Train4CleanAir (T4CA)

General Air Quality Monitoring for Advancing Air Quality Management

Training Manual

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CLEAN AIR ASIA

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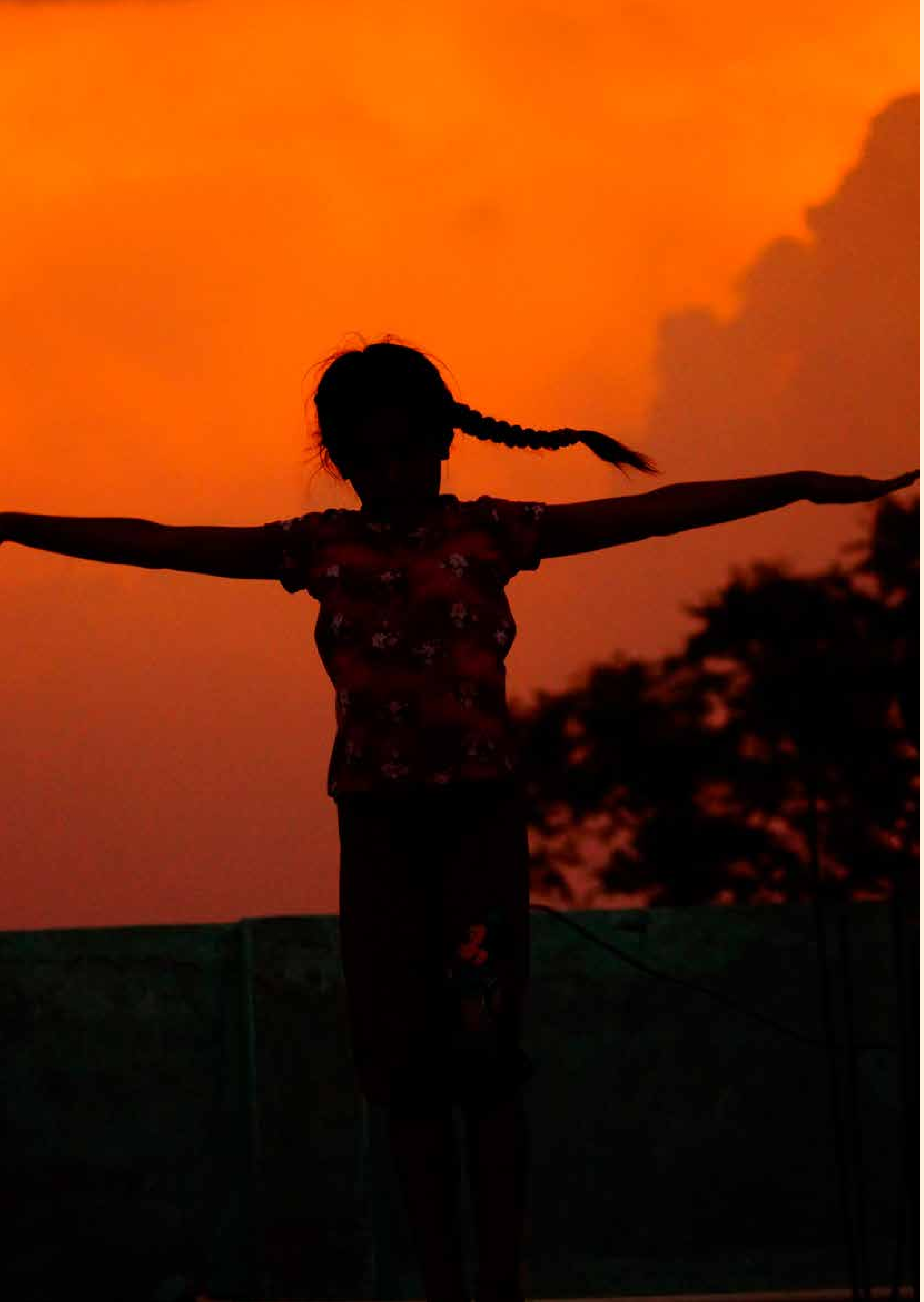


INTRODUCTION

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 need capacity development and could benefit through these manuals.

This manual titled General Air Quality Monitoring for Advancing Air Quality Management is designed for influencer groups like local organisations, academic institutions, media, civil society and non-government organisations who play a role in cities to advocate the use of data on air quality for establishing policy frameworks for AQM, clean air action planning, championing air quality improvement and mitigation of climate change impacts and gaining support from citizens.

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.

Table of Contents

Table of Contents

Table of Abbreviations

AQ	Air Quality
AQI	Air Quality Index
AQM	Air Quality Management
AWASI	Area Watch and Sanction Inspection
B(a)P	Benzo(a)pyrene
CAP	Comprehensive Action Plan
C6H6	Benzene
CO	Carbon Monoxide
CH_4	Methane
CEA	Central Environmental Authority
CFCs	Chlorofluorocarbons
CFD	Car Free Day
CPCB	Central Pollution Control Board
ECR	Environmental Conservation Rules
EPCA	Environmental Pollution Control Authority
GHGs	Green House Gases
GRAP	Graded Response Action Plan
GWP	Global Warming Potential
HAP	Hazardous Air Pollutants
HFC	Hydrofluorocarbons
LEP	Law on Environmental Protection
MONRE	Permanent Secretary of the Ministry of Natural Resources and Environment
NAAMP	National Ambient Air Quality Monitoring Programme
NAAQS	National Ambient Air Quality Standards
NCAP	National Clean Air Programme
NEERI	National Environmental Engineering Research Institute
NH_3	Ammonia
NO_x	Nitrogen oxides
NO	Nitric Oxide
NO_2	Nitrogen dioxide
N_2O	Nitrous Oxide
O_3	Ozone
PAHs	Poly Aromatic Hydrocarbons
Pb	Lead
PAN	Peroxyacetyl Nitrate
PCD	Pollution Control Department
PFCs	Perfluorocarbons
PM	Particulate Matter
PSI	Pollutant Standard Index
QA	Quality Assurance
QC	Quality Control
RAAQS	Regional Ambient Air Quality Standard
SF_6	Sulfur hexafluoride
SO_x	Sulphur oxides
SO	Sulfur monoxide
SO_2	Sulfur dioxide
SPCB	State Pollution Control Board
SPM	Suspended Particulate Matter
VOC	Volatile Organic Compounds
UNFCCC	United Nations Framework Convention on Climate Change
USEPA	U.S. Environmental Protection Agency
WHO	World Health Organization

List of Tables, Figures and Boxes

General Air Quality Monitoring for Advancing Air Quality Management

Learning Objectives

Goal

This manual enables participants to develop their understanding of the need for data on air pollution and the key components required to develop a scientific air quality monitoring programme in a city. By working through this manual participants will gradually achieve a higher level of understanding of the measures taken to monitor air quality and its role in air pollution mitigation in India.

Target Audience

The manual is designed for influential groups such as environment related NGOs, local community groups and leaders, environment related media groups who are engaged in informing for air quality management and want to generate public support for air pollution control with the help of scientific data on air quality.

Contents of the Manual

In the manual, General Air Quality Monitoring for Advancing Air Quality Management, participants will examine the importance and methods of data generation for better air quality and clean air action planning. The manual contents include:

- Information on key air pollutants
- Air pollution monitoring methods
- Data generation and communication
- Regulations, standards, and enforcement in India
- Air quality monitoring rules, regulations, and procedures for Indian cities

Objectives of the Manual

The manual can be used to support training around *General Air Quality Monitoring for Advancing Air Quality Management. With the help of this manual participants can*

- Identify key air pollutants that need to be monitored in their cities.
- Understand about the status of air quality in their cities and identify indicators of bad air quality
- Know about the role of data, methods of generating data and its importance to air quality management.
- Determine how scientific data inputs can be used for Clean Air Plans
- Identify areas where good data can contribute towards strategies for better air quality in their cities.

1. Air Pollution And Its Effects On Health And Ecosystems

1.1 Introduction To Air Pollution

This chapter includes everything in connection with air pollution and will discuss what air pollution is, what types of air pollutants are present on Earth, how they are created, and the effects of air pollution to human's health and ecosystem. Upon reading this chapter the participants should be able to answer the questions presented. Towards the end of this manual an exercise will be done wherein a case study is presented to the participants and discussion among participants will be practiced.

Stewardship to planet Earth is perhaps the biggest responsibility humans hold because without it humans become victim to the very thing they create, pollution. So, what is the air that is being referred to as being polluted? Earth's atmosphere is made up of air, a clear gas with no color, no smell, with a mixture of mainly nitrogen (78 percent) and oxygen (21 percent), and lesser amount of argon, carbon dioxide, hydrogen, neon, helium and other gases. Air has weight, and creates atmosphere pressure.

The atmosphere is a complex dynamic natural gaseous system that is essential to support life on planet Earth. Damaging it can mean damaging the giant safety blanket of Earth that keeps the temperature on Earth's surface from dipping to extreme icy cold that would freeze everything solid, or from soaring to blazing heat that would burn up all life. The atmosphere is made up of many layers of air namely: troposphere, stratosphere, mesosphere, thermosphere, and exosphere. In the study of air pollution control the layers of the air that are most important are the troposphere and the stratosphere. (See Figure 1)

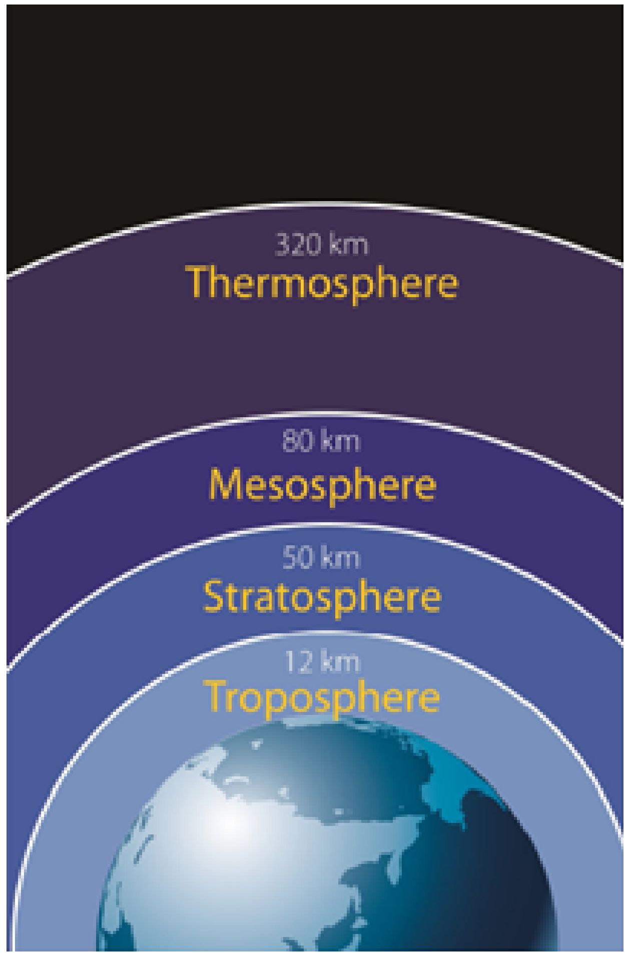


Figure 1: Layers of Earth

An important layer of atmosphere containing ozone is located inside the stratosphere. Ozone is a special form of oxygen, and the ozone layer is very important to all life on earth. The ozone layer blocks large amounts of solar ultraviolet radiation from entering the troposphere. Too much solar radiation can harm living things, including people. It is damage to these layers of the atmosphere that puts life on earth at risk.

1.2 What Is Air Pollution And How Does It Occur?

Air pollution is the introduction of chemicals, particulate matter, or biological materials into the atmosphere that cause harm or discomfort to humans and other living organisms, or damages the natural environment.[1]

In theory air has always been polluted to some degree. Natural phenomena such as volcanoes, windstorms, decomposition of plants and animals, and even the aerosols emitted by the ocean 'pollute' the air. However, the pollutants usually referred to when talking about air pollution are those generated as a result of human activity, such as driving motor vehicles, burning of coal, oil and other fossil fuels, and manufacturing chemicals. Air quality can be affected in many ways by the pollution emitted from these sources.

Ambient air is the air to which the general public has access, i.e. any unconfined portion of the atmosphere. There are hundreds of pollutants in ambient air. With this **air pollutant** are substances in the air that causes harm to humans and the environment. Air pollutants can be in the form of solid particles, liquid droplets, or gases, which can be classified as either primary or secondary.

Primary pollutants are substances directly emitted from a process, such as ash from a volcanic eruption, carbon monoxide gas from a motor vehicle exhaust or sulfur dioxide released from factories.

Secondary pollutants are not emitted directly. Rather, they form in the air when primary pollutants react or interact.

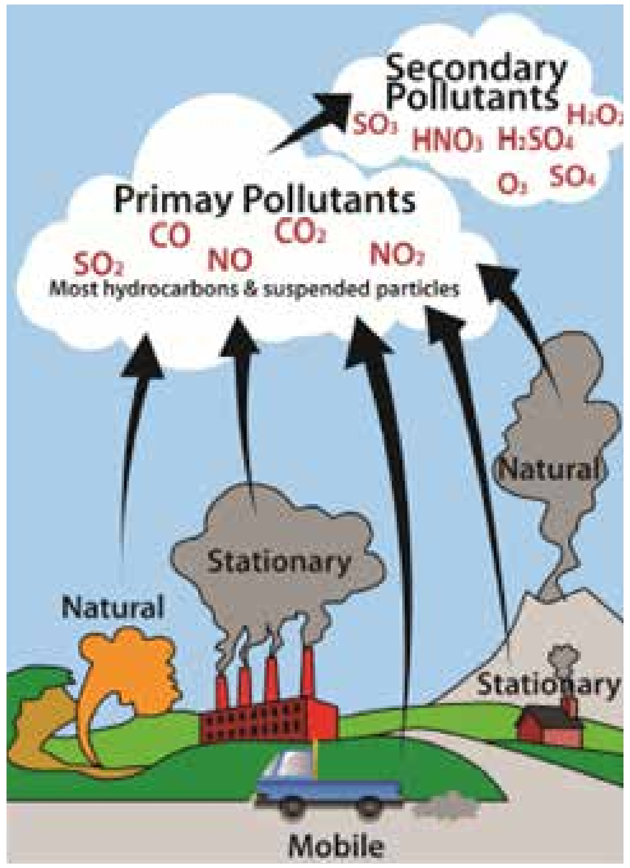


Figure 2: Sources of Air Pollution

1 Copenhagen Consensus on Human Challenges (2011), Guy Hutton, PhD 'Air Pollution: Global Damage Costs of Air Pollution from 1900 to 2050

Examples of major primary air pollutants produced by human activity include Particulate Matter, Sulfur Oxides (SO_X) Nitrogen Oxides (NO_X), Carbon monoxide (CO), and Volatile organic compounds (VOCs). Secondary air pollutants on the other hand include ground level ozone (O_3), and smog.

For regulatory purposes, air pollutants have also been further classified as criteria pollutants and hazardous air pollutants (HAPs).

Criteria pollutants are pollutants that have been identified as being both common and detrimental to human welfare.

Hazardous 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.

Put into simpler terms, the introduction of the different types of pollutants to the ambient air results into air pollution.

1.3 Types Of Air Pollution

In general, there are several main types of air pollution and well-known effects that are commonly discussed. These include black carbon and noxious gas pollution, smog, acid rain, the greenhouse effect, and 'holes' in the ozone layer.

1.3.1 Black carbon and noxious gas pollution

Black carbon pollution has been a major problem since the beginning of the industrial revolution and the development of the internal combustion engine. Black carbon[2] is the result of burning of fuel for energy releasing particles into the air. Diesel smoke is a good example of this type of pollution.

Mankind has become so dependent on the burning of fossil fuels (petroleum products, coal, and natural gas) that the sum of all combustion-related emissions now constitutes a serious widespread problem, not only to human health, but also to the entire global environment.

Noxious gas pollution on the other hand is a result of further chemical reactions in the atmosphere forming smog and acid rain. Examples of noxious gases include SO_2, CO, NO, and chemical vapours.

1.3.2 Smog

The word 'smog' is derived from the combination of the words smoke and fog. Classic smog results from large amounts of coal burning in an area resulting to a mix of smoke and sulfur dioxide (SO_2). But now modern smog comes from vehicular and industrial emissions that combine with primary pollutants and are acted on in the atmosphere by sunlight resulting in photochemical smog. It is called photochemical smog due to the mixture of gases and is formed through photochemical reactions. This type of smog is mainly composed of ozone (O_3), peroxyacetyl nitrate (PAN), and nitrogen oxide (NO_X). There are two kinds of photochemical smog, one that is a yellowish-brown haze also known as brown air due to intense solar radiation. The other is called grey air due to lesser solar radiation resulting to incomplete smog formation.

Figure 3: City of Smog

2 UNEP and WMO (2011), Integrated Assessment of Black Carbon and Tropospheric Ozone: Summary for Decision Makers.

1.3.3 Acid rain

Acid rain is caused by emissions of sulfur dioxide and nitrogen oxides, which react with the water molecules in the atmosphere to produce acids. However, it can also be caused naturally by the splitting of nitrogen compounds by the energy produced by lightning strikes, or the release of sulfur dioxide into the atmosphere by volcano eruptions.

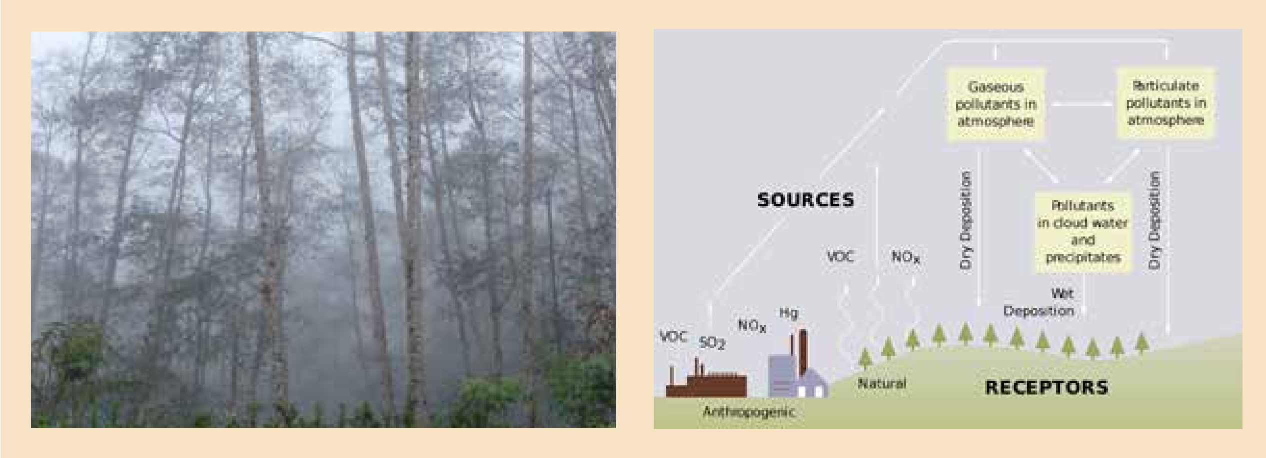


Figure 4: Acid Rains

1.3.4 Rural air pollution

Most people expect that ambient air quality in rural areas is better than that in towns and cities. For the most part this is true since emissions of primary pollutants are greater in urban areas. However, levels of ozone are generally higher in suburban and the surrounding countryside because of its special atmospheric chemistry.

