAIR, AP-42 or RIAS emission factors)
- Interfaces an emission computation model with key technology and management options (e.g. Fuel change, conversion of two stroke to four stroke engines etc.)
- Links emissions to ambient air quality through an externally created or supplied source-receptor matrix (this allows user to apply an urban air quality model of their choice; SIM-AIR is thus independent of the air quality model)
- Allows estimation of economic impacts on health; the user can edit exposure-damage relationships according to local knowledge
- Allows input of cost data for a broad range of air quality management options
- Encourages rapid assessment of management options in terms of cost
- Provides an optimization scheme to identify most cost-effective option combinations

SIM-AIR uses a “main” worksheet and eight other “theme” worksheets to display the output in Excel format. The eight themes include emission distribution of non-mobile sources, vehicle data, emissions inventory, a menu of options, health impacts, transfer coefficients to compute ambient concentrations, ambient concentrations, and, finally, a help worksheet. The result is that for any grid of the study area, the input data contains information on emission distribution, ambient concentration, health impacts, and management options.

The tools of the SIM-air family have been applied in a number of cities inside and outside Asia

¹²⁵ Sun, L., K. Wong, P. Wei, S. Ye, H. Huang, F. Yang, D. Westerdahl, P. Louie, C. Luk, Z. Ning (2016). Development and Application of a Next Generation Air Sensor Network for the Hong Kong Marathon 2015 Air Quality Monitoring. Sensors 16, 211.

¹²⁶ WHO (2018). Ambient (outdoor) air quality and health. (2018, May 2). Retrieved June 19, 2018, from [http://www.who.int/en/news-room/fact-sheets/detail/ambient-\(outdoor\)-air-quality-and-health](http://www.who.int/en/news-room/fact-sheets/detail/ambient-(outdoor)-air-quality-and-health)

(Guttikunda & Jawahar, 2012). The SIM-air model is primarily a training tool and should not be used as the only support system for decision-making. However, as a training tool, it helps to understand how different management options can influence health impacts.

5.8.7 Use of AERMOD and ADMS-Urban for PM Monitoring in New Delhi

In New Delhi, the AERMOD (07026) and ADMS-Urban (2.2) were applied to undertake performance evaluation of these models with respect to estimate ambient PM concentrations for 2000 and 2004 over seven sites in the city. In addition, model evaluation and inter-comparison were performed. The models included emissions from all urban sources (elevated point sources, vehicle traffic, domestic and other sources).

Performance of the models was examined based on their boundary layer parameterisations. Concentrations were estimated for the winter seasons in both years as the low temperature and low speed wind conditions led to higher PM concentrations.

Though both models tended to underestimate PM concentrations, the values agreed with observed concentrations within a factor of two. While ADMS-Urban results show better correlation with observed values, the bias between observed and estimated values is lower for AERMOD results. Inter-comparison of the models can assist in furthering increase the accuracy of the models with corresponding enhancement of their reliability in AQM.¹²⁷

5.8.8 USEPA Environmental Benefits Mapping and Analysis Program

The latest USEPA's Environmental Benefits Mapping Program (BenMAP) allows greater flexibility for its users. The BenMAP – CE (community edition) can perform a full-scale benefits assessment but easy enough for beginners to use. Users can load their own data or use pre-loaded data such as:

- Air quality data
- Demographic data
- Economic values
- Concentration – response relationships

Sample visuals generated by BenMAP CE are presented below, illustrating how the program calculates for health benefits due to improved air quality. The assumption is that through a policy or measure to reduce air pollution, there will be change in the level of pollutants. The pollution change is related to the population in the study area, and the baseline incidence of health impacts. A built-in dose response function will lead to the calculation of the estimated effects, and ultimately the health impacts,

which are represented by the number of deaths and morbidity avoided because of the decreased pollution level.

The economic benefits can also be quantified if economic input value such as cost of illness (COI) and value of statistical life (VSL) are available. The main output is that given the number of deaths and sicknesses avoided, this is the amount of money saved due to improved air quality .



Figure 26: EPA BenMAP website

Carvour, et al. (2018), further explained the BenMAP process through the diagram below:

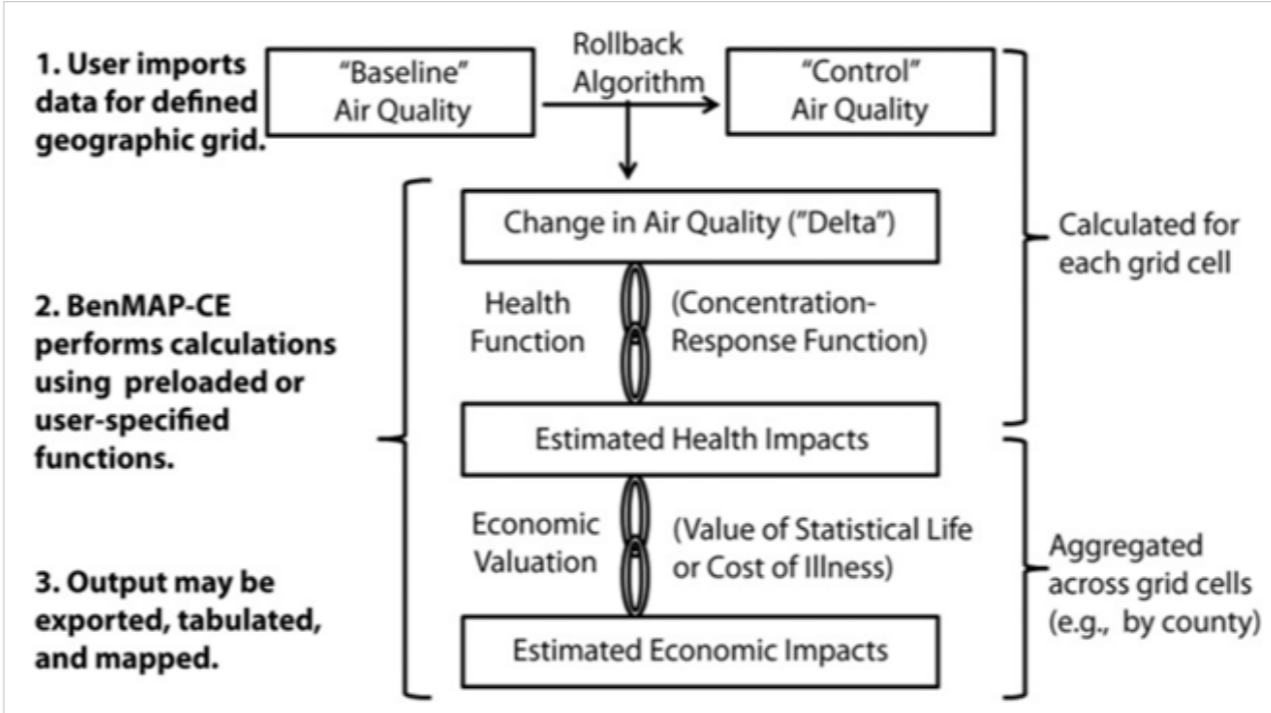


Figure 27: BenMAP Process Diagram

The USEPA undertake an assessment of the health impacts of O₃ changes in Texas. Two scenarios of pollution reduction were considered for a period of three years: (1) incremental rollback of the daily 8-hour maximum ozone levels by 10 parts per billion, and (2) a rollback-to-a-standard ambient level of 65

parts per billion. Various health impact functions can be run per scenario. Results showed that for an incremental rollback scenario, as many as 116 deaths would have been avoided (year 2011), saving as much as 932 million USD in related costs.¹²⁸