Ozone is created from sunlight-initiated oxidation (reaction with oxygen) of volatile organic compounds in the presence of nitrogen oxides (NO_X), mostly NO and NO_2. Once formed, ozone is scavenged by NO, and in the absence of other competing reactions, an equilibrium state in the concentration of NO, NO_2, and ozone (O_3) is formed. In rural areas away from major sources of NO, such as urban road traffic, ozone scavenging by NO is lower, and consequently ozone concentrations are higher in the atmosphere.

Primary pollutants such as sulfur dioxide and nitrogen oxides also undergo chemical transformation as they are dispersed in the atmosphere. With this sulfuric acid and nitric acid is formed respectively, which may be deposited downwind as acid rain in rural areas.

1.3.5 Indoor air pollution

Air pollution also needs to be considered inside our homes, offices, and schools whether in town, cities or rural area. Some air pollutants can be created by indoor activities such as smoking and cooking.
In many homes around the world, we spend about 80-90 percent of our time inside buildings, and so our exposure to harmful indoor pollutants can be serious. It is therefore important to consider both indoor and outdoor air pollution.

Sources of indoor air pollution include the following but not limited to tobacco smoke, cooking and heating appliances, and vapours from building materials, paints, furniture, among others. Radon is a natural radioactive gas and carcinogen that is released from the earth and can be found in high concentrations in basements. Formal dehyde gas is also emitted by building materials including carpeting and plywood. Volatile organic compounds can also be found indoors from paint and solvents as they dry. Lead paint can degenerate into dust and be inhaled.

Intentional air pollution is also introduced in indoor environments through the use of air fresheners, incense, and other scented items. Controlled wood fires in stoves and fireplaces can add significant amounts of smoke particulates into the air, inside and out.

Indoor pollution fatalities also occur. These may be caused by the use of pesticides and other chemical sprays used indoors without proper ventilation. CO poisoning and fatalities are often caused by faulty vents and chimneys or by the burning of charcoal indoors. Asbestosis is a chronic inflammatory medical condition that affects the tissue of the lungs. This is caused by the use of asbestos. Though its uses have now been banned in many countries, the extensive use of asbestos in industrial and domestic environments in the past has left large amounts of potentially dangerous material in many localities.

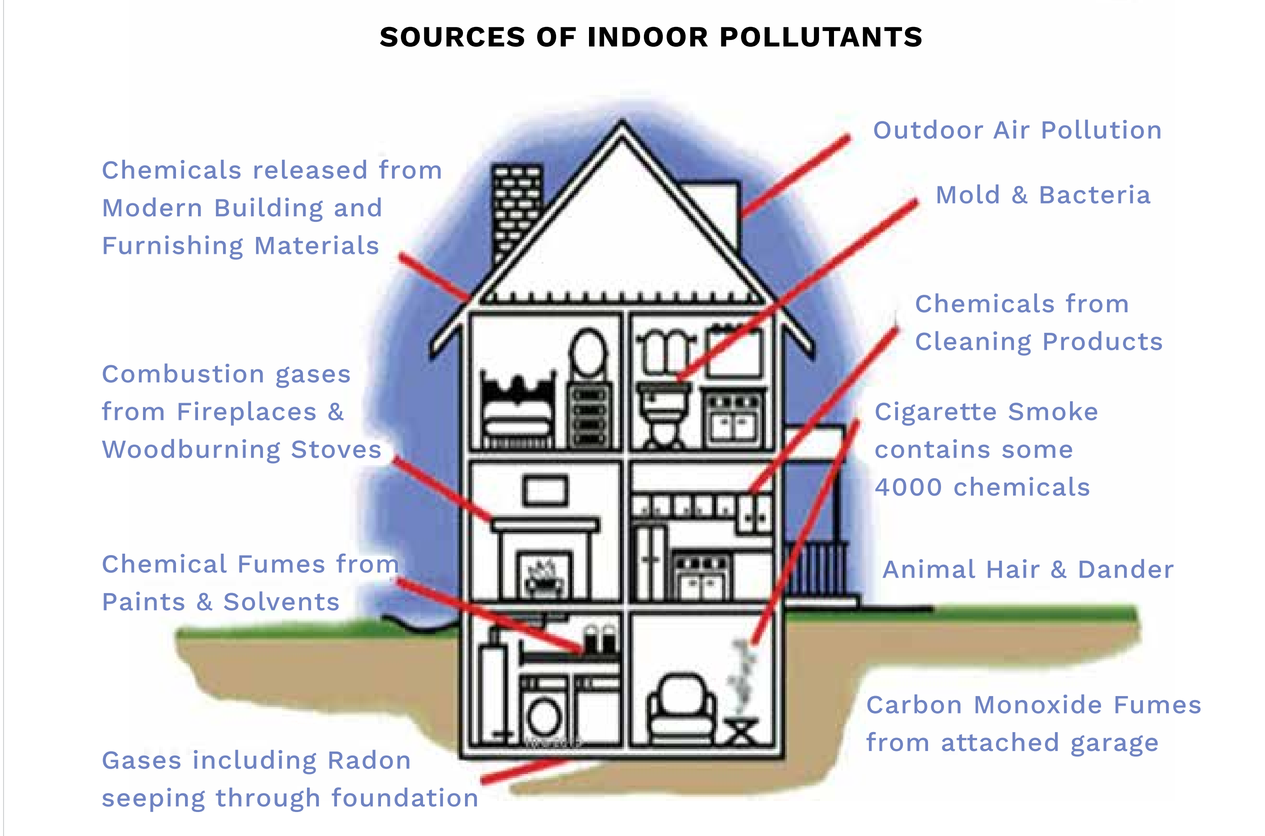


Figure 5: Sources of Indoor Pollutants (Image Source mastercleaning.org)

Biological sources of air pollution are also found indoors as gases and airborne particulates. With the lack of air circulation indoors, these airborne pollutants accumulate to levels that are more than they would otherwise occur in nature.

1.4 How Does Air Pollution Problem Occur?

Air pollution problem occurs when gas, particle, and other chemicals mix with the air and their concentrations from the measurement exceed the pollutant concentration threshold and maximum allowable duration of exposure to the damaging chemicals. The threshold values are determined based on the extensive scientific evidence on air pollution and its health consequences. Although this information has gaps and uncertainties, it offers a strong foundation for the guidelines to protect human health with an adequate margin of safety, including sensitive populations such as children, the elderly, and individuals suffering from respiratory disease. It is when these concentrated gases or particles exceed safe limits that we have a pollution problem.

1.5 Transport And Dispersion Of Air Pollutants

The transport and dispersion of air pollutants in the ambient air are influenced by many complex factors. Global and regional weather patterns and local topographical conditions affect the way that pollutants are transported and dispersed.[3] Weather refers to the state of the atmosphere at a given time and place. On a more local level, the primary factors affecting transport and dispersion of pollutants are wind and stability. The dispersion of pollutants from a source is also influenced by the amount of turbulence in the atmosphere near the source.

Wind is the natural horizontal motion of the atmosphere. It occurs when warm air rises, and cool air comes in to take its place. Wind is caused by differences in pressure in the atmosphere. The pressure is the weight of the atmosphere at a given point. The height and temperature of a column of air determines the atmospheric weight. Because cool air weighs more than warm air, a high-pressure mass of air is made up of cool and heavy air. Conversely, a low-pressure mass of air is made up of warmer

3 Air Pollution, THE Automobile and Public Health, Perry J. Samson 'Atmospheric Transport and Dispersion of Air Pollutants Associated with Vehicular Emissions', University of Michigan

and lighter air. Differences in pressure cause air to move from high pressure areas to low pressure areas, resulting in wind. Wind speed can greatly affect the pollutant concentration in a local area. The higher the wind speed, the lower the pollutant concentration. Wind dilutes pollutants and rapidly disperses them throughout the immediate area.

Atmospheric stability[4] refers to the vertical motion of the atmosphere. Unstable atmospheric conditions result in a vertical mixing. Typically, the air near the surface of the earth is warmer in the day time because of the absorption of the sun's energy. The warmer and lighter air from the surface then rises and mixes with the cooler and heavier air in the upper atmosphere causing unstable conditions in the atmosphere. This constant turnover also results in dispersal of polluted air. Stable atmospheric conditions usually occur when warm air is above cool air and the mixing depth is significantly restricted. This condition is called a temperature inversion. During a **temperature inversion**, air pollution released into the atmosphere's lowest layer is trapped there and can be removed only by strong horizontal winds. Because high pressure systems often combine temperature inversion conditions and low wind speeds, long residency over an industrial area result in episodes of severe smog.

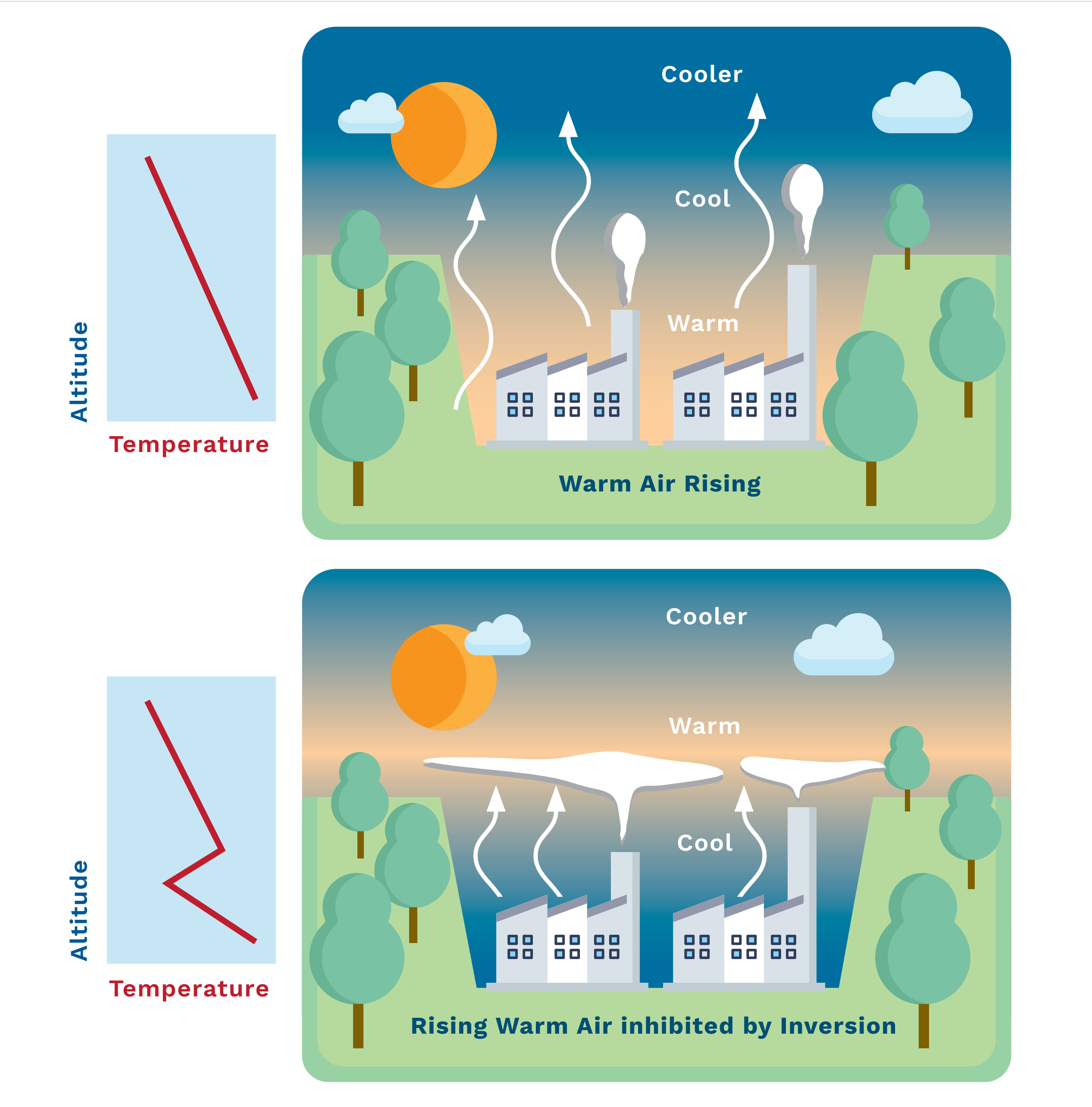


Figure 6: Unstable Atmosphere and Inversion

4 Air Pollution Training Institute (2003), Principles and Practices of Air Pollution Control', United States Environmental Protection Agency

Turbulence[5] can be created by both the horizontal and vertical motion of the atmosphere. Other basic meteorological factors that affect concentration of air pollutants in the ambient air are: solar radiation, precipitation, and humidity. Solar radiation contributes to the formation of ozone and acts to create secondary pollutants in the air. Humidity and precipitation can also act on pollutants in the air to create more dangerous secondary pollutants, such as the substances responsible for acid rain. Precipitation can also have a beneficial effect by washing pollutant particles from the air. Because of the factors responsible for the transport and dispersion of pollutants, air pollution produced in an area can have adverse effects on other areas far away from the location where air pollution is produced. On the other hand, cities bordered by complex topography, such as valleys or mountain ranges, often experience high concentrations of air pollutants because of the natural barrier that interrupts pollution dispersion. These cities experience high levels of air pollution influenced by the topography of the surrounding area. Although the overall causes of their respective pollution problems are complex, they are examples of situations where natural factors result in higher pollutant concentrations.

1.6 What Effects Does Air Pollution Cause?

Air pollution has a detrimental effect on our lives. Along with the health effects there are many ecosystem effects of air pollution. These include effects on vegetation, soil, water, manmade materials, climate, and visibility.

1.7 Effects On The Ecosystem

1.7.1 Greenhouse effect

The earth's climate is fuelled by the sun. Most of the sun's energy, called solar radiation, is absorbed by the earth, but some is reflected back into space. Clouds and a natural layer of atmospheric gases absorb a portion of earth's heat and prevent it from escaping into space. This keeps our planet warm enough for life and is known as the natural 'greenhouse effect'. Without the natural greenhouse effect, the earth's average temperature would be much colder, and the planet would be uninhabitable.

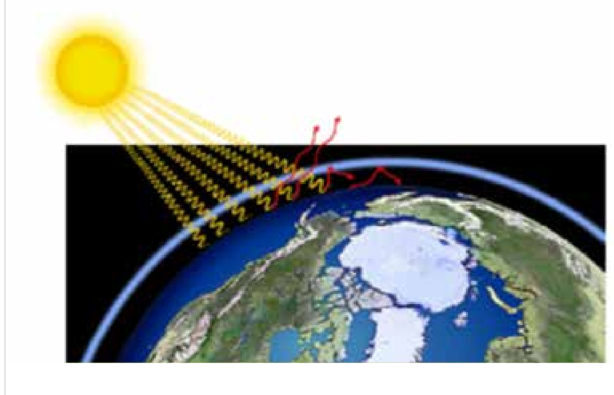


Figure 7: Greenhouse Effect

Scientific evidence shows that the greenhouse effect is being increased by the release of certain gases into the atmosphere that cause the earth's temperature to rise. This is called **global warming**. Carbon dioxide, methane, particulate matter (especially black carbon or soot), nitrous oxide, fluorinated compounds, and ozone are some of the compounds contributing to global warming.

Carbon dioxide (CO_2) is a greenhouse gas emitted from combustion but is also a gas vital to living organisms. It is a natural gas in the atmosphere. Carbon dioxide accounts for the major greenhouse gas released in the world. CO_2 emissions are largely due to the combustion of fossil fuels in electric power generation, motor vehicles, and industries. Plants convert carbon dioxide back to oxygen, but the release of carbon dioxide from human activities is higher than the world's plants can process. The situation is made worse since many of the earth's forests are being removed, and plant life is being damaged by acid rain. Thus, the amount of carbon dioxide in the air is continuing to increase.

Methane[6] **(CH_4)** emissions, which result from agricultural activities, landfills, and other sources, are the next largest contributors to greenhouse gas emissions in the world. CH_4 is not toxic; however, it is extremely flammable and may form explosive mixtures with air. CH_4 has a global warming potential of 21, which indicates that it is approximately 21 times more heat absorptive per unit of weight higher than carbon dioxide. Global warming potential[7] (GWP) is a measure of how much a given mass of greenhouse gas is estimated to contribute to global warming.

Nitrous oxide[8] **(N_2O)** is a greenhouse gas released from biomass burning, nitrogen fertilizers, and

6 United States Environmental Protection Agency, Overview of Greenhouse Gases, EPA
7 Global warming potential (GWP) is a measure of how much a given mass of greenhouse gas is estimated to contribute to global warming.
8 United States Environmental Protection Agency, Overview of Greenhouse Gases, EPA

sewage. Nitrous oxide is most commonly used as an anaesthetic in dentistry and a propellant in the food industry. It has a GWP of 310 indicating that it is approximately 310 times more heat absorptive per unit weight higher than carbon dioxide.
Other greenhouse gases which are subject to the Kyoto Protocol include sulfur hexafluoride (SF_6), hydrofluorocarbons (HFCs), and perfluorocarbons (PFCs). SF_6 is used as a gas medium in the electrical industry and medical applications. HFCs are used in refrigeration and air conditioning, solvents, degreasing agents, and cleaning agents. Use of PFCs is found in medical and non-medical applications such as in insulation, refrigerating unit, and fire extinguisher. The Kyoto Protocol is a protocol to the United Nations Framework Convention on Climate Change (UNFCCC) aimed at fighting global warming. The UNFCCC is an international environmental treaty with the goal of achieving stabilization of greenhouse gas concentrations in the atmosphere at a level that would prevent dangerous anthropogenic interference with the climate system.

Continued emissions of **greenhouse gases** could cause rise in temperature and global warming. This could lead to more extreme weather events such as drought and floods, threaten coastal resources and wetlands by raising the sea level as a result of increased polar ice cap melting, and increase the risk of certain diseases by producing new breeding sites for pests and pathogens. Agricultural regions and woodlands are also susceptible to changes in climate that could result in increased insect populations and plant disease. This degradation of natural ecosystems could lead to reduced biological diversity.

1.7.2 Ozone depletion

Chemicals released by our activities affect the stratosphere. Release of chlorofluorocarbons (CFCs) from aerosol cans, cooling systems and refrigerator equipment accumulate in the lower atmosphere and are eventually transported to the stratosphere and then converted to more reactive gases that participate in reactions that destroy ozone in the stratosphere. The ozone layer in the stratosphere protects the Earth from harmful ultraviolet radiation from the sun.[9] The depletion of stratospheric ozone due to the release of gases containing chlorine and bromine allows additional ultraviolet radiation to pass through the atmosphere and reach the Earth's surface. Additional ultraviolet radiation leads to increases in ultraviolet-related health effects, such as skin cancer and cataracts, and damaging effects on plants and wildlife.