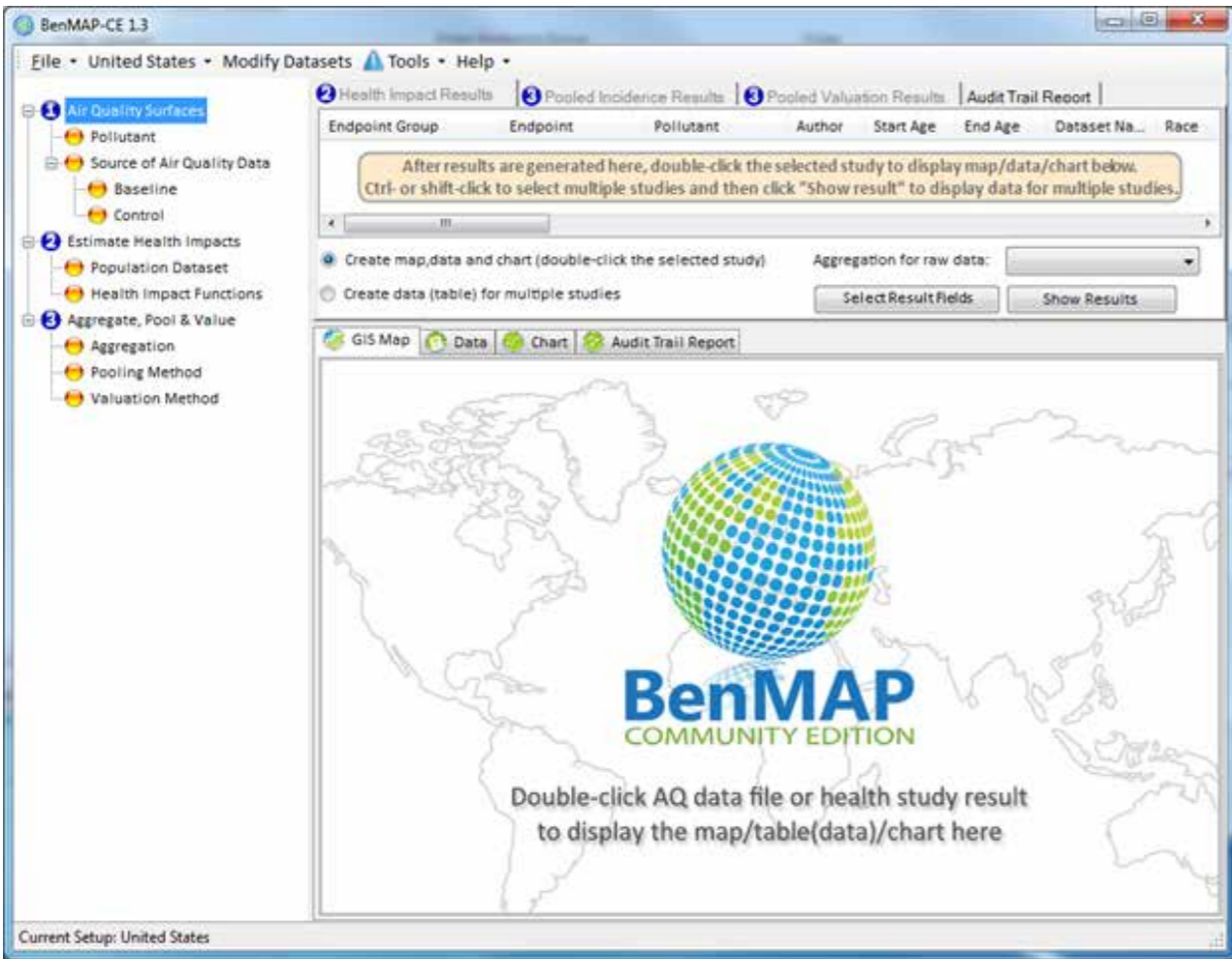


Figure 25: Screenshot of the BenMAP – CE software

127 Mohan, M., Bhati, S., Sreenivas, A., Marrapu, P., 2011. Performance Evaluation of AERMOD and ADMS-Urban for total suspended particulate matter concentrations in Megacity Delhi. Aerosol and Air Quality Research 11: 883-894.

128 The full summary data can be seen in Table 2 of the journal that can be accessed through this link: <https://www.ncbi.nlm.nih.gov/pmc/articles/PMC5922206/pdf/AJPH.2017.304252.pdf>.

5.8.9 Hong Kong's Air Pollution Index

Since 1995, Hong Kong has developed and implemented an API (or Air Quality Index or AQI) system that reports an aggregated index based on the pollutant with the highest level of concentration for a given day or hour at a specific station. The index covered four pollutants with indexes based on Hong Kong's Air Quality Objectives. The main limitation of this API approach was that it does not cover the joint effects of different air pollutants on the health of the exposed community.

As a response to the 2005 WHO Air Quality Guidelines, the Hong Kong government commissioned university teams to review its Air Quality Objectives and consequently, its API system. After studying the different index systems implemented around the world, the team of experts recommended an approach similar to what Canada has adopted, which made use of local air pollution and health data. The Air Quality and Health Index (AQHI) of Canada ensures that the air quality reporting system is based on health outcomes observed locally.

In December 2013, Hong Kong adopted an AQHI system that utilized health risks derived from local hospital admissions data for air pollution-related illnesses. While the Canada AQHI made use of mortality data, Hong Kong revised the approach to use morbidity data instead. The Hong Kong AQHI system is reported on a scale of one to 10; those 10 and above are grouped into five AQHI health risk categories, with health advice provided for general public and at-risk groups.

This reporting system, which informs the public of the short-term health risk of air pollution in Hong Kong, is the first of its kind in Asia. Following its launch, the system now reports higher pollution category indexes compared to the previous system, prompting more residents to voice their concern.

The latest hourly AQHI and forecast is communicated using the following platforms:

- Environmental Protection Department (EPD) website at <http://www.aqhi.gov.hk>, accessible from a personal computer or a mobile device such as a smartphone;
- AQHI application for mobile devices or an AQHI alert wizard for desktop computers; or

- AQHI hotline (2827 8541), which gives verbal updates through an interactive voice recording system, or provides a printed update through the fax-on-demand service.

All of the above methods provide AQHI information 24 hours a day. Updates are also provided at regular intervals through the mass media, on different television, and radio channels.

The adoption of the AQHI system in Hong Kong enables the public with the information to put pressure on the national government to prioritize air pollution response. If local air pollution and hospital data are available, other Asian cities can adopt this AQHI system using the methodology developed by Hong Kong.¹²⁹

5.8.10 Handbook for clean air management in smaller cities

For a clean air action plan (CAAP) to be effective, it is important to: (i) address dominant pollution sources and reduce their emissions; (ii) mitigate health risks posed by pollution to vulnerable groups and/or densely populated areas; and (iii) ensure that air quality and public health improvements are the overarching goals of the plan.¹³⁰

A step by step guide provided by this document aims to help city AQM practitioners in developing a CAAP. In this manual you will find:

- Key steps your city needs to go through in developing and implementing a CAAP; and
- Considerations when working on each activity in the CAAP process.

The general flow in conducting a Clean Air Action Plan is illustrated below:

**Plan the process → Allocate and secure resources
→ Propose policy and action recommendations
→ Monitor and evaluate implementation**

STEP 1: Establish the planning process

The objectives of this step include: (1) levelling off with concerned groups; (2) engaging stakeholders on what has to be done or is expected in conducting a CAAP; (3) building connections and the network to begin the process of planning.

STEP 2: Establish baselines

After the planning process is established, the magnitude of the city's air pollution problem needs to be understood. This step is crucial in ensuring that the pollution reduction measures in the CAAP target the most critical pollutants, pollution sources and/or areas within the city.

STEP 3: Target setting, selecting appropriate control measures, and planning for operationalisation

There are five sub-steps that the Working Group must consider in carrying this out. In summary, Step 3 applies to what has been learned from the baseline assessment in formulating strategies and actions to improve air quality as well as protect public health and the environment. This also includes developing a communication plan with aims to raise awareness, change attitudes and foster behaviour change in support of the city's AQM efforts. A CAAP will only be considered to have served its purpose if the pollution control measures in the plan are adopted by policymakers and stakeholders. Communication promotes cooperation and collaboration by conveying the relevance and benefits of the measures to stakeholders. An effective air quality communication strategy considers the intended outcomes of the communication activities, target audience, key messages and communication channels to be utilized (Clean Air Asia, 2016 as cited in Clean Air Asia and UNEP 2019).

STEP 4: Work towards mainstreaming AQM and the CAAP into the city's urban development

To ensure that the CAAP is fully implemented is aligned with the city's overall development goals and plans, AQM and the CAAP must be mainstreamed into the city's urban development. This can be facilitated through: (1) integrating air quality management into governance, institutional arrangements and processes; and (2) including air quality goals and considerations in the city's overall development goals, performance indicators and plans.



129 Wong, T.W., Tam, W.W.S., Lau, A.K.H., Ng, S.K.W., Yu, I.T.S., Wong, A.H.S., & Yeung, D. (2012). A study of the Air Pollution Index Reporting System. Tender Ref. AP 07-085. Hong Kong: The Chinese University of Hong Kong.

130 German International Cooperation [GIZ] and Clean Air Asia. (2015). Handbook for Clean Air Management in Smaller Cities. Pasig City, Philippines: Clean Air Asia.

6. Urban Air Pollution and Climate Change



Air quality and climate change are closely interconnected. Many traditional urban air pollutants and GHGs have similar sources. Common air pollutants, such as black carbon, CH₄, ground-level O₃, and hydrofluorocarbons are the most important contributors to the human-made global greenhouse effect after CO₂, responsible for up to 45% of current global heating.

These pollutants are called short-lived climate pollutants and are powerful climate forcers that remain in the atmosphere for a much shorter period of time than CO₂, yet their potential to heat the atmosphere can be many times greater.

6.1 Short-Lived Climate Pollutants

Certain short-lived climate pollutants are also dangerous air pollutants that have harmful effects for people, ecosystems and agricultural productivity. If no action to reduce emissions of these pollutants is taken in the coming decades, they are expected to account for as much as half of warming caused by human activity.

There is a clear difference in the spatial scales between urban air pollution and GHGs. Ambient air pollutants generally stay in the atmosphere for a short period (e.g. days or weeks). In contrast, CO₂ has a lifetime of approximately 150 years and methane 12 years. These pollutants affect the climate of countries around the world.

Though differentiated by the length of time they stay in the atmosphere, emissions of some GHGs and air pollutants are from the same sources such as fuel combustion in transport, power generation and industry, and biomass burning. Incomplete fuel combustion produces emissions of primary particles of black carbon, organic carbon, CO, VOCs and CH₄.

6.1.1 Black carbon

Black carbon is a potent climate-warming component of PM formed by the incomplete combustion of fossil fuels, wood and other fuels. Complete combustion would turn all carbon in the fuel into CO₂, but combustion is never complete and CO₂, CO, VOC, and organic carbon and black carbon particles are all formed in the process. The complex mixture of PM resulting from incomplete combustion is often referred to as soot.

Black carbon is a short-lived climate pollutant with a lifetime of only days to weeks after release in the atmosphere. During this short period of time, black carbon can have significant direct and indirect impacts on the climate, glacial regions, agriculture and human health.

Black carbon is always co-emitted with other particles and gases, some of which have a cooling effect on the climate. The type and quantity of co-pollutants differs

according to the source. Sources that release a high ratio of warming to cooling pollutants represent the most promising targets for mitigation and achieving climate and health benefits in the near term.

Several studies have demonstrated that measures to prevent black carbon emissions can reduce near-term warming of the climate, increase crop yields and prevent premature deaths.