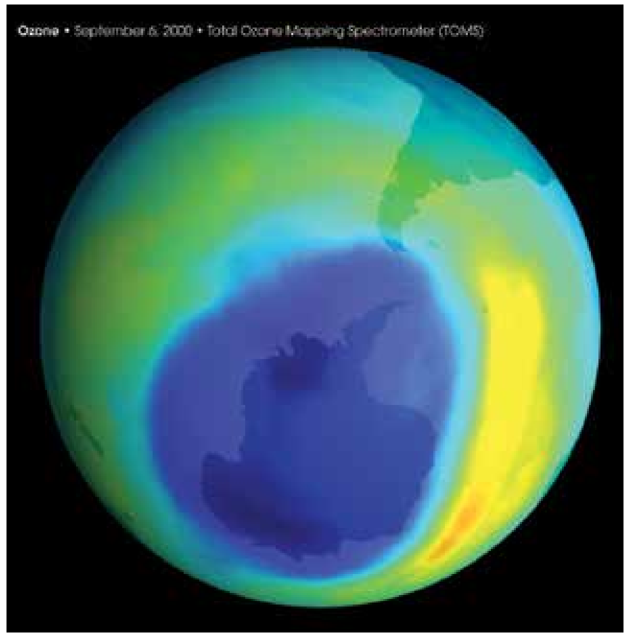


Figure 8: Ozone hole over Antarctica

1.8 Effects On Human Health

Air pollution can affect our health in many ways with both acute (short-term) and chronic (long-term) effects. **Acute effects** are usually immediate and often reversible when exposure to the pollutant ends. Some acute health effects include eye irritation, headaches, nausea, and upper respiratory infections such as bronchitis and pneumonia. **Chronic effects** are usually not immediate and tend not to be reversible when exposure to the pollutant ends. Some chronic health effects include decreased lung capacity, heart disease, lung cancer, and even damage to the brain, nerves, liver or kidneys resulting from long-term exposure to toxic air pollutants.

Different groups of individuals are affected by air pollution in different ways. Some individuals are much more sensitive to pollutants than are others. Young children and elderly people often suffer more from the effects of air pollution. People with health problems such as asthma, heart and lung disease may also suffer more when the air is polluted. The extent to which an individual is harmed by air pollution usually depends on the total exposure to the damaging chemicals, i.e. the duration of exposure and the concentration of the chemicals must be taken into account. Besides, individual reactions to air pollutants also depend on the individual's health status and genetics.

9 USEPA, Ozone Layer Protection

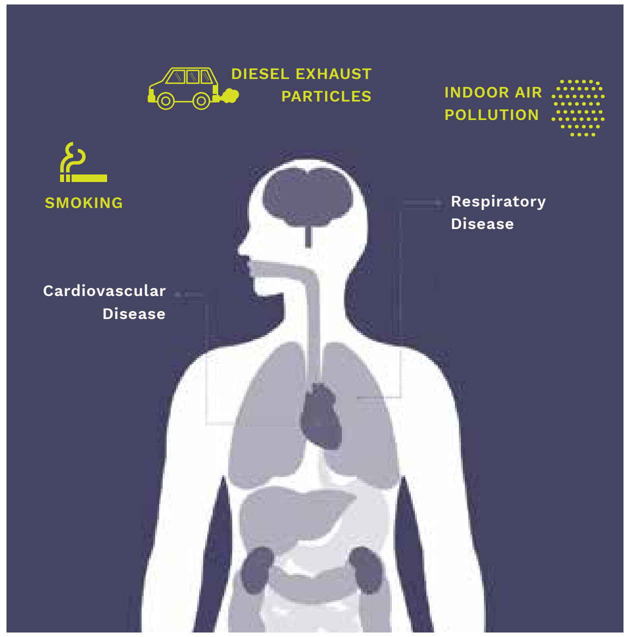


Figure 9: Health Effects of Air Pollution

Both gaseous and particulate air pollutants can have negative effects on the lungs. Solid particles can settle on the walls of the trachea, bronchi, and bronchioles. Most of these particles are removed from the lungs through the cleansing (sweeping) action of 'cilia', small hair like outgrowths of cells, located on the walls of the lungs.[10] This is what occurs when you cough or sneeze.

A cough or sneeze transports the particles to the mouth. The particles are removed subsequently from the body when they are swallowed or expelled. However, extremely small particles may reach the alveoli, where it takes weeks, months, or even years for the body to remove the particles. Gaseous air pollutants may also affect the function of the lungs by slowing the action of the cilia. Continuous breathing of polluted air can slow the normal cleansing action of the lungs and result in more particles reaching the lower portions of the lung.[11]

The lungs are the organs responsible for absorbing oxygen from the air and removing carbon dioxide from the blood-stream. Damage to the lungs from air pollution can inhibit this process and contribute to the occurrence of respiratory diseases such as bronchitis, emphysema, and cancer. This can also put an additional burden on the heart and circulatory system.

Air pollution also has an effect on **visibility**. Visibility is a measure of aesthetic value and the ability to enjoy scenic view, but it also can be an indicator of general air quality. Visibility degradation results when light encounters tiny pollution particles (sulfates, nitrates, organic carbon, soot, and soil dust) and some gases (nitrogen dioxide) in the air. Some light is absorbed by the particles and other light is scattered away before it reaches the observer. More pollutants mean more absorption and scattering of light, resulting in more haze. Haze obscures the clarity, color, texture, and form of what we see. Humidity magnifies the haze problem because some particles, such as sulfates, attract water and grow in size, scattering more light.

Table 1 and Figure 11 summarizes the sources, health and welfare effects for the criteria pollutants as per Environmental Protection Agency and Central Pollution Control Board. Hazardous air pollutants may cause other less common but potentially hazardous health effects, including cancer and damage to the immune system, and neurological, reproductive and developmental problems. Acute exposure to some hazardous air pollutants can cause immediate death..

Figure 10: Reduced Visibility (Image by Rahmad Gunawan)

10 Richa and Smirti, Malfunctioning of Pulmonary Health, International Journal of Geology, Earth and Environmental Sciences, Volume 1 Issue 2, 2014
11 Air Pollution Effects on Lungs

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 11: Air Quality Index and Health Impacts

Table 1: Sources, health and welfare effects for criteria pollutants

Pollutant	Sources	Health effects	Welfare effects
Carbon monoxide (CO)	Motor vehicle exhaust, indoor sources include kerosene or wood burning stoves	Headaches, reduced mental alertness, heart attack, cardiovascular diseases, impaired fetal development, death	Contribute to the formation of smog
Sulfur dioxide (SO_2)	Coal-fired power plants, petroleum refineries, manufacture of sulfuric acid and smelting of ores containing sulfur	Eye irritation, wheezing, chest tightness, shortness of breath, lung damage	Contribute to the formation of acid rain, visibility impairment, plant and water damage, aesthetic damage
Nitrogen dioxide (NO_2)	Motor vehicles, electric utilities, and other industrial, commercial, and residential sources that burn fuels	Susceptibility to respiratory infections, irritation of the lung and respiratory symptoms (e.g., cough, chest pain, difficulty breathing)	Contribute to the formation of smog, acid rain, water quality deterioration, global warming, and visibility impairment
Ozone (O_3)	Vehicle exhaust and certain other fumes. Formed from other air pollutants in the presence of sunlight	Eye and throat irritation, coughing, respiratory tract problems, asthma, lung damage	Plant and ecosystem damage
Lead (Pb)	Metal refineries, lead smelters, battery manufacturers, iron and steel producers	Anemia, high blood pressure, brain and kidney damage, neurological disorders, cancer, lowered IQ	Affects animals and plants, affects aquatic ecosystems
Particulate matter (PM)	Diesel engines, power plants, industries, windblown dust, wood stoves	Eye irritation, asthma, bronchitis, lung damage, cancer, heavy metal poisoning, cardiovascular effects	Visibility impairment, atmospheric deposition, aesthetic damage

Source: www.epa.gov

2. Causes And Sources Of Air Pollution

2.1 Introduction

Although, the causes and sources of air pollution are related topics and appear to be of the same context, the fact is that both discuss very different aspects of air pollution. The causes of air pollution are defined as the driving forces of air pollution, while the sources of air pollution are the various locations or activities responsible for the release of pollutants in the atmosphere. In this manual the reader will encounter the different causes of air pollution and the numerous sources where air pollution comes from. Towards the end of this manual the reader should be able to determine the amount of air pollutants present in a location and from which sources these are released. There will be a thorough discussion on emission inventory, what it is, the process of creating it, its uses and its importance to public control and policy making.

2.2 What Are The Causes Of Air Pollution?

2.2.1 Population growth and urbanization

As population grows, demand for transport, energy, housing, and environmental services also increases. The increase on these demands creates pressure on the environment in the form of emissions of air pollutants which affects air quality. Over the past decades, urban population has grown more rapidly than rural population. This is true as cities and towns become the engine of economic development in many countries. The dynamic growth of cities has attracted rural people to move to cities in the hopes of a better life. More so when they have seen its positive effects to the lives of friends and neighbours. As cities expand to their hinterlands so does the distance from home to work in the city centers which further raises the need for energy and transport, creating more burden on the environment.

2.2.2 Economic development

Many countries have experienced economic development and higher standards of living over the past decades. Conventional wisdom relates economic growth to increased air pollution; however this is not the case for all countries. Some developed countries reported that their nation's air pollution had declined even without limiting their economic growth. This was the result of tightened environmental controls such as policies. On the other hand, many developing countries that undergo economic development, industrial development, and motorization, the demand for fossil fuels tend to increase. Thus, increasing levels of air pollution occur in the absence of effective policies that could've put a control to the amount of air pollution.

2.2.3 Motorization

The number of motor vehicles on the road has been growing at a considerable pace, which is primarily influenced by increasing affluence and population growth. Although this is not necessarily true for all countries, especially in countries with active controls that limit the number of vehicles, promote public transport options, and non-motorized forms of transport such as cycling and walking. As cities grow and sprawl, the number of trips made by public transport become limited and two-wheelers play an important role as an alternative mode of transport because they are more accessible to a larger portion of the population who cannot afford to own a car. Increase in use of two-wheelers has added to significant motorization rates in Asia. The continued growth in motorization will further aggravate traffic congestion and result in increased traffic emissions.

Figure 12: Traffic Congestion

Figure 13: Sea of Motorcycles

2.2.4 Reliance on fossil fuels as sources of energy

Fossil fuels such as coal, oil, and natural gases currently provide majority of all the energy consumed worldwide. These remain as the dominant source of energy since it is relatively cheap and it is the only viable solution to meeting the increasing demand in the next two decades even with aggressive development and deployment of new renewable and nuclear technologies. Coal remains the dominant source of the power sector but higher fossil-fuel prices in the future and increasing concerns over energy security and climate change are expected to boost the share of renewable-based power generation. Nevertheless, it is likely that the world's reliance on fossil fuels to power expanding economies continues to increase. The continuation of current trends would have dire consequences for climate change and also exacerbate air pollution, particularly in developing countries.

2.3 Sources Of Air Pollution

As discussed earlier the sources of air pollution refer to the various locations or activities which are responsible for the releasing of pollutants in the atmosphere. These sources can be classified into two major categories, **natural** or **biogenic sources** and **anthropogenic (human-induced) sources**. There have always been natural sources of air pollution.

This includes volcanoes that have spewed particulate matter and gases into our atmosphere, lightning strikes that have caused forest fires, with their resulting contribution of gases and particles, organic matter in swamps that decay and windstorms that whip up dust. Trees and other vegetation also contribute to large amounts of pollen and spores to our atmosphere. These natural pollutants can be problematic at times, for example the haze in

Indonesia caused by forest fires. But generally is not as much of a problem as are anthropogenic sources. **Anthropogenic sources** are categorized in two ways: stationary and mobile sources.

Stationary sources[12] of air pollution consist of non-moving sources such as power plants, manufacturing facilities (factories), oil refineries, chemical plants, and waste incinerators, as well as furnaces and other types of fuel-burning heating devices. Air pollution from stationary sources is produced by two primary activities: combustion of fuel such as coal and oil at power generating facilities, and the pollutant losses from industrial processes such as refineries, chemical manufacturing facilities and smelters. Stationary sources are classified further into either point source or area source.

Figure 14: Stationary Source

A **point source** refers to a source at a fixed point, such as a smokestack or storage tank that emits air pollutants. Large, stationary sources of emissions that have specific locations and release pollutants in quantities above an emission threshold are also considered as point sources. Coal and oil-fired power plants facilities are usually the largest point sources within a city because of the large amount of fuel they consume. An **area source** refers to a series of small sources that together can affect air quality in a region. Area sources represent numerous facilities or activities that individually release small amounts of a given pollutant, but collectively can release significant amounts of a pollutant. For example, dry cleaners, vehicle refinishing, gasoline dispensing facilities, and residential heating will not typically qualify as point sources, but collectively the various emissions from these sources are classified as an area source. Another example, a community of homes using woodstoves from heating would be considered as an area source, even though each individual home is contributing small amounts of various pollutants. Forest fires and open burning of waste are also considered as an area source.

Figure 15: Forest Fires

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

Mobile sources of air pollution include a wide variety of vehicles, engines, and equipment that generate air pollution and that move, or can be moved from place to place. Mobile sources are classified as either on-road or non-road sources. **On-road sources** include vehicles used on roads for transportation of passengers or freight, such as passenger cars, trucks, and motorcycles. On-road vehicles may be fueled with gasoline, diesel fuel, or alternative fuels, such as alcohol or natural gas. **Non-road sources** on the other hand include gasoline and diesel powered vehicles, engines, and equipment used for construction, agriculture, transportation, recreation, and many other purposes. Examples of non-road sources are marine vessels, aircrafts, railways, tractors, among others.

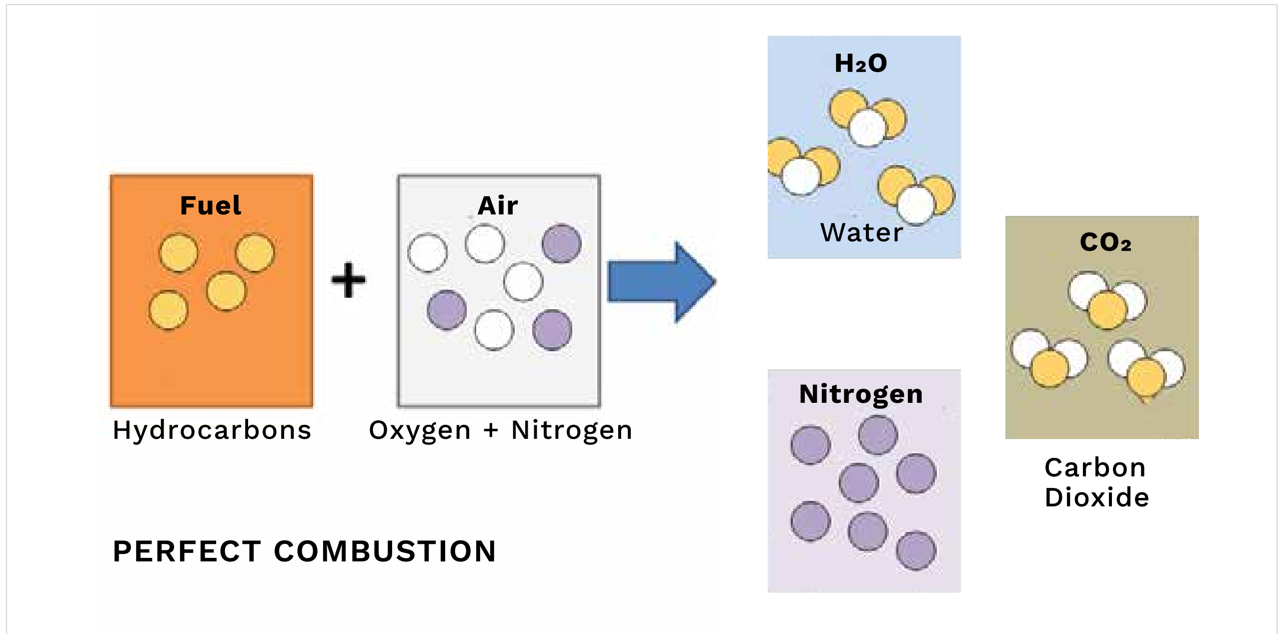


Figure 16: Perfect Combustion

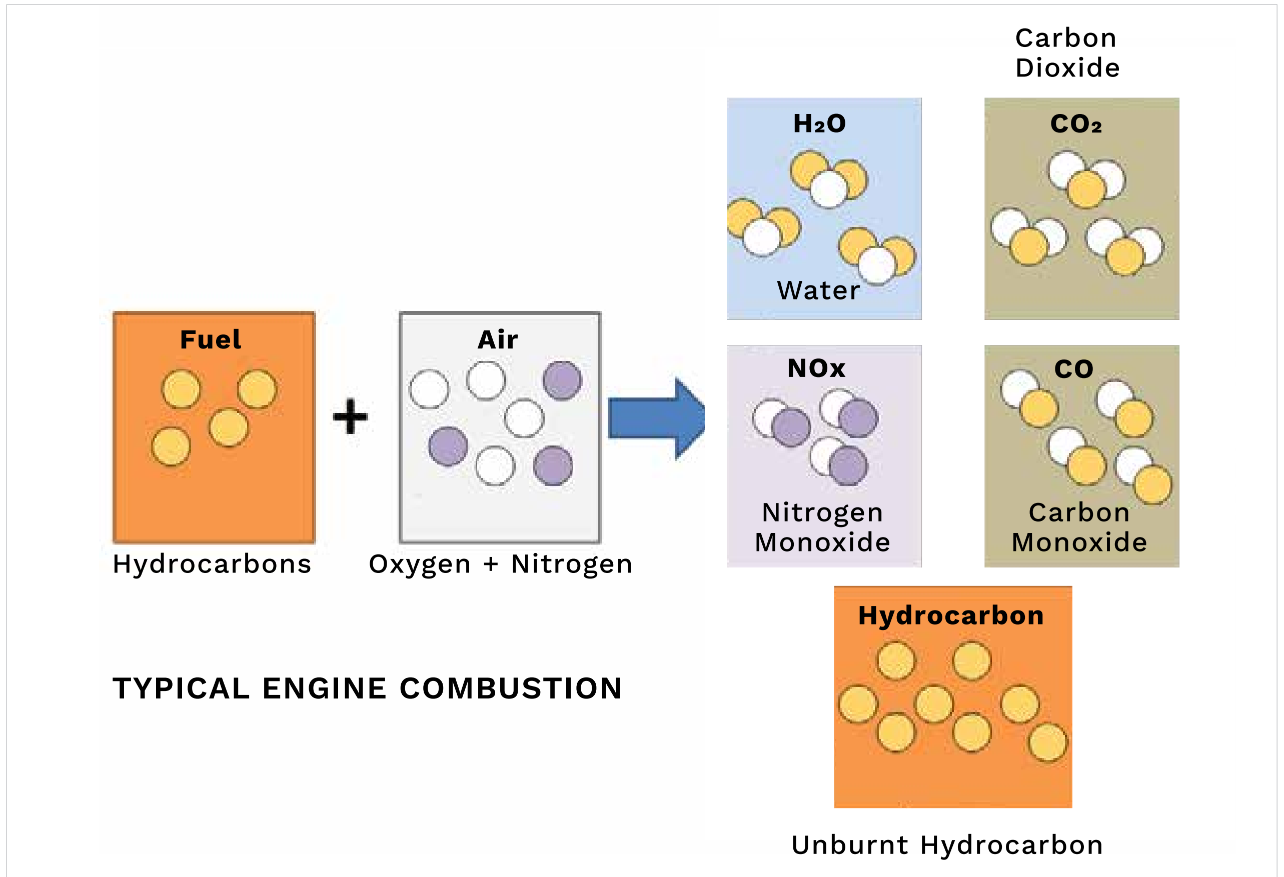


Figure 17: Typical Engine Combustion

Mobile sources pollute the air through combustion. **Combustion** is the process of burning, in the case of motor vehicles and equipment, fuel is burned in an engine to create power. Gasoline and diesel fuels are mixtures of hydrocarbons, which are compounds that contain hydrogen and carbon atoms. In 'perfect' combustion, oxygen in the air would combine with all the hydrogen in the fuel to form water and with all the carbon in the fuel to form carbon dioxide. Nitrogen in the air would remain unaffected. But in reality the combustion process is not 'perfect' and engines emit several types of pollutants as combustion byproducts.