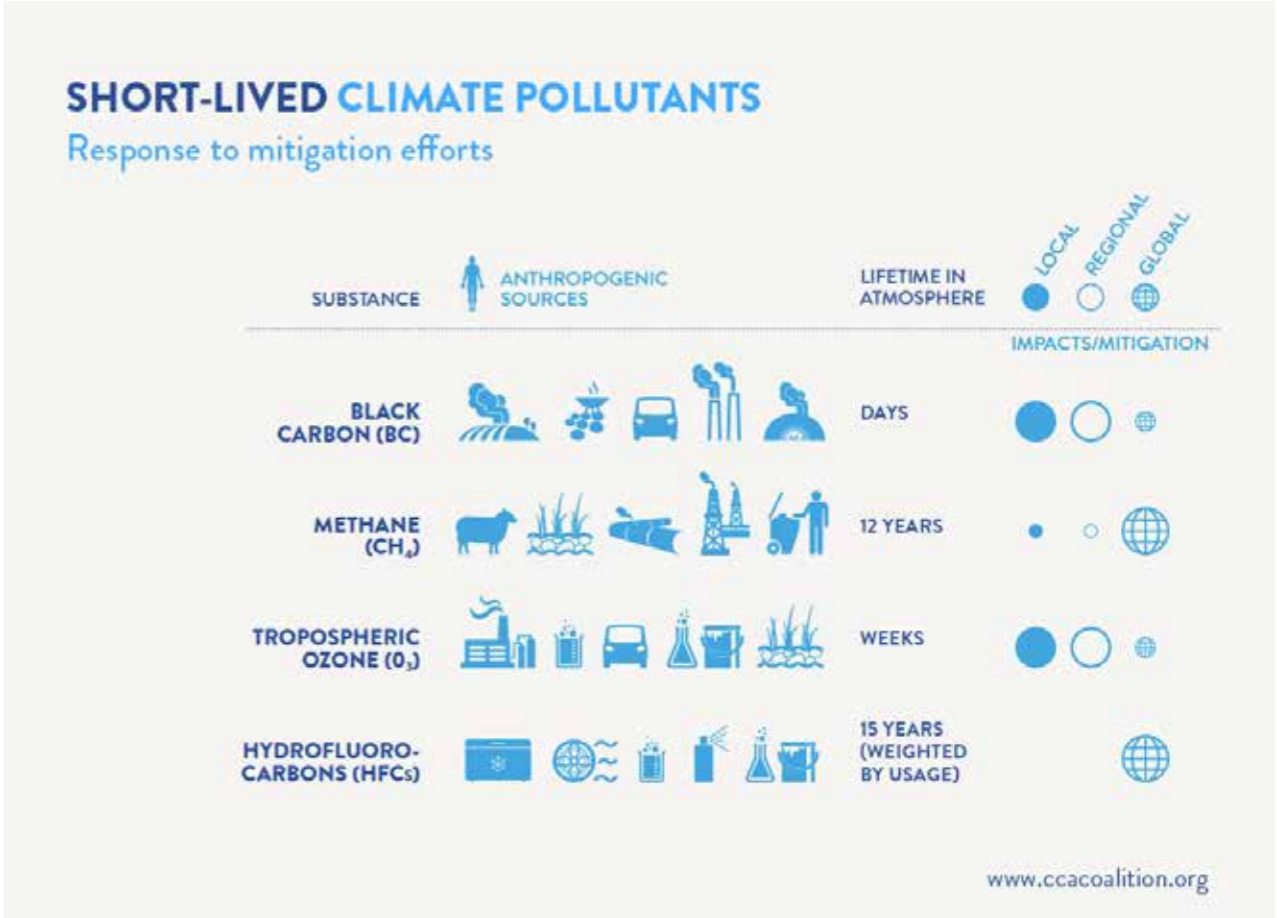


Figure 28: Short-lived climate pollutants and their lifetime in the atmosphere¹³¹

Black carbon contributes to direct warming of the atmosphere by absorbing incoming solar radiation.¹³² Although these particles do not persist long in the atmosphere, they have a large effect on climate forcing. Black carbon can also fall onto glaciers and icecaps, absorbing heat and hastening their melting as well as reducing the ‘albedo’ (the amount of light that is reflected) therefore further heating the ground.

Black carbon and its co-pollutants are key components PM_{2.5} pollution, the leading

environmental cause of poor health and premature deaths. It can also affect the health of ecosystems in several ways: by depositing on plant leaves and increasing their temperature, dimming sunlight that reaches the earth, and modifying rainfall patterns.

Changing rain patterns can have far-reaching consequences for both ecosystems and human livelihoods, for example by disrupting monsoons, which are critical for agriculture in large parts of Asia and Africa.

¹³¹ Climate and Clean Air Coalition (2020) What are short-lived climate pollutants? CCAC, Paris, France.
¹³² UNEP/WMO (2011) Integrated Assessment of Black Carbon and Tropospheric Ozone. United Nations Environment Programme/World Meteorological Organisation.

Box 12: Black Carbon Emissions in India

A black carbon (BC) emission inventory for India (Paliwal et al., 2016)¹³³ estimated emission at the district level (2011). The inventory included open burning, forest fires, municipal solid waste burning, agricultural residue burning, industry, brick industry, cement manufacturing, iron and steel production, sugar mills, power plants, transport, road vehicles, railways, shipping, aviation, domestic fuel use. In addition, it considered other high emitting sources such as kerosene lamps, diesel generators and irrigation pumps.

It found that the Indo-Gangetic Plain (IGP) is the main contributor to national BC emissions. This can be attributed to the very high population density and presence of major BC emitting industries such as sugar and brick production in this region. Some of the states in the IGP are among the least developed in India, with little access to basic amenities (e.g. electricity, clean cooking fuels, sanitation, health care, etc).

More than 90% of the rural households in Uttar Pradesh and Bihar use biomass fuels as their primary source of cooking, and more than 65% are dependent upon kerosene lamps as their primary source of lighting. The high dependence on biomass fuels and the presence of brick and sugar industry accentuates the emissions from this region.

With annual emissions of 140 Gigagrams (Gg), the state of Uttar Pradesh emits the most in the IGP followed by West Bengal (57.67 Gg), Bihar (47.8 Gg), Punjab (34.01 Gg), Haryana (26.82 Gg) and the National Capital Territory (NCT) of Delhi (6.74 Gg). T

The major emissions sources in Uttar Pradesh are kerosene lamps (12%), biomass cooking fuels (30%), brick kilns (20%) and sugar mills (17%). High emissions from IGP and its vicinity to the Himalayas potentially pose a serious threat to water security in the region, resulting from impacts on the cryosphere from BC deposition and atmospheric heating.

6.1.2 Ground-level ozone

Ground-level O₃ is a short-lived climate pollutant with an atmospheric lifetime of hours to weeks. O₃ absorbs radiation and consequently acts as a strong GHG. O₃ affects the climate beyond increased warming, having impacts on evaporation rates, cloud formation, precipitation levels, and atmospheric circulation. These impacts mainly occur within the regions where O₃ precursors are emitted, and so disproportionately affect the Northern Hemisphere.

O₃ does not have any direct emissions sources, rather it is a secondary pollutant gas formed by the interaction of sunlight with hydrocarbons – including methane – and NO_x, which are emitted by vehicles, fossil fuel power plants, and other human-made sources.

Strategies to prevent the formation of O₃ are primarily based on methane reductions and cutting the levels of atmospheric pollution arising from

man-made sources, such as agriculture and fossil fuel production and distribution.

6.1.3 Methane

Methane (CH₄) is a powerful GHG produced by human activities such as agriculture, including rice cultivation and ruminant livestock; coal mining; oil and gas production and distribution; biomass burning; and municipal waste land filling. It is not only produced from human activities but also from animal and stagnant water. According to the Inventory the U.S. Greenhouse Gas Emissions and Sinks 1990–2015, cows produce 150 billion gallons of methane per day. Wetland is also the largest natural source of anthropogenic methane in the world, contributing approximately 167 Tg of methane to the atmosphere per year.

It has a direct influence on climate, but also a number of indirect effects on human health, crop yields and the quality and productivity of vegetation through its

role as an important precursor to the formation of ground-level O₃.

CH₄ is a short-lived climate pollutant with an atmospheric lifetime of around 12 years. While its lifetime in the atmosphere is much shorter than CO₂, it is much more efficient at trapping radiation. Per unit of mass, the impact of methane on climate change over 20 years is 84 times greater than CO₂ over a 100-year period it is 28 times greater.

While CH₄ does not cause direct harm to human health or crop production, O₃ is responsible for about 1 million respiratory deaths globally. In India, there is an estimated 400,000 O₃ attributable respiratory deaths.¹³⁴

The relatively short atmospheric lifetime of methane, combined with its strong warming potential, means that targeted strategies to reduce emissions can provide climate and health benefits within a few decades.

6.1.4 Hydrofluorocarbons

Hydrofluorocarbons (HFCs) are a group of industrial chemicals primarily used for cooling and refrigeration. HFCs were developed to replace stratospheric ozone-depleting substances that are currently being phased out under the Montreal Protocol on Substances that Deplete the Ozone Layer.

Many HFCs are powerful GHG and a substantial number are short-lived climate pollutants with a lifetime of between 15 and 29 years in the atmosphere.

Though HFCs currently represent around 1% of total GHG, their impact on global heating can be hundreds to thousands of times greater than that of carbon dioxide per unit of mass.

They are primarily produced for use in refrigeration, air-conditioning, insulating foams and aerosol propellants, with minor uses as solvents and for fire protection. Most HFCs are contained within equipment, so emissions are the result of wear, faulty maintenance, or leakage at the end of a product's lifetime.