Mobile sources also pollute the air through fuel evaporation. **Evaporation** is the process by which a substance is converted from a liquid into a vapor. 'Evaporative emissions' occur when a liquid fuel evaporates and fuel molecules escape into the atmosphere. A considerable amount of hydrocarbon pollution results from evaporative emissions that occur when gasoline leaks or spills or when gasoline gets hot and evaporates from the fuel tank or engine.

2.4 How To Determine The Amount Of Air Pollutants And From Which Sources?

To determine the amount of air pollutants emitted from a source or sources and the contribution of the sources to the total emissions of a certain pollutant, one deals with emissions estimation also known as **'emission inventory'**. An emission inventory is a current, comprehensive listing, by source, of air pollutant emissions associated with a specific geographic area for a specific time interval.
It can have different geographical scales ranging from global to individual plant level emissions. An inventory can be compiled at the national level or compiled at smaller geographical scales (e.g. county, municipality, facility level) and summed up at the national 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.

A complete emission inventory contains the following information:

- Background information about the need for an inventory
- A tabular summary of emission estimates by source category
- A description of the geographic area covered
- The time interval represented (annual, seasonal, hourly)
- Population, employment and economic data used to estimate and allocate the emissions
- A complete narrative of each source category describing how the data was collected, the sources, and the emission estimation methods and calculations. Also, copies of any questionnaires and the results, and the documentation of assumptions and references should be included. Finally, the sources that are not included in the inventory should be identified.

2.4.1 Emission inventory process

The creation of an emission inventory has six parts: planning, development, quality assurance/quality control procedures, documentation, reporting, and maintenance and update.

2.4.2 Planning activities

Careful and thorough planning of the inventory procedures will greatly facilitate the process and can prevent the need for costly revisions to the inventory during and after review. Planning includes detailing inventory objectives and general procedures and addresses important issues such as: How do I determine which pollutants as inventory, how do I identify sources of concern, and what data do I report? By considering all of the components of developing an inventory up front, the planning process ensures that proper action can be taken.

2.4.3 Inventory development

This is the main part of the inventory development process where the data collection and actual estimating and calculating of emissions take place. Selection of the estimation method and approaches based on the best available data are critical to ensure that the most accurate and representative emissions estimates are included in the inventory.

2.4.4 Quality control/Quality assurance (QC/QA) procedures

A comprehensive QC/QA program is essential to the preparation of a reliable, defensible emissions inventory. Without certain checks along the way, flaws can compound and ruin the entire inventory.

2.4.5 Documentation

Complete and well-organized documentation is necessary to prepare a reliable and technically defensible inventory document. The goal of inventory documentation is to ensure that the final written compilation of the data accurately reflects the inventory effort.

2.4.6 Reporting

The reporting phase in developing an emissions inventory involves the presentation of the data which have been collected, compiled, and analyzed. Proper reporting of the data ensures that the information collected will be used and interpreted correctly.

2.4.7 Maintenance and Update

Compiling an emissions inventory is a continuous process. Maintaining and updating the inventory will ensure its usefulness and accuracy beyond the year it was first developed.

2.5 Methods For Estimating Emissions

There are two main approaches in estimating emissions: the bottom-up approach and the top-down approach. The bottom-up approach estimates emissions from individual sources and sums up all sources to result in local or national emissions (aggregation). The top-down approach on the other hand calculates emissions from national or provincial data disaggregated to local data using factors that affect air emissions. Whether using the top-down or the bottom-up approach, the main methods used in estimating emissions include:

2.5.1 Emission factors

An emission factor is a ratio that relates the emissions of a pollutant to an activity level at a plant that can be easily measured, such as the amount of material processed, or the amount of fuel used. Given an emission factor and a known activity level, a simple multiplication yields an estimate of the emissions. Emission factors are generally developed from measured data for one or more facilities within an industry category, so they represent typical values for an industry, but do not necessarily represent what is occurring at a specific source. Published emission factors are available in numerous sources. Emission factors allow the development of generalized estimates of typical emissions from source categories or individual sources.

The basic emission estimation equation is:

$$E = A \times EF$$

Where: **E** = emission estimate for the proces
A = activity level such as throughput
EF = emission factor assuming no control.

Area source emissions sometimes are not easily estimated by a direct measure of activity. In such a case, an emission factor that is based on a surrogate measure for activity level such as population or employment in an industry can be used.

2.5.2 Material balance[13]

Material balance emissions are determined based on the amount of material that enters a process, the amount that leaves the process, and the amount shipped as part of the product itself. Fuel analysis is an example of a material balance. Emissions are determined based on the application conservation laws. The presence of certain elements in fuels may be used to predict their presence in emission streams5. For example, sulfur dioxide emissions from oil combustion can be calculated based on the concentration of sulfur in the oil. This approach assumes complete conversion of sulfur to SO_2. For every kilogram of sulfur burned, 2 kilograms of SO_2 are emitted.

Material balance is equally applicable to both point and area sources. In particular, it is useful for sources resulting in evaporative losses, such as solvent degreasing and surface coating processes. This method should not be used for processes where material reacts to form secondary products or where material undergoes chemical changes.

Example: Emission estimation of volatile organic carbon (VOC) from degreasing process

Q_{in}	= 14.2 ton of material per day
Q_{out}	= 1.6 ton of waste per day
CVOC	= 0.5% VOC in material
VOC emission	= (14.2 - 1.6) x 0.5% = 0.063 ton per day

The basic emission estimation equation is

$$E_x = (Q_{in} - Q_{out}) \times C_x$$

Example: CO emission estimation from gas-powered turbine

A	= 50,000 MJ per year (total energy input from natural gas)
EFCO	= 0.0473 kg/MJ
CO emission	= 50,000 x 0.0473 = 2.365 kg per day

13 Air Pollution Training Institute (2003), Principles and Practices of Air Pollution Control', United States Environmental Protection Agency

Where: E_x = Total emissions for pollutant x
Q_{in} = Quantity of material entering the process
Q_{out} = Quantity of material leaving the process as waste, recovered, or in product
C_x = Concentration of pollutant x in the material

2.5.3 Source testing

Source testing emission rates are derived from short-term emission measurements taken at a stack or vent. Emission data can then be extrapolated to estimate long-term emissions from the same or similar sources. Continuous emission monitors or CEMs continuously measure and record actual emissions during the time of monitor operation. CEMs data can also be used to estimate emissions for different operating and longer averaging times. Results of source testing conducted by either a state or local agency or by the source itself can be used for estimating air emissions.

Examples of emission estimation using stack sampling and CEMs are provided in excel sheet.

2.5.4 Emission estimation models (usually software)

Emission estimation models are empirically developed process equations used to estimate emissions from certain sources. Some emission estimation models that are currently available are based on measured or empirical values. Emission estimation software is used when a large number of equations and interactions must be manipulated and the effect of many different parameters must be accounted for in order to emissions.

2.5.5 Surveys and questionnaires[14]

Surveys and questionnaires are commonly used to obtain facility-specific data on emissions and their sources. Also, they can be used to collect local or nationwide data for certain source categories, such as wood burning for home heating. The use of this method requires designing and clarifying the scope of the survey which shall be determined during the planning phase of the inventory. This approach would reduce the number of sources contacted and improve the quality of the data collected because the survey questionnaire is tailored to specific types of sources with similar processes.

14 Air Pollution Training Institute (2003), Principles and Practices of Air Pollution Control', United States Environmental Protection Agency

But there is a negative side to using this method because the survey may not target specific sources nor limit the pollutants to be included in the inventory or inventories. This approach will require a more generic design of the survey questionnaire and consequently may result in less detailed and possibly less accurate data.

2.5.6 Engineering judgment/Best approximation

An engineering judgment is made when the specific emission estimation techniques such as stack testing, material balance, or emission factor are not possible. This estimation is usually made by an engineer familiar with the specific process, and is based on whatever knowledge may be available. Engineering judgment or best approximation must be considered as a last resort if none of the methods previously described can be used to generate accurate emission estimates. Engineering judgment may involve the application of speculative or innovative ideas, a poorly documented emission factor, or a crude material balance. In cases where no emission factors are available but adverse risk is low, it may be acceptable to apply factors from a similar source category using engineering judgment.

2.6 Selecting An Emissions Estimation Method[15]

Selecting a method to estimate emissions warrants a case-by-case analysis considering the cost and required accuracy in the specific situation. When selecting an emissions estimation method, several issues related to the trade-offs between cost and accuracy of the resulting estimates should be considered. These issues include:

- Availability of quality data needed for developing emissions estimates
- Practicality of the method for the specific source category
- Intended end use of the inventory (for example, an inventory in support of significant regulatory implications such as residual risk or environmental justice issues may require more accurate and costly emission estimation methods as compared to an inventory intended simply for source characterization)
- Source category priority (for example, if a source category is of relatively high priority, it may require a more accurate emission estimation method)
- Time available to prepare the inventory
- Resources available in terms of staff and funding

Emission factor is the most common used method for estimating emissions at city or country level for reasons of data availability, intended us (policy related purposes), and practicality.

2.7 Types Of Pollutants Inventoried

The types of pollutants inventoried generally include criteria pollutants as indicator of air quality. But they may also include toxic air pollutants and greenhouse gases subject to priority of pollutants which need to be inventoried. Moreover, some source categories may be of greater importance; therefore, the pollutants emitted from these sources would be of greater concern.

2.8 Types Of Sources Inventorised

Criteria pollutants, toxic pollutants, and greenhouse gases are produced by three basic source types: point, area, and mobile sources, and thus these sources are generally inventoried.

2.9 Uses For Emission Inventories

Emission inventories are most often developed in response to regulations and are used for a wide variety of purposes. For example, emission inventory data are used to evaluate the status of existing air quality as related to air quality standards and air pollution problems. They are also used to assess the effectiveness of air pollution policy and to initiate changes as needed.

15 Stockholm Environment Institute. (2008a). Foundation Course on Air Quality Management in Asia: Emissions. Schwela, D., & Haq, G. [Ed]. Stockholm: Stockholm Environment Institute

Where do we get the information?

- By contacting each point source in the inventory area
- Surveys and plant inspections
- Examining permit applications and compliance files
- From statistics and published documents

Specific Uses of Emission Inventories

- Meeting regulatory mandates for specific inventories
- Tracking progress towards ambient air quality standards and emission reductions
- Determining compliance with emission regulations and setting the baseline for policy planning
- Identifying sources and general emission levels, patterns, and trends to develop control strategies and new regulations
- Predicting pollutant concentrations in the ambient air through the use of dispersion modeling
- Providing input for human health risk assessment studies
- Developing residual risk standards
- Serving as the basis for preparing construction and operating permits
- Citing ambient air monitors

2.10 Importance Of A Complete And Accurate Emissions Inventory

A technically defensible emissions inventory serves as the foundation for sound public policy. Formulation of appropriate control strategies requires a reliable base of quality emissions estimates. If the data used to derive control strategies are flawed, the public policy6 resulting from the strategy will also be in error. These errors can be costly as the public is exposed to pollutants, the industry becomes subject to control, and the environment is damaged.

Example: The consequences of an incomplete inventory (Adopted from SEI, 2008)

Houston, Texas has some of the most frequent violations of the US National Ambient Air Quality Standards. Emissions inventories in the late 1990s indicated that to meet the one-hour ozone standard it would be required to reduce nitrogen oxides (NO_x) emissions by 90 percent. However, a 2000 study on the atmospheric chemistry affecting Houston's ozone problem found previously unidentified sources of highly reactive volatile organic compounds (VOCs) and therefore a control strateg 78 for NO_x only would not achieve the desired reductions in ozone levels. The strategy was then revised to require more VOC control and only 79 percent NO_x emission reductions. Subsequent studies showed that the 90 percent NO_x control strategy would have resulted in the loss of 60,000 jobs and a US$ 9 billion smaller regional economy compared to the adopted 79 percent NO_x strategy. Obtaining accurate and complete emissions inventories is therefore extremely important and cost-effective.

3. Regulations, Standards, And Enforcement

3.1 Introduction

Knowing about air pollution, what's causing it, sources, and its effect on health and ecosystem is obviously not enough to achieve clean air. Therefore, action should be taken and it is in this manual that the participants shall learn about different control strategies when it comes to air pollution. Towards the end of this manual the participants should be able to differentiate laws from regulations and standards. A group discussion is included at the end of the manual to enable the participants to discuss points taken from the manual.

3.2 What Are Air Quality And Emission Regulations And Standards For?

3.2.1 History

Air pollution initially was recognized more as a nuisance than as a threat to human health. The earliest sign of pollution may have taken place in Northern Europe when the Industrial Revolution 1 introduced point sources of larger emissions and the smoke was produced by burning poor quality coal for energy production. Some laws, as early as 1300s, were enacted to prevent this air pollution.

As the years passed, air pollution got worse, and yet it was still not widely recognized as a threat to human health. Coal burning continued in small and large sources without required abatement except making the stacks elevated. The London air pollution episode in 1952 was the worst episode which caused an estimated 4,000 deaths in five days. This incidence prompted more stringent laws in England and other countries and marked the beginning of modern history of air quality management.

The delay in recognizing air pollution as a health risk was partly a result of the nature of air pollution. Air pollution is usually not recognizable as is water pollution; therefore, it can be ignored as a health threat until the problem reaches crisis proportions.

3.2.2 Air quality regulations and standards

Since then, many countries have begun efforts to control air pollution with the passage of laws and regulations. The process by which air quality laws and regulations are created is subject to a country's constitutional framework. In general, a law is enforced through a set of institutions, where both the executive and legislative bodies have to approve it. Once approved, the new law is called an act. Laws often do not include all the details. In order to make the laws work on a day-to-day level, the legislative body authorizes certain government agencies to create regulations. Regulations set specific rules about what is legal and what is not. For example, a regulation might state what levels of a pollutant such as sulfur dioxide are safe. It would tell industries how much sulfur dioxide they can legally emit into the air, and what the penalty will be if they emit too much. In some cases, the penalty may be defined in the laws. Laws and/or regulations can also include provisions regarding programs to address air quality problems, enforcement authority, source operating permits, ambient air quality and emissions standards, enforcement mechanism, and other provisions.

3.2.3 Air quality management

Air quality management (AQM) is all activities that are aimed at creating and maintaining clean air to protect human health and provide protection for ecosystems. Management activities can include standard setting, ambient monitoring, developing permitting programs, enforcement activities, and establishment of economic incentives to reduce air pollution. Air quality management, through policy and legislation, prescribes a set of responsibilities and relationships among government agencies at national and local level. Government policy is the foundation for AQM. Without an appropriate policy and adequate legislation, it is difficult to maintain successful AQM program.

3.2.4 Air quality standards

Air quality standards are intended to provide the basis for protecting human health and the environment from the harmful effects of air pollutants. Although they are considered to be protective to human health, it does not mean that it is a green light for pollution to increase until it reaches the allowable limits. Attempts should be made to keep air pollution levels as low as practically achievable. Following are some factors to be considered while setting legally binding standards[16]:

- **Sensitive receptor** – human population such as children, the elderly and disabled persons and people with asthama, vulnerable to air pollution
- **Pollutant behavior** – the reactions the pollutant undergoes, its residence time in the atmosphere and its ability to accumulate or decompose
- **Natural levels** – concentration levels and fluctuations of pollutants that occur naturally or enter the atmosphere from uncontrollable sources such as volcanoes
- **Technical feasibility** – the cost and availability of technology to control or avoid emissions

The authorities of a state decide on the air quality standards. The setting and application of air quality standards is an example of the authorities' right and obligation to define the standards and implement them.

3.2.5 Ambient air quality standards

Ambient air is the air to which the general public has access, as opposed to air within a facility or at a smokestack. An ambient air quality standard for a specific pollutant is a limit beyond which the concentration of the pollutant must not exceed.

The World Health Organization (WHO) sets threshold limits for various air pollutants which are derived from the concepts of lowest-observed-effect level on health and environment.

However, these are not standards as they are. Several countries have adopted the WHO guidelines for laying down standards after considering various factors such as prevailing exposure levels, natural background concentration, meteorological conditions, topography, and socio-economic considerations.

The U.S. Environmental Protection Agency (USEPA) says that the ambient air quality standards consist of two types, i.e. primary and secondary. Primary standards are intended to protect against adverse human health effects. Secondary standards are intended to protect against welfare effects such as decreased visibility and damage to farm crops, vegetation and buildings.

The USEPA regulates ambient air quality standards for six criteria pollutants, which are: carbon monoxide (CO), nitrogen dioxide (NO_2), sulfur dioxide (SO_2), lead (Pb), particulate matter (PM), and ozone (O_3).

Each standard corresponds to a specific averaging time, and some pollutants have standards for more than one averaging time, i.e. short-term and long-term averaging times. The averaging time is the time period over which air pollutant concentrations are averaged for the purpose of determining compliance with the standards. The short-term standards are designed to protect against acute health effects due to short-term exposure, whilst the long-term standards are meant to protect against chronic health effects due to long-term exposure.

16 Clean Air Asia, 2016. "Guidance Framework for Better Air Quality in Asian Cities". Pasig City, Philippines

3.2.6 Source specific emissions standards

In order to achieve the ambient air quality standards, it is necessary to define source specific emissions standards. These include industries, power plants, and motor vehicles. The major air polluting industries such as smelters, cement plants, chemical manufacturing units, iron and steel, petroleum refineries, and pulp and paper mills are covered through such emissions standards.

Emissions from power plants and major industries can be measured during a stack sampling or continuous emission monitoring. In stack sampling, samples are collected using probes inserted into the exhaust stack, and pollutants are collected in or on various media and sent to a laboratory for analysis or analyzed on-site.

Continuous emission monitoring provides a continuous record of emissions and flow rates over an extended and uninterrupted period of time. Various principles are employed to measure the concentration of pollutants in the gas stream; they are usually based on photometric measurements.

Mobile sources have been recognized as one of the most important sources in cities. Many Asian countries have adopted European emission standards for automobiles and introduced increasingly stricter standards with the lag time as European standards are being reduced. European standards have been implemented in Europe in stages, starting with the Euro 1 standard in 1991. At present, the Euro 5 standard is under implementation in the European Union countries. Standards for mobile sources are generally divided into two types: standards for new vehicles and standards for in-use vehicles. The European (Euro) standards for new vehicles are called the type approval standards. Emissions from new vehicle prototypes are tested against these standards by vehicle manufacturers. The Euro standards specify limit values for nitrogen oxides (NOx), hydrocarbons (HC), and carbon monoxide (CO). Vehicle exhaust emissions are measured during a standard test cycle simulated in a laboratory.

In-use vehicle standards are used for existing vehicles in operation. Testing of compliance against these standards is performed as part of vehicle inspections and maintenance programs. In-use standards may also be tested during on-road testing, where vehicles are stopped through random testing. In-use standards generally specify maximum allowable concentration during idling of CO and HC for petrol vehicles and smoke for diesel vehicles.

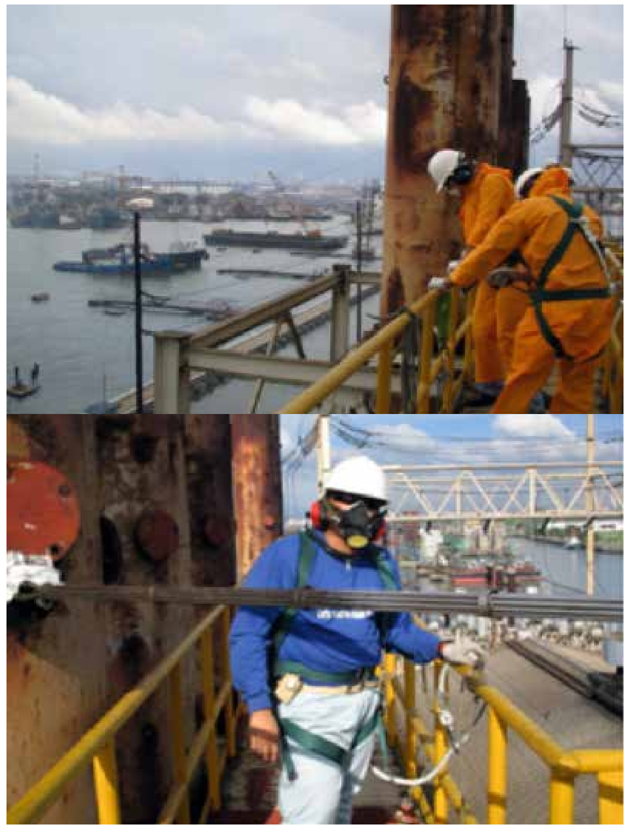


Figure 18: Stack Monitoring

Figure 19: Mobile Emission Laboratory and Equipment

Figure 20: Emission Inspection and On-Road Emission Check

3.3 Local And National Regulations And Standards In Comparison With International Perspectives

Many Asian countries have set air quality regulations and standards to achieve cleaner air. Types of air quality regulations generally range from command-and-control to self-imposition of regulations. Table 2 highlights types of regulation, its applications and examples.

There are five types of regulations highlighted in the table, each having its advantages and disadvantages. These regulations include: Command and control, Economic instruments, Co-regulations and voluntary initiatives, Self-regulation, and Education and information.

Table 2: Types of Environment Regulations, *Source: Stockholm Environment Institute (2008), Governance and Policies,* Foundation Course on Air Quality Management in Asia, *Source: Adapted from SEI, 2008e*

Type	Description	Example	Advantages/Disadvantages
Command and Control	Issues of licenses, setting of standards, checking for compliance with standards, sanctions for non-compliance	➢Air pollution control regulations ➢Government monitoring ➢Emission Standards ➢Enforcement policies	±Widely used technique ±Has public confidence ±Provides degree of certainty ±Time-consuming, expensive, legalistic, rigid, potential for arbitrary decisions ±Focused on end-of-pipe solutions instead of pollution prevention ±Provides no incentive to minimize emissions ±Has been successful in control of large point sources, but less for small and medium sized organizations ±Requires regulators to have comprehensive and accurate knowledge
Economic Instruments	Use of pricing, subsidies, taxes and charges to alter productions and consumption patterns	➢Load-based emissions charges ➢Tradeable emission permits ➢Differential taxes ➢True cost pricing of resources	±Economic pricing policy is most popular ±Market mechanism may determine the most cost-effective control technology ±May lead to more cost-effective pollutant reduction measures ±Must be tailored to conditions of specific market and pollutant(s) being addressed
Co-regulations and Voluntary Initiatives	Adoptions of rules, regulations and guidelines, negotiated within prescribed boundaries. Voluntary adoption of rules and guidelines and environmental management measures between individual organizations and regulators.	➢National registers of pollution emissions inventories ➢Environmental management systems	±Needs capacity of regulators to take action when circumstances require it ±Enables regulators to audit performance companies ±Enables more time and resources to be focused on poor environmental performers and command and control regulation of those organizations requiring this direct form of regulation
Self-Regulation	Self-imposition of rules and guidelines and environmental audits by industry groups	➢Industry codes of practice ➢Self-audit within industry groups ➢Emission reduction targets	±Flexible, responsive to market conditions and efficient ±Requires less government intervention and thereby costs to the taxpayer than command and control ±Standards are often weak ±Monitoring is superficial ±Enforcement is ineffective and not transparent ±Where self-regulation is effective, governments maintain a watching brief ±Where self-regulation is considered to be failing in part or in whole it can be replaced by government regulations
Education and Information	Education and training; Community's right-to-know; Corporate reporting programmes	➢Education, training and information programmes ➢Pollution inventories ➢Corporate sustainability reports	±Raises awareness of air quality issues ±Can be important in changing behaviour and attitudes ±Complaints from public can trigger action by government ±Actions are sometimes possible by establishing communications between local communities, local government and relevant national government agency

3.4 Involvement Of Stakeholders

The stakeholders in air quality management include the national and local governments, private sector and civil society. In most countries, the legislative and executive bodies are the major constituents of the governance structures. The legislatures are responsible for framing the laws which are to be implemented by the concerned agencies of the government. At the national level, the national policies and laws are formulated by the national legislatures and the national government for adoption and implementation through local government. The local governments, through their respective elected bodies and concerned government agencies, are also responsible for formulation of policies and laws for implementation within their jurisdictions.

The private sector and the civil society have an important role in influencing the policies and laws on AQM. The private sector and civil society include the private enterprises such as industries, non-governmental agencies, academic and research institutions, and mass media. In the decision-making process, formal as well as informal methods for involvement of private sector and the civil society are adopted in different countries.

The implementation of strategies and policies to reduce air pollution requires partnerships among government and non-government agencies. Changes to regulations and amendments to other legislation and changes in institutional arrangements may be needed to ensure continued institutional support for implementation.

Box 3.1: Leaded gasoline phase-out in Indonesia

The dangers of lead on human health, particularly children were beginning to be widely talked about in Indonesia in mid 1990. At that time, studies found high lead level in urine of traffic policeman, ambient air, as well as sample of blood in children. The primary source of exposure is leaded gasoline.

Campaign efforts by a small group of people began to appear to raise public attention on this pressing issue and urge the government and Pertamina (national oil company) to issue nationwide leaded gasoline phase-out. Soon afterwards, the government announced that leaded gasoline will be removed in phases starting in 1996. However, as time passes, the plan has not been realized and the schedule for lead phase-out became unclear.

In October 1999, several NGOs formed coalition to pressurize the government for removal of leaded gasoline. The coalition is named Joint Committee for Leaded Gasoline Phase out or Komite Penghapusan Bensin Bertimbel (KPBB) in Indonesian initiated by Wahana Lingkungan Hijau (Lemkohi-Green Consumers Institute) and Indonesian Center for Environmental Law (ICEL). The clean air campaign by Swisscontact, Segar! Jakartaku supported the formation of the coalition.

During the New Order era from 1971 to 1998, advocacy and public campaign activities were virtually not possible because freedom of speech was limited. However, through educational campaign and public dialogue with various stakeholders such as parliament, government, businesses, universities, grassroot groups, mass media, etc., KPBB tirelessly continued mobilizing public support for Indonesia without leaded gasoline.

As a result of pressure from the public who demanded lead-free gasoline, the government finally decided to reschedule the removal of leaded gasoline to 2001, which was later revised again to 2003; and after another delay, finally in 2006 leaded gasoline was completely phased out in Indonesia. This historic moment shows that even the most difficult and interest laded policy changes can be achieved when the people take part in the policy reform process.

3.5 Comparison Of Ambient Air Quality Standards

The majority of the Asian countries have generally adopted the National Ambient Air Quality Standards (NAAQS) for criteria pollutants, except for $PM_{2.5}$ (CAI-Asia, 2010). The standards are either based on the WHO or European Union guideline values, or the USEPA standards. However, the standards are more lenient than the WHO Air Quality Guideline or USEPA NAAQS. The WHO and European Union guideline values and USEPA standards are defined based on comprehensive studies of available ambient air monitoring data, health effects data, and material effects studies. The following tables show ambient air quality standards in selected countries and their comparison with the international perspectives.

Table 3: WHO guidelines and USEPA NAAQS

Pollutant	Averaging Time	WHO Guidelines	USEPA NAAQS[c]
$PM_{2.5}$	Annual mean	10[a]	15
	24-hour mean	25[a]	35
PM_{10}	Annual mean	20[a]	-
	24-hour mean	50[a]	150
Ozone (O_3)	8-hour mean	100[a]	147
	1-hour mean	-	235
Nitrogen (NO_2)	Annual mean	40[a]	100
	1-hour mean	200[a]	-
Sulfur Dioxide (SO_2)	Annual mean	-	78
	24-hour mean	20[a]	365
	10-minute mean	500[a]	-
Lead (Pb)	Annual mean	0.5[b]	-
	3-month mean	-	1.5
Carbon Monoxide (CO)	1-hour mean	30,000[b]	40,000
	8-hour mean	10,000[b]	10,000

Source: CAI-Asia Center, 2010

Legend

$PM_{2.5}$ = particles less than 2.5 micrometers in aerodynamic diameter
PM_{10} = particles of 10 micrometers or less in aerodynamic diameter
WHO = World Health Organization
EPA = Environmental Protection Agency
NAAQS = National Ambient Air Quality Standards

a WHO, 2006. WHO Air Quality Guidelines for particulate matter, ozone, Nitrogen dioxide and Sulfur \ dioxide. Global Update 2005. Summary of Risk Assessment. http://whqlibdoc.who.int/hg/2006/WHO_SDE_PHE_OEH06.02.eng.pdf
b WHO, 2000. "Guidelines for Air Quality." http://whqlibdoc.who.int/hg/2000/WHO_SDE_OEH00.02pp1-104.pdf
c National Ambient Air Quality Standards http://www.epa.gov/air.criteria.html

Table 4: National ambient air quality standards in selected countries (μg/m³)

Countries	$PM_{2.5}$		PM_{10}		SO_2		NO_2		O_3		CO ('000)		Pb
	24-Hr	Annual	24-Hr	Annual	24-Hr	Annual	24-Hr	Annual	1-Hr	8-Hr	1-Hr	8-Hr	Annual
Afghanistan	-	-	-	-	-	-	-	-	-	-	-	-	-
Bangladesh	65	15	150	50	365	80	-	100	235	157	40	10	0.5
Bhutan	-	-	-	-	-	-	-	-	-	-	-	-	-
Cambodia	-	-	-	-	300	100	100	-	200	-	40	20	-
China: Grade I	-	-	50	40	50	20	80	40	160	-	10	-	1
China: Grade II	-	-	150	100	150	60	120	80	200	-	10	-	1
China: Grade III	-	-	250	150	250	100	120	80	200	-	20	-	1
Hong Kong SAR	-	-	180	55	350	80	150	80	240	-	30	10	-
India*	60	40	100	60	80	50	80	40	180	100	4	2	0.5
India **	60	40	100	60	80	20	80	30	180	100	4	2	0.5
Indonesia	-	-	150	-	365	60	150	100	235	-	30	-	1
Lao PDR	-	-	-	-	-	-	-	-	-	-	-	-	-
Malaysia	-	-	150	50	105	-	10	-	200	120	35	10	-
Mongolia	-	-	-	-	30	-	40	-	120	0	-	-	-
Nepal	-	-	120	-	70	50	80	40	-	-	-	10	0.5
Pakistan	-	-	-	-	-	-	-	-	-	-	-	-	-
Philippines	-	-	150	60	180	80	150	-	140	60	35	10	1
Rep of Korea	-	-	100	50	131	52	113	56	196	118	28.6	10.3	0.5
Singapore	35	15	150	-	365	80	-	100	-	147	40	10	-
Sri Lanka	50	25	100	50	80	-	100	-	200	-	30	10	-
Thailand	-	-	120	50	300	100	-	-	200	140	34.2	10.3	-
Viet Nam	-	-	150	50	125	50	-	40	-	120	30	10	0.5

Source: CAI-Asia Center, 2010

Legend

$PM_{2.5}$ = particles less than 2.5 micrometers in aerodynamic diameter
$PM_{2.5}$ = particles with aerodynamic particle diameters of 2.5 or less
PM_{10} = particles with aerodynamic particle diameters of 10 micrometers or less
Pb = lead
PDR = People's Democratic Republic
SAR = Special Administrative Region

China: Grade I = applies to specially protected areas, such as natural conservation areas scenic spots, and historical sites
China: Grade II = applies to residential areas, mixed commercial/residential areas, cultural, industrial, and rural areas
China: Grade III = special industrial areas

India* NAAQS for industrial, residential, rural and other areas
India ** NAAQS for Ecologically sensitive areas (notified by Central Government)

3.6 Examples Of Local And National Regulations

(Taken from Urban Air Pollution in Asian Cities by Schwela, et al., 2006)

3.6.1 Bangkok, Thailand

The 1992 Enhancement and Conservation of National Quality Act outlines the responsibility of the Pollution Control Department (PCD) in determining pollution control areas and establishing ambient air quality and emission standards.

The Act required the establishment of Pollution Control Committee chaired by the Permanent Secretary of the Ministry of Natural Resources and Environment (MONRE). The Committee is responsible for the formulation of plans, policies and pollution preventions measures.

Thailand has adopted ambient air quality standards and emission standards for both stationary and mobile sources. For the mobile source, Euro II equivalent standards for new vehicles were adopted in 2001 and Euro III standard for light-duty vehicles in 2004. Mobile source emission and fuel standards in Thailand are more advanced compared to other developing countries in Asia. For stationary sources, Thailand has introduced desulphurization units in power plants and has set emission standards for key sources.

3.6.2 Colombo, Sri Lanka

The 1980 National Environmental Act No 47 was the first comprehensive legislation which covered environmental management and protection in Sri Lanka. In 1981 the Central Environmental Authority (CEA) was established to implement the provisions of this Act. Since then, the CEA has been instrumental in developing the necessary standards relevant for managing air quality in Colombo and for the rest of the country.

The 1994 National Environmental Regulations set out standards for CO, SO_2, NO_2, O_3, TSP and lead. On January 2003 standards for mobile emissions, fuel quality, and vehicle importation became effective.

In a dialogue on "Development of Fuel Quality and Emission Standards Road Map for Managing Air Quality in Sri Lanka" on the 23rd of May, 2014 the Clean Air Action Plan 2020 was introduced by the draft committee. It is an air quality management program with three types of regulation that depend on the existence of each other. These regulations include the Ambient Air Quality Standards, which is under review; the Source Emission Standards, with standards on stationery sources to be enforced, and standards on mobile sources under review process; and the Fuel Quality Standards that is under review with stricter regulations being added. (Stakeholder Dialogue on Development of Fuel Quality and Emission Standards Road Map for Managing Air Quality in Sri Lanka 2014).

3.6.3 Dhaka, Bangladesh

The 1995 Bangladesh Environmental Conservation Act and the 1997 Environmental Conservation Rules (ECR) are the primary legislation introduced to mitigate air pollution. The ECR outlines the national air quality standards.

However, the legislation failed to include appropriate monitoring methods, frequency, averaging time, compliance requirements and other necessary factors, which are important for the enforcement of the air quality standards. The current motor vehicle emission standards for Bangladesh are outlined in the ECR. The ECR does not specify if the standards are applicable for new or in-use vehicles or both and for which vehicle type.

3.6.4 Hanoi, Vietnam

The 1993 Law on Environmental Protection (LEP) provides the basic framework for Vietnam's environmental policy. The 1993 LEP government decree provided guidance on the implementation of the LEP and outlines the responsibilities of the National Environmental Protection Agency. There is still no specific Act addressing air quality. The 1995 Vietnamese standard TCVN 5937-1995 outlined national ambient air quality standards for six key pollutants. The standards were updated in 2005 and new standards have been proposed but are not yet enforced. Additional standard to control other hazardous air pollutants were also established in 1995. Emission standards for both in-use and newly registered gasoline or diesel vehicles in Vietnam were also issued. As with the other major cities in the country, Hanoi is implementing more stringent standards than the rest of the country. Vietnam has established a large number of national standards to limit industrial emissions. In addition to standards imposed on industries and commercial establishments, a separate regulation is imposed on emissions from medical solid waste.

On the 3rd quarter of year 2015 the Ministry of Natural Resources and Environment (MONRE) has introduced a national draft plan for managing air quality by 2020 entitled the National Action Plan for Green Growth. This plan aims to control sources of emissions, improve ambient air quality, and ensure a healthy environment for the people. (Hanoitimes 2015).

3.6.5 Jakarta, Indonesia

Indonesia had recently replaced Act No. 23 of 1997 on Environmental Management by Act No. 32 of 2009 on Environmental Conservation and Management which confers each individual the obligation to preserve the environment and restricts activities that exceed environmental quality standards. The 1999 Government Regulation No. 41 on Air Pollution Control today remains the main regulation controlling air pollution in Indonesia. The 1999 Regulation lays out the mandate for setting up standards and acceptable practices in air pollution control for the stationary and mobile sources. The national ambient air quality standards are also defined through this Regulation. The City of Jakarta issued the Bylaw No. 2 of 2005 on Air Pollution Control which defines air quality management strategies and action plans including gas fuel usage for public transport and government operational vehicles, vehicle emission test and vehicle maintenance for private vehicles, and non-smoking areas.

A series of implementing regulations to control mobile and stationary emissions were issued by the Government of Indonesia, including new emission standards for in-use vehicles in 2008 replacing the 1995 standards, the new 2009 emission standards for vehicle type approval, and emissions standards for major stationary sources. In Jakarta the standards for in-use vehicles are stricter than those of the national government as notified under the 2001 Governor Decree No. 1041. This legislation was implemented in order to support the development of the inspection and maintenance system for private passenger vehicles in Jakarta.