HFCs can be most effectively controlled through a phase down of their production and consumption.

6.2 What are Co-Benefits?

Co-benefits approach is described as a 'win-win' strategy aimed at capturing both development and climate benefits in a single policy or measure"; it meets immediate development needs while simultaneously tackling long-term climate concerns.

Co-benefits at the point where addressing local needs intersect with global environmental issues such as climate change mitigation. In particular, this is the juncture of strategies undertaken at the local level to balance the adverse impacts of economic development (e.g. traffic congestion, construction activities) on public health and the environment and mitigation measures to curb the effects of climate change at the global level.

In 2016, India has ratified the Paris Agreement to combat climate change, this required proposing emission reduction measures in the NDCs. Transport is one area which could have potential co-benefits by reducing urban air pollution and reducing GHG emissions.

However, initial NDCs produced by signatories to the Paris Agreement only address transport in a limited manner and do not fully exploit the available opportunities. Most NDCs do not specify measures to avoid unnecessary travel in carbon-intensive modes; shift to low-carbon modes of transport such as public transport, intercity bus and rail, cycling, and walking; and improve vehicle technology, particularly through electrification as well as fuel efficiency.

There are opportunities to achieve air and climate co-benefits and enhance NDCs via transport. These include accelerating electrification while addressing fuel economy; strengthening measures that support travel by low-carbon modes; and exploiting new opportunities to address freight emissions via electrification and use of information technology.¹³⁵ These will not only improve urban air quality but contribute to achieving the SDGs.

One concrete example is the design of an effective public transport system in a rapidly urbanising city. This not only addresses local development concerns

¹³³ Paliwal, U., Sharma, M., and Burkhart, J. F. (2016) Monthly and spatially resolved black carbon emission inventory of India: uncertainty analysis. *Atmos. Chem. Phys.*, 16, 12457–12476, 2016

¹³⁴ Malley, C. S. et al. (2017) Updated Global Estimates of Respiratory Mortality in Adults ≥30 Years of Age Attributable to Long-Term Ozone Exposure. *Environmental Health Perspectives*.

¹³⁵ WRI (2019) Enhancing NDCs: opportunities in transport. World Resources Institute, Washington DC, USA.
Gargava, Prashant, and V. Rajagopalan. 2016. "Source Apportionment Studies in Six Indian Cities— drawing Broad Inferences for Urban PM10 reductions." *Air Quality, Atmosphere and Health* 9(5): 471– 81. <http://dx.doi.org/10.1007/s11869-015-0353-4>.
Cropper, Maureen L. et al. 2006. "The Health Benefits of Air Pollution Control in Delhi." *American Journal of Agricultural Economics* 79(5): 1625.

Annexure I

Non-attainment cities

Sl. No	State	Cities Sl. No	Cities
1	Andhra Pradesh	1	Guntur
		2	Kurnool
		3	Nellore
		4	Vijaywada
		5	Vishakhapatnam
		6	Anantpur
		7	Chittoor
		8	Eluru
		9	Kadapa
		10	Ongole
		11	Rajahmundry
		12	Srikakulam
		13	Vizianagaram
2	Assam	14	Guwahati
		15	Nagaon
		16	Nalbari
		17	Sibsagar
		18	Silchar
3	Chandigarh	19	Chandigarh
4	Chattisgarh	20	Bhillai
		21	Korba
		22	Raipur
5	Delhi	23	Delhi
6	Gujarat	24	Surat
		25	Vadodara
		26	Ahmedabad

such as traffic congestion but also results in shorter commuting times, fuel savings, and improvement in local air quality. Concomitant reduction in GHGs will then contribute to climate change mitigation.

However, not all actions generate co-benefits. Certain actions and policies necessitate costs or incur negative consequences. For example, shifting from fossil fuels to nuclear power plants will reduce emissions from the energy sector but can lead to unintended, adverse side effects such as increased competition for agricultural land or loss of biodiversity.

Actions or policies therefore undertaken must have benefits and co-benefits greater than the sum of costs to undertake them. This will justify implementing the action or policy, as immediate benefits outweigh the risks or uncertainties to do so.

6.3 Opportunities for Co-Benefits in India

Outcomes from co-benefits are numerous and varied. It can range from more efficient use of human and financial resources, reduction of local air pollution, fuel savings, and leverage for local and global support.

To realise these and other outcomes, the co-benefits approach needed is one that actively integrates AQM with climate change mitigation. This is plausible as both air pollutants and GHGs are emitted from fuel combustion in transport, power generation, and industry, and biomass burning. Therefore, solutions, whether policy or technological, will overlap through energy and fuel efficiency.

In Asia, while opportunities for co-benefits exist, there are realities that must be faced and overcome before these outcomes are achieved. The two major problems of air pollution in Asian cities and climate change need to be addressed urgently. While city leaders acknowledge this urgency, cities typically lack information on the sources of air pollution and GHG, much less, address them.