3.7 Air Quality Institutional Arrangement And Enforcement Of Regulations And Standards

Air pollution laws and regulations are monitored and enforced by national and local agencies. Three key aspects determine the success of a country or city in providing better air quality for its people. They are:

- The existence of laws, regulations, standards and plans which reflect the policy and its implementation details
- Provisions of enough resources to implement them
- Actual implementation of the laws, regulations, standards and plans

The following examples from Singapore, Shenyang and Jakarta show how cities implement air pollution control policy using their available resources.

3.7.1 Singapore: Air Pollution Control Policy
(Source: SEI, 2008e)

In the 1970s rapid industrialization and urbanization led to a deterioration of air quality in Singapore. In order to address poor air quality, the Singapore government implemented comprehensive air pollution control programs targeted at stationary and mobile sources.

For stationary sources, actions included:

- Adopting air quality standards and reviewing those standards regularly,
- Undertaking enforcement measures such as licensing, and inspections and checks on industries to ensure they complied with pollution control requirements, and
- Empowering industries to conduct their own source emission tests.

For mobile sources, actions included:

- Setting vehicle emission standards and tightening standards when necessary
- Enforcing mandatory periodic inspections of in-use vehicles
- Controlling fuel quality, including the use of unleaded petrol, low sulphur diesel, etc.
- Promoting the use of low emission vehicles, for example, compressed natural gas vehicles
- Launching a fuel economy labelling scheme to promote greater awareness of fuel economy among vehicle owners.

Singapore made considerable progress in improving urban air quality and developing a comprehensive AQM system.

3.7.2 Shenyang, China: control of dust from wind and waste burning
(Source: SEI, 2008e)

Dust from soil, roads and waste burning contributed to approximately half of particulate pollution in

Shenyang, especially during spring and autumn. In order to address this problem, a comprehensive action plan was developed with the following as its concrete actions to address the issues:

- Requirements to reduce stockpiles of dust-generating materials
- Replacement of dry sweeping of roads with road-washing
- Re-vegetation of the city and paving of unpaved areas
- Improved management of construction sites to reduce dust emissions
- Enforcement of regulations to prevent burning of vegetation and waste.

3.7.3 Jakarta, Indonesia: Car Free Day

Car Free Day (CFD) was first carried out in 2002 through the initiative of several non-governmental organizations supported by the City Government of Jakarta. The initiative that was initially voluntary was eventually adopted by the City Government of Jakarta and became mandatory activity as per the Bylaw No. 2 of 2005 concerning Air Pollution Control. CFD aims at increasing the public awareness about the importance of controlling air pollution. For one day the "air" is freed from the pollution of motor vehicles. Starting from 2007, only then CFD could be implemented regularly. The main location of CFD is the Sudirman Thamrin area which is the main business district in Jakarta. The road is closed for 8 hours from 6 in the morning to noon every last Sunday of the month for motor vehicles except public transportation including Bus Rapid Transit Transjakarta. However other motor vehicles are allowed to pass through at a certain point due to the difficulty in creating traffic detour.

When CFD was first introduced, a few motor vehicle users refused the idea of CFD. Traffic jam occurred in the slow lane and alternative roads around the CFD area.

Figure 21: Car Free Day in Jakarta

Information was not readily available so vehicle users did not anticipate and made trip plans beforehand. Good coordination with traffic police was also not yet taken place. Sometimes police allowed certain motor vehicles to pass through. However, through time, more and more people are aware that the Sudirman Thamrin area is closed every last Sunday of the month. For that reason, people plan their trips or other activities they want to do in the CFD locations ahead of time.

The public makes use of the CFD location as a place to conduct various activities, such as cycling, playing, walking, sports and other activities that generally could not be done in those places during normal days, and the lack of public open space in the city further motivates the public to make the best use of CFD locations. In the densely- populated area of Suprapto Road, CFD even received an overwhelming response; the citizens feel like their hunger for "space" has been fulfilled.

Figure 22: Car Free Day in Bandung

As a result, they ask for CFD to be implemented not only once in a month but twice in a month and even once in a week! Thus, at their request, in several locations, CFD have been conducted twice in a month starting in 2009. The success of CFD has inspired other cities -Bandung, Palembang, Denpasar, Yogyakarta, Medan and Pekanbaru- to initiate similar activities.

4. Interpretation And Communication Of Air Quality Data

4.1 Introduction

By now the participants should have sufficient knowledge about air pollution, its causes, its sources, its effects to health and ecosystems, and knowledge on laws, regulations, and standards on air quality management. Having laws and regulations is still not enough to create a change in the quality of air therefore the implementation of these laws and regulations should be put to work. In this manual the participant will learn about the importance of monitoring, interpreting and communicating to the public about air quality data.

4.2 Air Quality Monitoring

4.2.1 Importance of air quality monitoring

Air quality monitoring is one key element of air quality management (AQM). It provides data that is required to assess compliance with current ambient air quality guidelines and standards and trends in air pollutant concentration. With these collected data, development and evaluation of existing and proposed control policies and strategies is possible. During the development phase, air quality data is used to determine if an area is attaining or not attaining the air quality standards.

This determination is critical for proper designing of control strategies. After the implementation plans are put into force, ambient air quality monitoring is required to assure that attainment is maintained or progress toward reaching attainment is evaluated.

In addition to the requirement that National Air Quality Standards be achieved and maintained, air quality monitoring is necessary to determine the impact on the existing ambient air quality of an area by a planned new emissions source. The estimated emissions contributed by the new source must be compared to the existing air quality to determine whether the new source would significantly deteriorate the present air quality.

Other purposes of air quality monitoring might be to: generate or validate computer models of air pollution dispersion, which are used in the development of control strategies; inform the public about air quality and raise awareness; enable comparison of air quality data from different areas and countries; collect data for traffic and land-use planning purposes; determine exposure and assess effects of air pollution on health, vegetation or building materials; and develop warning systems for prediction of air pollution episodes.

Through monitoring of air quality data, the overall goal of protecting human health and welfare is achievable.

4.2.2 Design of air quality monitoring

The design of an air quality monitoring network is dependent on the specific monitoring objectives specified in the area. Defining the problems and expected output as clearly as possible will influence the design of the air quality monitoring network and optimize resources used for monitoring. The design involves determining the number and location of air quality stations and using monitoring methods appropriate with respect to objectives, costs and available resources.

The typical approach to designing a national or city-wide air quality monitoring network involves placing monitoring stations or sampling points at carefully selected locations representative for population exposure. These locations are chosen on the basis of required information and known emission/dispersion patterns of the pollutants under study. This scientific approach will produce a cost-effective air quality monitoring program.

Ideally, the system will have to provide on-line data and information transfer with automatic/ online quality control of the collected data. Several monitors, sensors and data collection systems may be applied to make on-line data transfer and control possible. For less developed countries and cities, however, it does not make sense to request on-line data transfer to start with. For example, in order to find out if there is a significant air pollution problem with respect to certain compounds, it would be logical to start monitoring with cost-effective diffusive samplers for gaseous compounds and simple monitors for estimating particulate concentrations.

4.3 Monitoring Methods And Instruments

The components of an air quality monitoring system include the collection or sampling of pollutants, the analysis or measurement of the pollutant concentrations, and the reporting and use of the information collected. Two broad categories of methods for measurements of air pollutants are recognized: manual methods and automated methods.

Manual methods are specific techniques that must be followed when collecting and analyzing an air pollutant sample. Automated methods are primarily used to collect and analyze ambient air on a continuous basis. The methods specify precise procedures that must be followed for any monitoring activity related to the compliance provisions of the applicable regulations.

These procedures regulate sampling, analysis, calibration of instruments, and calculation of emissions. The specific method chosen for an analysis depends on a number of factors, the most important being the chemical characteristics and state of the pollutant. Table 5 shows the different types of instruments used for air quality monitoring.

Table 5: Types of Air Quality Monitoring Instruments

Instrument Type	Description	Typical Averaging Time	Typical Price (US$)
Passive Sampler	➤Manual, in situ ➤Data is analyzed in laboratory ➤Inexpensive, simple to handle; adequate precision and accuracy, collection of air pollutants without use of pumps. ➤Sampling rate cannot be controlled, regarded as complementary to other techniques (continuous, semi-continuous, manual pumped method); only useful for long exposure time	1 day-60 days	10-70 per sampler
Sequential Sampler	➤Manual-semi-automatic, in situ ➤Measure gaseous and particulate compounds ➤Data is available after lab analyses ➤Gas flow rate is measured (use of pumps) ➤Collection of time integrated samples, discrete sampling periods ➤High-volume sampler (to measure particulates) is part of this method	24 hours	1,000-3,000 per sampler
Dust Trak	➤ Automatic, continuous, in situ ➤ Data is available directly, online ➤ Easy to operate, monitor sample different sized airborne particulates	1 hour, 24 hours	6,000 per Dust Trak
Monitors	➤ Automatic, continuous, in situ ➤ Data is available directly online ➤ Air is continuously pumped into analyzer ➤ Pollutants concentrations are stored by the analyzer	1 hour	10,000 per monitor
Remote Monitoring	➤ Automatic, continuous, path integrated (space) ➤ Data is available directly online ➤ Use of laser-based sensor	1 min-1 hour	70,000 per sensor

Source: Adapted from SEI, 2008e

Figure 23 (A): Passive Sampler

Figure 23 (B): Passive Sampler

Figure 24: Different types of Samplers

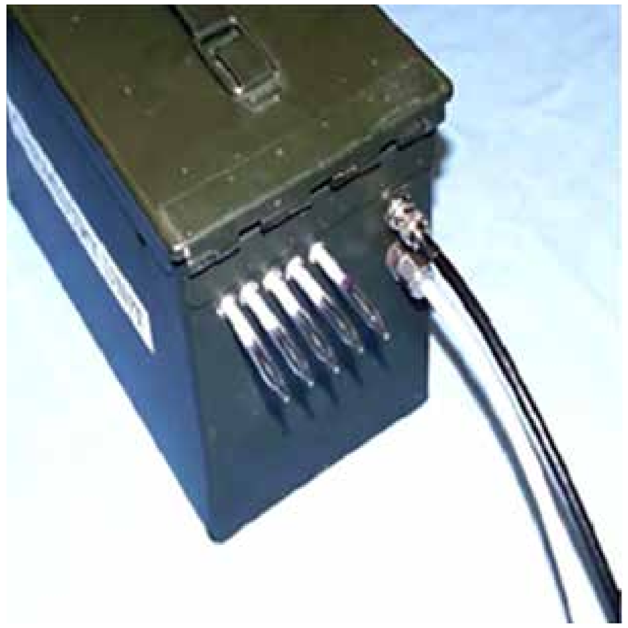


Figure 25 (A) Sequential Sampler (outside view)

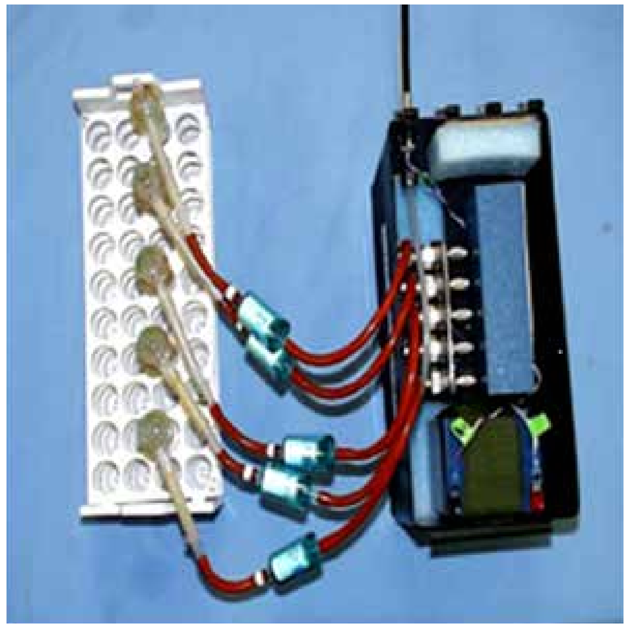


Figure 25 (B) Sequential Sampler (inside view)

Figure 26: Dust Tracker

Figure 27: Air Monitor

Figure 28: Fixed Continuous Monitoring Station

Figure 29: Gas Analyser in continuous monitoring station

Figure 30: Instruments in continuous monitoring station

4.4 What Does Air Quality Tell Us?

Before air quality data can be used to assess the situation in the area, it is important that the data collected meets the following characteristics:

Data validity: The correctness and reasonableness of data is important in assessing the situation in the area. It is supported by documentation as proof that all applicable standard scientific procedures were adhered to and reference to external information to which calculations, processes and conclusions are based.

Traceability: The data should have the documented history of all processes performed on each raw data set, transmitted to the database. It indicates the chain of steps along with the verification and quality assurance procedures implemented and the corresponding results.

Reproducibility: Allows the duplication of results at any data validity level. Reproducibility requires traceability, since all processing steps performed in producing specific results must be duplicated.

The documentation to support the credibility of data collection and initial data quality assurance are the responsibility of the data provider. The provider should ensure that the data collected are true estimates of concentrations. The following questions should be answered:

- Have suitable quality assurance/quality control (QA/QC) procedures been set up for all stages and activities?
- Was a QA/QC plan followed rigorously?
- Has monitoring been carried out at suitable locations?
- Have suitable arrangements for data handling and storage been made and implemented?

4.5 Data Analysis And Interpretation

Data analysis and data interpretation should be conducted to provide quantitative responses with respect to the objectives of the monitoring program. The process should be designed to provide useful information in an appropriate format for the end-user.

- What pollutants are present and at what concentrations?
- Do the concentration or emission levels exceed standards or targets?
- Which are the sources and their individual contributions?
- Which population is exposed and what may be the impacts?
- To what extent would different mitigation measures help in reducing air pollution? It is critical that in the planning of the monitoring program the exact questions to be addressed in the data analysis and interpretation are very clearly identified.

Here are some examples on how air quality data can be interpreted and presented.

Example 1:
Air quality data was collected from high-volume sampler in City of Bandung, Indonesia. Monitoring was carried out at kerbside. The 24-hour standard for PM_{10} is 150 µg/m³. The data shows that in some locations the concentration of PM_{10} exceeds the standard value. At 'Terminal Ledeng' , one busiest bus station, the daily PM_{10} concentration in 2004 and 2005 exceeded the standard value by two-fold. Motor vehicles are the major contributing source of PM_{10} pollution.

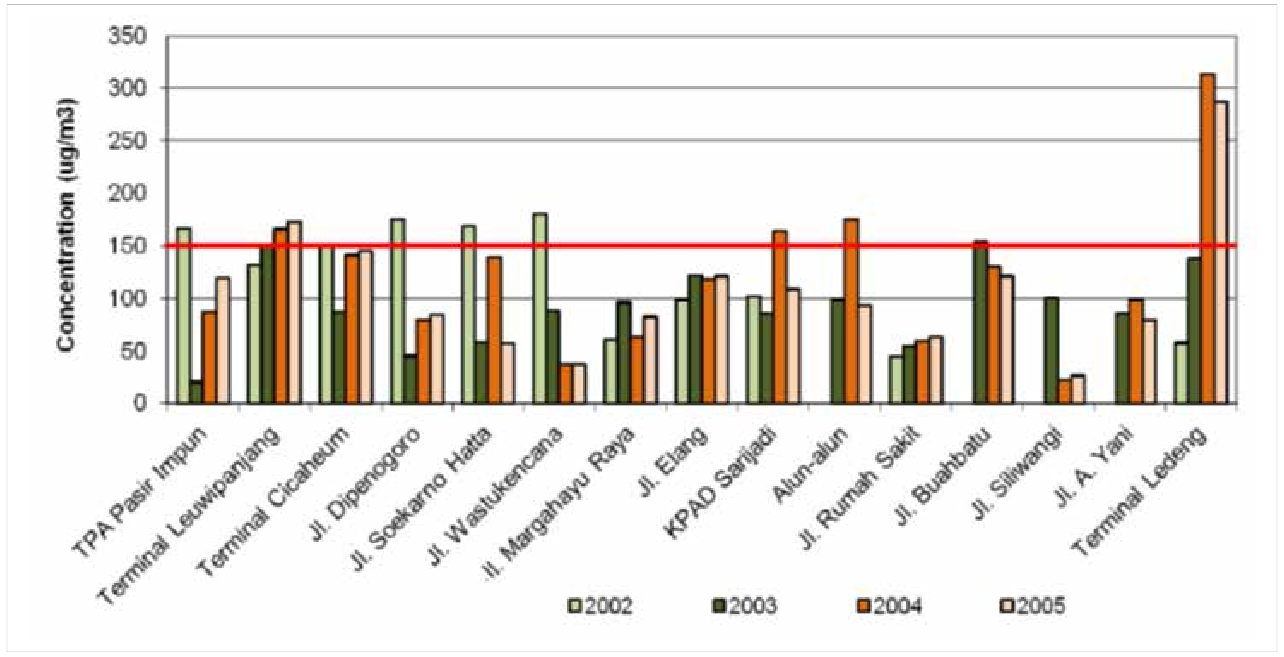


Figure 31: Daily PM_{10} concentrations in Bandung, 2002-2005 (Source: Adapted from the Environment Agency of City of Bandung)

Example 2:
Air quality data was collected from a continuous monitoring station JAF 1 in Jakarta, Indonesia during a period between March and December 2002. The station was located in East Jakarta near an industrial zone. The 24-hour standard for NO_2 is 150 µg/m³. The data shows that the concentration of NO_2 throughout the period of monitoring is within the standard.

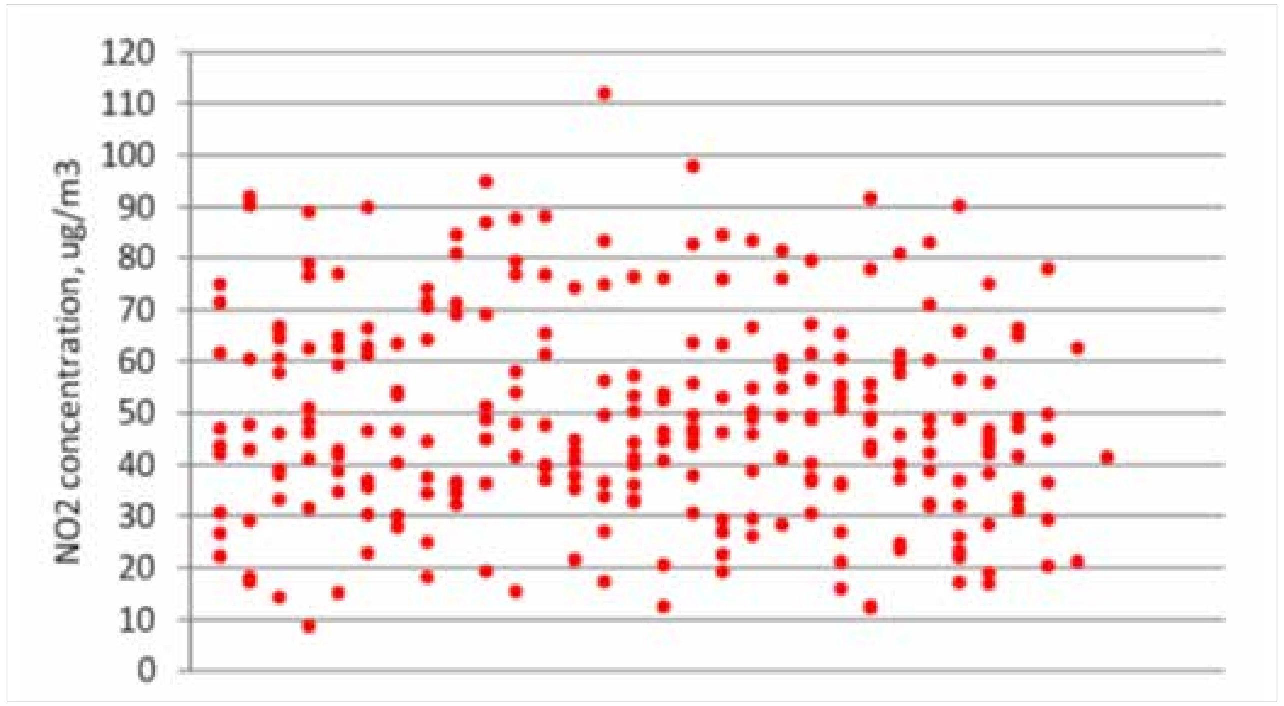


Figure 32: Daily NO_2 concentration in Jakarta, 2002 (source: The Regional Environment Agency of Jakarta)

Example 3:
A continuous air quality monitoring in Jakarta for ozone indicated that during a period of 2001-2003 at four monitoring stations, the annual Regional Ambient Air Quality Standard (RAAQS) for ozone was exceeded. The RAAQS is more stringent than the National Ambient Air Quality Standard (NAAQS).

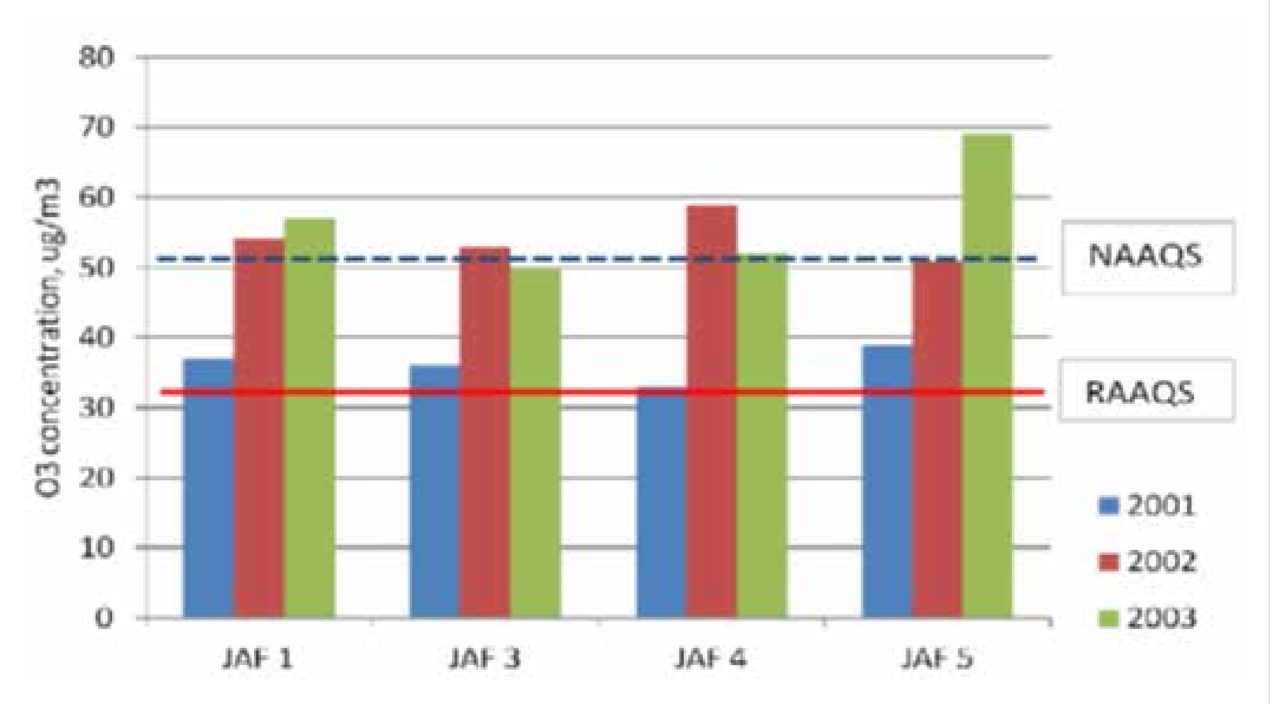


Figure 33: Annual O_3 concentrations in Jakarta, 2001-2003 (Source: The Regional Environment Agency of Jakarta)

4.6 Air Quality Index

The Air Quality Index (AQI) is an index for reporting daily air quality. It tells you how clean or polluted the air is, and what associated health concerns people should be aware of. The AQI focuses on health effects that can occur within a few hours or days after breathing polluted air. The idea of an AQI was first introduced and applied in the U.S. in the form of the Pollutant Standard Index (PSI). The PSI was defined as the sum of the ratios of the concentrations of criteria pollutants and their corresponding standards.

Today most of the air quality monitoring systems in Asia present daily values of AQI. USEPA's AQI is based on five major air pollutants regulated by the Clean Air Act: ground-level O_3, PM, CO, SO_2 and NO_2. For each of these pollutants, USEPA has established national air quality standards to protect against harmful health effects.

The AQI can be considered a yardstick that runs from 0 to 500. The higher the AQI value, the greater the level of air pollution is and the greater the health danger. Many countries and urban areas in Asia have adapted AQI values with the intent to inform the public about the pollution levels.

The purpose of the AQI is to help the user to understand what local air quality means to health. In order to make the AQI as easy to understand as possible, the AQI values have been divided into six categories, often presented to the public as a color code. Each category corresponds to a different level of health concern. For example, when the AQI for a pollutant is between 51 and 100, the health concern is "Moderate" (see Figure 34).

Air Quality Index (AQI) Values	Levels of Health Concern	Colors
When the AQI is in the range:	Air Quality Conditions are:	As symbolized by this color:
0 - 50	Good	Green
51 - 100	Moderate	Yellow
101 - 150	Unhealthy for Sensitive Groups	Orange
151 - 200	Unhealthy	Red
201 - 300	Very Unhealthy	Purple
301 - 500	Hazardous	Maroon

Figure 34: Air Quality Index- USEPA

4.7 Conveying Air Quality Data To The Public

Public communication is the sending and receiving of messages on a large scale that impacts groups of people. For the communication to be considered effective, the messages must be clearly and accurately sent and received with full comprehension. The purpose of public communication differs based on the intention of the message. It is to inform and educate the public about the status of air quality in the city that constitutes the purpose of public communication of air quality data.

For effective public communication, air quality data can be conveyed in different ways. This includes:

- Display (billboard)
- Publications (report, flyer, etc.)
- Mass Media (TV, radio, newspaper, websites, Forum)
- Social Media

The type of air quality information communicated can include past, current and forecast air quality.

Figure 35: Air quality information displayed on website (source: //bplhd.jakarta.go.id)

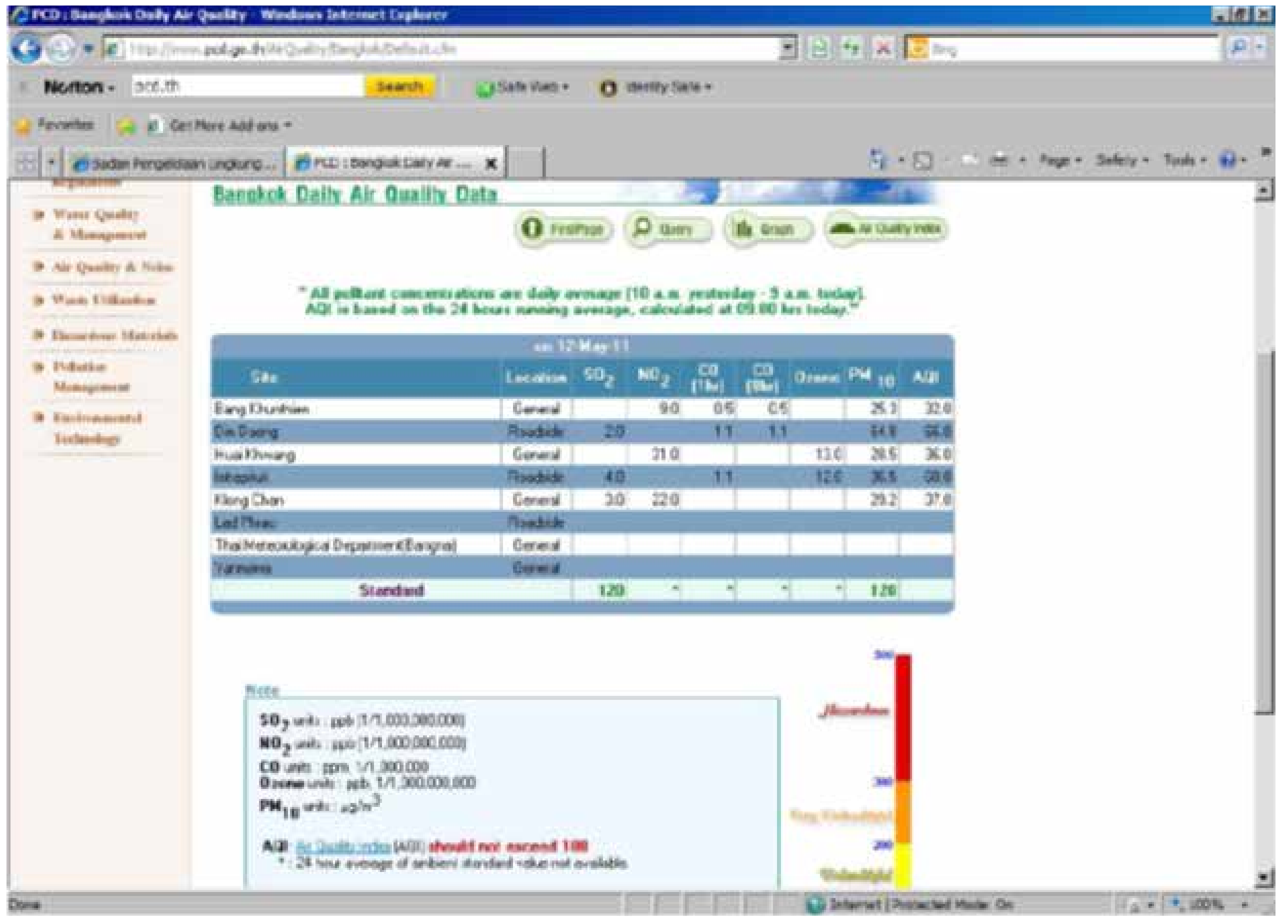


Figure 36: Air quality information displayed on website (source: www.pcd.th/airquality)

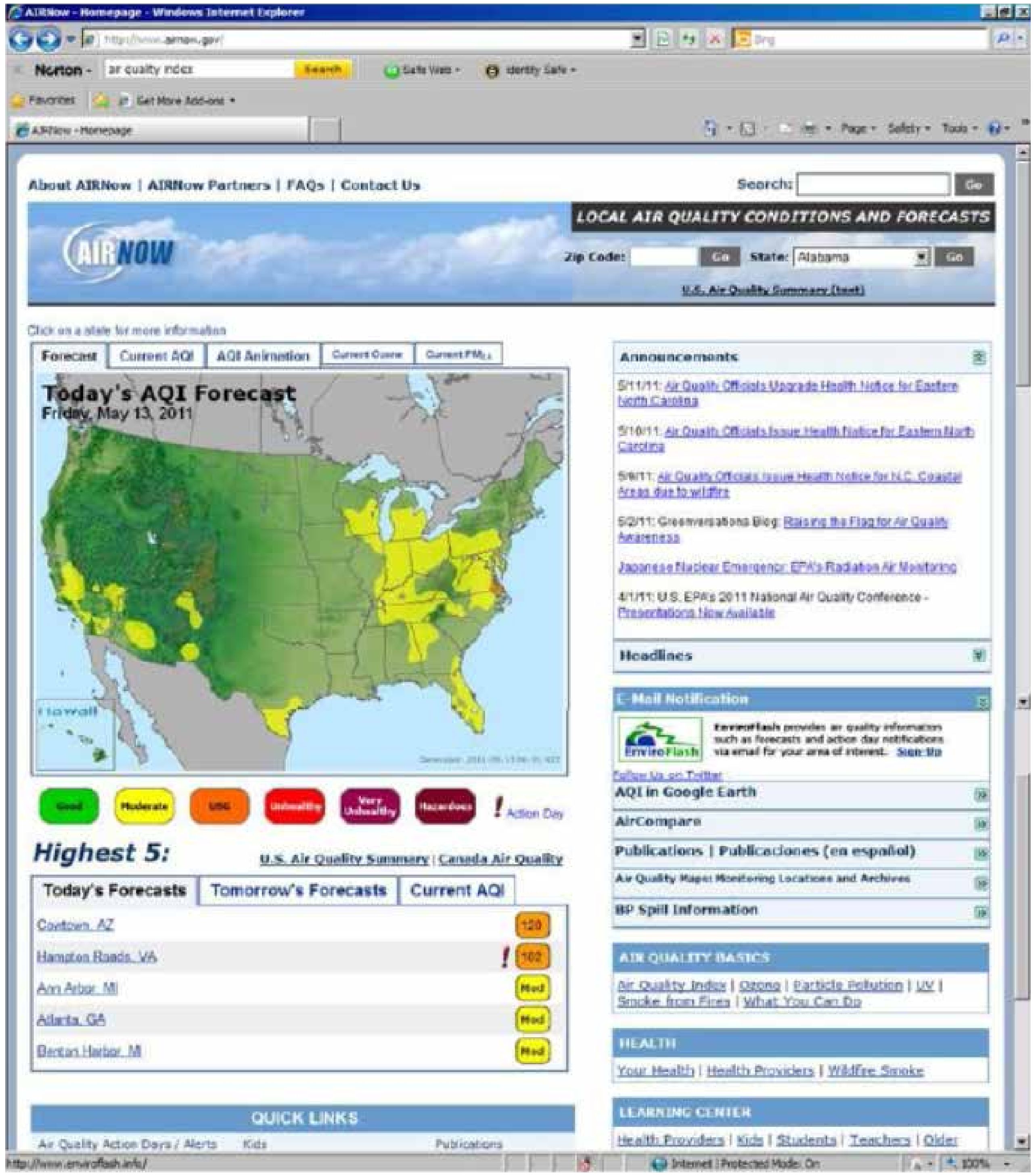


Figure 37: Air quality real time information displayed on website

5. Available Measures For Better Air Quality

5.1 Introduction

Almost done! But not quite yet, now that the participants have been equipped with numerous learnings on how to challenge the change and improvement of air quality, we move on to how the participants can avoid adding more burden to the air quality through the measures to be presented in this manual.

5.2 Available Measures For Improving Air Quality[17]

Several different types of measures for improving air quality can be broadly identified and categorized. These include:

- **Conservation:** reducing the use of resources through energy conservation
- **Efficiency:** carrying out activities in a more efficient manner , thus reducing resource use and emissions of air pollutants
- **Abatement:** the application of a technological approach to reducing emissions
- **Fuel switching:** substituting a lower emission fuel in place of 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 individuals or organizations in such a way as to reduce emissions e.g. travelling by public transportation instead of privately owned vehicles eg : Car, bikes etc.

These measures can be brought about in many different ways including through legislation, economic instruments, voluntary agreements and ongoing technological change. In specific terms, measures to reduce air pollution from mobile and stationary sources i.e. transport sector, industrial and area sources can be summarized as follows.

17 Clean Air Asia, 2016, Guidance Framework for Better Air Quality in Asian Cities

5.3 Measures To Reduce Air Pollution From Transportation

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

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. The following table presents an overview of measures to control emission from transport.

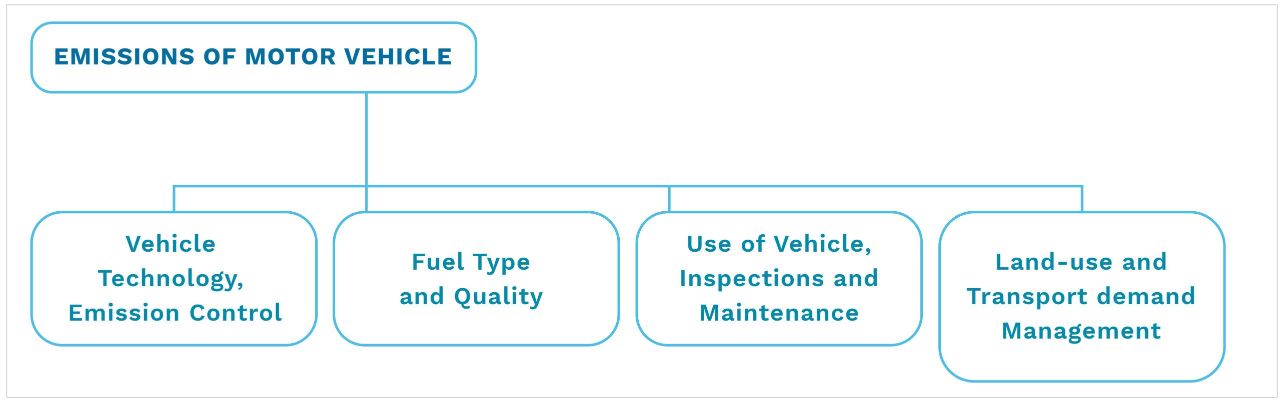


Figure 38: Factors affecting motor vehicle emissions

Table 6: Overview of measures to control emissions from transport

Measure	Regulation	Economic
Emissions standards and technologies	➢ Maximum emission standards for conventional emissions (CO, HC, NO_x, PM) and for toxic air pollutants ➢ Certification and assembly line testing	➢ Tax differentials favouring abatement technology ➢ Vehicle taxes for emission levels ➢ Incentives/ disincentives ➢ Fiscal incentives for scrapping old vehicles
Cleaner Fuels	➢ Fuel quality standards for gasoline (lead, volatility, benzene, aromatics) ➢ Fuel quality standards for diesel fuel (volatility, sulphur, aromatics, cetane number, PAH) ➢ 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 optimal anti-congestion measures, combine with measures controlling vehicle kilometres travelled	➢ Broad based carbon tax on fuels/emission charges ➢ Fuel-economy based vehicle taxes ➢ R&D incentives (direct funding, tax credits, emissions test exemptions)
Inspection and maintenance	➢ Mandatory inspection & maintenance, anti-tampering and enforcement programs ➢ Diesel smoke control programs	
Transport Planning and Traffic Demand Management: To increase load of fleet, reduce travel demand times and reduce travel time	➢ 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" programs ➢ Limitations and restrictions on freight transport	➢ Road base carbon tax on fuel ➢ Emission-related vehicle taxes ➢ Road pricing or distance charges ➢ Parking charges ➢ Fiscal incentives for carpool programs ➢ 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

Source: Adapted from SEI, 2008e

5.4 Measures To Reduce Air Pollution From Industrial Sources

Measures to reduce air pollution from industrial sources include the following key areas:

5.4.1 Land use planning and zoning

- Use of planning regulations to restrict the location of new industries and to establish suitably industrial areas/zones.
- 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.
- Relocation of existing industries away from residential and other sensitive land uses.