In AQM, an emission inventory needs to be conducted before Clean air Plans can be developed and corresponding course of actions undertaken. Cities often lack the technical knowhow and resources to take on these two key activities in AQM. This is due to limited understanding of the strong linkages between AQM and climate change mitigation as well as the co-benefits approach, this constrains the identification and implementation of optimal strategies that address both issues.

It is not for the lack of desire or interest on the part of the decision-makers that air pollution and climate change issues are not addressed; rather, there is a basic problem of weak institutional capacity as well as policies. For example, there is a lack of a financing mechanism to reduce level of air pollution and amount of GHGs as international efforts focus only on mitigating CO₂.

Furthermore, there are trade-offs in some policies that need to be taken into consideration. Also, there are overlaps in the responsibilities of institutions that causes confusion on accountability and hampers implementation. These and other issues need to be considered before the appropriate action is undertaken or policy enacted.

7	Himachal Pradesh	27	Baddi
		28	Damtal
		29	Kala Amb
		30	Nalagarh
		31	Paonta Sahib
		32	Parwanoo
		33	Sunder Nagar
8	Jammu & Kashmir	34	Jammu
		35	Srinagar
9	Jharkhand	36	Dhanbad
10	Karnataka	37	Bangalore
		38	Devanagere
		39	Gulburga
		40	Hubli-Dharwad
11	Madhya Pradesh	41	Bhopal
		42	Dewas
		43	Indore
		44	Sagar
		45	Ujjain
		46	Gwalior
12	Maharashtra	47	Akola
		48	Amravati
		49	Aurangabad
		50	Badlapur
		51	Chandrapur
		52	Jalgaon
		53	Jalna
		54	Kolhapur
		55	Latur
		56	Mumbai
		57	Nagpur
		58	Nashik
		59	Navi Mumbai

		60	Pune
		61	Sangli
		62	Solapur
		63	Ulhasnagar
		64	Thane
13	Meghalaya	65	Byrnihat
14	Nagaland	66	Dimapur
		67	Kohima
15	Orissa	68	Angul
		69	Balasore
		70	Bhubneshwar
		71	Cuttack
		72	Rourkela
		73	Talcher
		74	Kalinga Nagar
		75	DeraBassi
16	Punjab	76	Gobindgarh
		77	Jalandhar
		78	Khanna
		79	Ludhiana
		80	NayaNangal
		81	Pathankot/Dera Baba
		82	Patiala
		83	Amritsar
		84	Alwar
17	Rajasthan	85	Jaipur
		86	Jodhpur
		87	Kota
		88	Udaipur
18	Tamilnadu	89	Tuticorin
		90	Trichy
19	Telangana	91	Hydrabad
		92	Sangareddy

		93	Nalgonda
		84	Patencheru
20	Uttar Pradesh	95	Agra
		96	Allahabad
		97	Anpara
		98	Bareilly
		99	Firozabad
		100	Gajraula
		101	Ghaziabad
		102	Jhansi
		103	Kanpur
		104	Khurja
		105	Lucknow
		106	Muradabad
21	Uttarakhand	107	Noida
		108	Raebareli
		109	Varanasi
22	West Bengal	110	Kashipur
		111	Dehradun
		112	Rishikesh
		113	Kolkata
		114	Asansol
		115	Barrackpore
		116	Haldia
23	Bihar	117	Howrah
		118	Durgapur
		119	Raniganj
		120	Patna
		121	Gaya
		122	Muzaffarpur

Non-attainment cities

State/UT	City
Andhra Pradesh	Vishakhapatnam
Assam	Guwahati
Chandigarh	Chandigarh
Chhattisgarh	Raipur
Delhi	Delhi
Gujarat	Surat
	Vadodara
	Ahmedabad
Jammu & Kashmir	Jammu
	Srinagar
Jharkhand	Dhanbad
Karnataka	Bangalore
	Devanagere
	Hubli-Dharwad
Madhya Pradesh	Bhopal
	Indore
	Sagar
	Ujjain
	Gwalior
Maharashtra	Thane
	Amravati
	Aurangabad
	Mumbai
	Nagpur
	Nashik
	Navi Mumbai
	Pune
	Solapur
Nagaland	Kohima
Orissa	Bhubaneshwar
	Rourkela

Punjab	Jalandhar
	Ludhiana
	Amritsar
Rajasthan	Jaipur
	Kota
	Udaipur
Tamil Nadu	Trichy
	Tuticorin
Uttar Pradesh	Agra
	Allahabad
	Bareilly
	Ghaziabad
	Jhansi
	Kanpur
	Lucknow
	Moradabad
	Varanasi
Uttarakhand	Dehradun
West Bengal	New Town Kolkata
	Haldie
	Durgapur
Bihar	Patna
	Muzaffarpur