5.4.2 Promotion of cleaner production

- Increase the efficiency of industrial processes
- Energy and materials saving,
- Use of improved quality fuels (e.g. with lower sulphur content) or switch to cleaner fuels such as natural gas,
- Adoption of new technologies.

5.4.3 Reduction of emissions in industry

- Setting priorities by focusing on emissions from the major emission sources,
- Requirements for use of cleaner fuels,
- Requiring the use of best available technology for specific industrial processes.
- The industry must provide an action plan for how it will implement best available technology
- Compulsory notification of accidents,
- Licensing of specified polluting processes,
- Compulsory emission standards required: many developing countries have set emission standards for different types of industries. However, enforcement is often weak. An enforcement strategy should be addressed, and
- Setting strict fines for exceeding emission standards.

5.5 Measures To Reduce Air Pollution From Area Sources

Burning of biomass, open burning of waste, forest fires, and dust from soil, roads, and construction sites can be major area sources in a city. Measures to control these emissions may include:

- Enforcement of bans on burning of materials or waste,
- Promotion of alternatives to burning,
- Better waste management,
- Paving roads, re-vegetation programs in dust control areas and use of street sweeping equipment.

5.6 Co-benefits Of Air Pollution Control And Climate Change Mitigation

Measures to control air pollution tend to be immediate, more certain and occur at the place where the control measure is taken (at local or regional scale). In contrast, the impact of control measures on climate change is long-term and global. Looking at air quality and climate change from an integrated perspective and addressing these issues simultaneously offers potential for large cost reductions in health and risks to ecosystems.

Controlling air pollution and green house gases (GHGs) in an integrated way will be more effective than targeting each one individually, particularly for developing countries in Asia where economic and social development is a higher priority rather than climate change mitigation. Co-benefits also mean joint strategies that maximize synergies.

The following table presents measures which are likely to lead both to reductions in emissions of both air pollutants and GHGs.

Measure	Effect
Switching from coal to natural gas for power generation	Reduces CO_2 emissions for each kilowatt generated. Emissions of SO_2 and No_x are also reduced.
Efficiency improvements in domestic appliances and industrial processes	Reduces emissions of both types of pollutant, but efficiency measures sometimes result in increased demand, which must be avoided.
Energy conservation (use less energy)	Reduces emissions of both types of pollutant.
Use of new technologies in road transport e.g. • Hybrid vehicles • Hydrogen from natural gas or from renewable energy sources • Lean burn petrol vehicles fitted with nitrogen oxide traps	Reduces CO_2 emissions for each kilometer travelled and also emissions of NO_x and particulate matter. It is essential that the whole fuel/vehicle cycle is analysed (e.g. the emissions associated with hydrogen generation)
Demand management/behavioural change: improved public transport coupled with disincentives for private car usage.	Reduces emissions of both types of pollutant.

Figure 39: Examples of Measures to Reduce Emissions of Air Pollutants and GHGs Source: www.defra.gov.uk

5.7 Application Of Measures For Improving Air Quality[18]

Based on the information of the amount of emissions and source category contribution and the available measures, identify measures that are important and applicable in your city. The following case studies illustrate some measures that are applicable and implementable in a city.

Case study 1: City of Calcutta, India
Source: ADB & CAI-Asia Center, 2006f.

It is estimated by the National Environmental Engineering Research Institute (NEERI) that 60 percent of Calcutta's residents suffer from some kind of respiratory disease due to air pollution. The burning of coal as an industrial and domestic fuel accounts for a significant proportion of pollutant emissions, especially Suspended Particulate Matter (SPM). SPM from coal combustion is clearly a major problem throughout Calcutta and should be the main focus of immediate control efforts. Surprisingly, SO_2 concentrations are relatively low (within WHO guidelines) which is due to the low sulphur content (0.3 percent) of the local coal.

It would appear from the data that industrial emissions have, to a large extent, stabilized and in some cases declined. It is not clear what the reasons for these changes are, but it is likely that planning measures restricting industrial development have played an important role. Changes in domestic and commercial fuel use, principally a reduction in coal use, and improvements in burning efficiency will have also helped to reduce emissions.

Carbon monoxide and NO_x, emissions from motor vehicles are of increasing concern and probably present the greatest long-term threat to Calcutta's air quality. Calcutta's motor vehicle population doubles every six years, a trend which is likely to continue. With this rate of growth, it is unlikely that even the introduction of the most stringent control measures would reduce overall emissions and ambient concentrations from this source.

18 Asian Development Bank and the Clean Air Initiative for Asian Cities (2006), Country Synthesis Report, India and Malaysia, Manila: Asian Development Bank.

Case study 2: Klang Valley, Malaysia
Source: ADB & CAI-Asia Center, 2006e.

Malaysia is one of the few countries in Asia to have started early in addressing emissions from mobile sources. As such, it is also one of the countries that have a fairly advanced system in managing emissions from mobile sources. In 1977, the Government enacted the Motor Vehicle (Control of Smoke and Gas Emissions) Rules as part of the Road Traffic Ordinance of 1958. This enabled the control of excessive black smoke emitted from diesel vehicles. Regulations have since been in place for both petrol and diesel vehicles under Acts that came into force in 1996.

Though the government has actively pursued stricter vehicle emissions standards, the move toward the use of higher quality fuels has not been similarly aggressive. The current fuel quality for diesel and gasoline are still at Euro 1 levels. Current government plans to move to higher-quality fuels both for gasoline and diesel in two stages are underway. The last stage is equivalent to fuel required for Euro 4 emissions standards.

Malaysia has one of the advanced inspections and maintenance systems in place among Asian countries. Its inspection and maintenance system, which has been outsourced to a private entity, is still regularly monitored by the authorities. It started imposing roadside inspections and surprise checks of excessive black smoke emission in 1 September 1996. The Area Watch and Sanction Inspection (AWASI) Program was first introduced in Kuala Lumpur so that enforcement could be "seen and heard".

6. Air Quality Monitoring In India

6.1 Air Pollution

Air is the essential resource for sustenance of life on the earth.The very existence of life on the earth is due to the fact that there exists an atmosphere. All types of vegetation and creatures including human beings thrive due to the atmosphere in one form or another. For example, human beings need continuous supply of air almost at the rate of 10-20 cubic meters per day. It can easily be conceived that air not suitable for breathing can make people sick.

The atmosphere, appears just the same on a daily basis. In fact, the atmosphere represents a dynamic system, with its gaseous constituents continuously being exchanged with the oceans and biological and micro-biological cycles. When these natural cycles of exchanges of gases are disturbed by means of natural or man-made interventions, it becomes a matter of concern. Unfortunately, our very presence, to some extent, disturbs the atmospheric systems of gases. The valid question then arises is, if life has to exist on the earth how far can we intervene with the above -stated natural processes.

A simple answer to the question above is that as long as there are no known harmful impacts (short and long-term) of our activities to our living and to the atmosphere, we may intervene with the natural processes. To further elucidate on this, we should, therefore limit our discharges of gases, liquids and particulate matter (referred to as air pollutants) to the atmosphere only to an extent which would have no or minimal impacts on our living, and this is the basic philosophy of the air pollution prevention and control. A logical definition of air pollution then becomes "Presence of any substance in the atmosphere in such a concentration that may or may tend to be injurious to human health, other living creatures, vegetation, buildings and materials or to the atmosphere itself, is referred to as air pollution".

6.2 Air Pollution System

Air pollution problem can be depicted as a system consisting of three basic components (Figure 40): (i) emission sources (ii) atmosphere and (iii) receptors

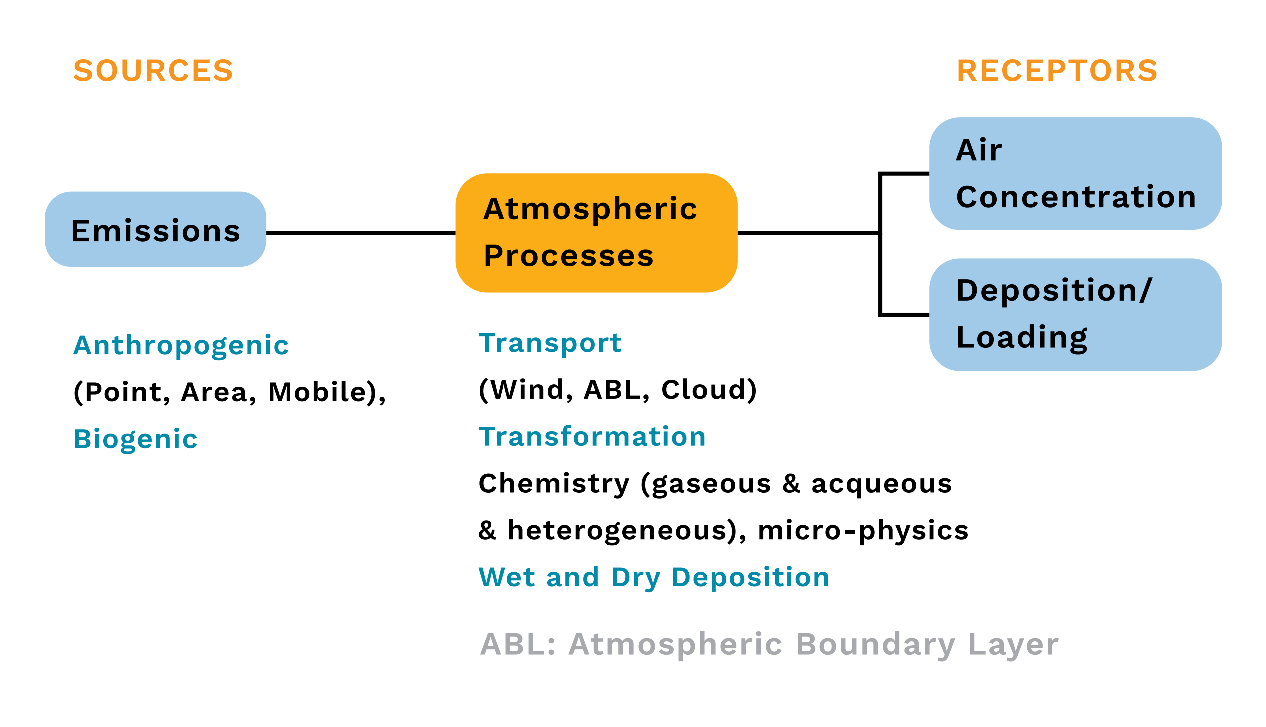


Figure 40 Three basic components of air pollution system

ABL: Atmospheric boundary layer

The air pollution problem begins with emission sources, which can be anthropogenic or natural. Anthropogenic sources include industrial establishments, household cooking and automobiles. Natural sources of air pollution include volcanic eruption, forest fires, desert storms and biogenic emissions. Anthropogenic sources are generally predominant over natural sources and by far the most important to air pollution, since these sources occur in close vicinity to where we live. The important aspect of these sources is their strengths in terms of emission quantities and height of release.

Atmospheric processes are responsible for transportation, mixing, physical and chemical transformation of pollutants. The wind speed and direction decide how quickly the pollutants will be dispersed and what will be the direction of impact. The vertical temperature profile of the atmosphere decides about the vertical mixing and turbulence in the atmosphere.

The third component are the receptors who receive the harmful impacts of air pollution. Receptors who are living creatures can have life threatening short term and long term impacts, whereas there could also be intangible effects like economic losses.

The ultimate aim of the study of this system is to provide an answer to the question: What is the optimum way to prevent/minimize impact of air pollution on the receptor. This can be accomplished by air quality measurements and modelling. In this manual the focus is on air quality monitoring, which represents, sampling, analysis and data interpretation. In simple terms, air quality modelling is a systematic approach that attempts to link the source emission strength (i.e. emission rate) through atmospheric processes to assess extent of impact on the receptors in terms of pollutant concentrations. Once such linkages are established between emission rate and impact (which is not easy) the required reductions in emissions at sources can be planned in a cost-effective way to attain safe air quality levels for the receptors.

Air pollutants are also classified as primary or secondary based on their characteristics at the time of emissions and physical/chemical changes they undergo while in the atmosphere largely because of atmospheric transformation mostly due to energy from the sun's radiation and many catalytic processes in the atmosphere (Table 7 and Figure 2). Some pollutants can fall in both the categories e.g. NO_2, particulate matter (PM), volatile organic compounds (VOCs).

Table 7: Primary and secondary air pollutants

Primary Pollutants	Secondary Pollutants
Emitted into atmosphere directly from the identifiable sources	Undergo chemical changes in the atmosphere as a result of reactions among two or more pollutants and/or atmospheric constituents
Found in the atmosphere in the same chemical from as at the time of emission from the sources. Example: SO_2, NO, CO, PM (particulate matter), VOCs, metals	Examples: NO_2, H_2SO_4, O_3, particulate sulfates, nitrates, PAHs (poly aromatic hydrocarbons), organic aerosols, HNO_3

Units of Measurements

The common units for expressing pollutant concentration in air are: percent (%), ppm (parts per million; vol/vol), ppb, (parts per billion, vol/vol), ppt (parts per trillion, vol/vol), μg/m³, μg/1000m³, ng/m³ etc. These units are commonly used in air pollution context)

Common units for air pollutant concentration

Unit	Commonly used for	Relationship with other units
Percent (%)	CO_2, water vapor	1 ppm = 10-4 percent
ppb	SO_2, NO, NO_2, O_3	1 ppm = 103 ppb
ppt	Dioxins, PCBs	1 ppm = 106 ppt
μg/m³ (1μg = 0.000001 g)	SO_2, NO, NO_2, O_3, particulate matter	1 ppm = 40.87 MW* μg/m³ (for gases only) at 1 atm pressure, 25 ºC
ng/m³	PAHs, heavy metals	1 μg/m³ = 1000 ng/m³
μg/1000m³	PAHs, heavy metals	1 ng/m³ = 1 μg/1000m³

* Molecular Weight; when pressure and temperature is not defined with m³; this msut be taken as 1 atm pressure and 25 ºC

Example: An air quality station has reported the annual concentration of benzene (C_6H_6) as 2.0 ppb. The air quality standard of benzene is 5.0 μg/m³. Is the air quality standard of benzene exceeding at the sampling site.

Solution: To be able to say if the standard is exceeding, the concentration unit's ppb must be converted to μg/m³. From the above Table, it can be seen that 2.0 ppb of C_6H_6 is equal to 0.002 ppm. For C_6H_6, the moelcular weight is 78. The ppm to μg/m³ relation for C_6H_6 would be:

$$1 \text{ ppm of } C_6H_6 = 40.87 \times 78 \text{ (i.e. MW of } C_6H_6) \ \mu g/m^3 = 3187.86 \ \mu g/m^3$$

Thus, 2.0 ppb of C_6H_6 is, 0.0020 × 3187.86 μg/m³ = 6.375 μg/m³.
It can be concluded that the air quality standard of C_6H_6 is exceeded at the air quality station.

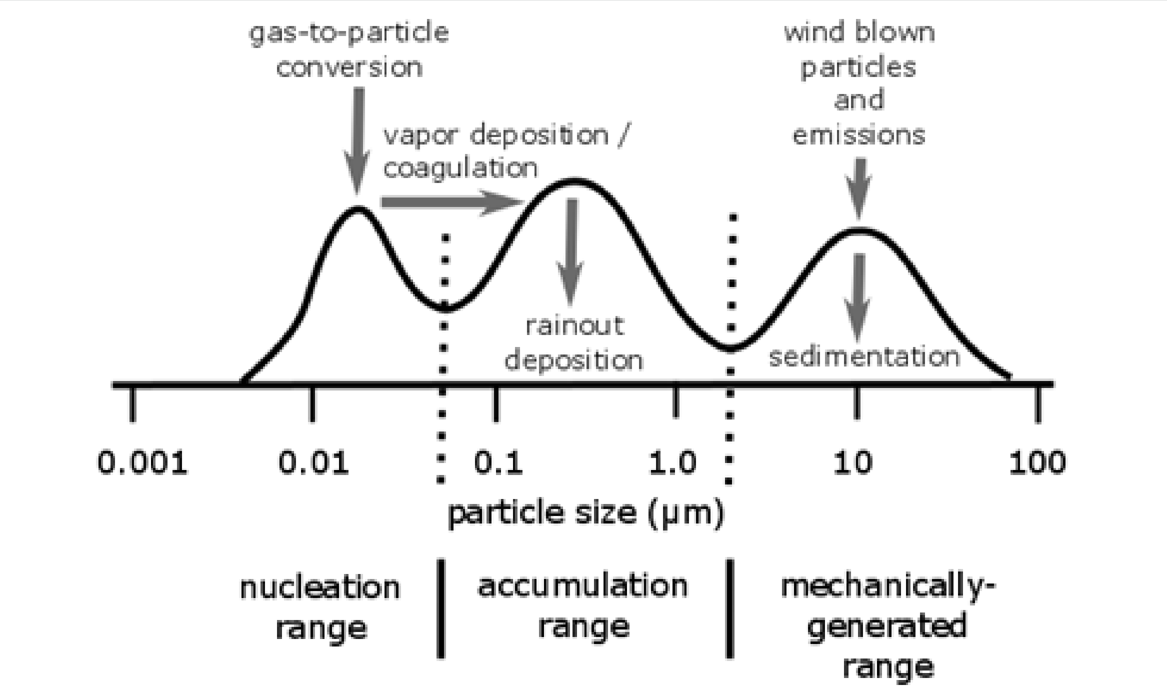
Size-based Classification of PM and Composition

There are typically three particles size ranges that are considered in atmosphere. These ranges represent the typical sources of particulate. These ranges are:

- $PM_{2.5}$: particles smaller than or equal to 2.5 μm in diameter formed through nucleation, condensation and accumulation from combustion processes, hot vapours, and inorganic gases;

- PM_{10}: particles smaller than or equal to 10 μm in diameter and includes $PM_{2.5}$ but also covers larger particles generated from crushing and grinding operations, road and soil dust etc.; and

- Suspended Particles SPM: all particles smaller than 50 μm in diameter generated from crushing operations, abrasive action at surfaces, road and soil dust and dust from river-bed. It may be noted that $PM_{2.5}$ and PM_{10} are subset of SPM.



Typical aerosol size distributions ((Brune, 2019)

The regulatory framework in India

The 1981 Air Act (prevention and control of pollution), 1981 gave responsibility of air pollution control and restauration of air quality to the Central Pollution Control Board (CPCB) and State Pollution Control Board (SPCB). The function of CPCB and SPCB are as follows:

Functions of CPCB
The main functions of CPCB are to:
- Advise the Central Government on any matter concerning the improvement of the quality of air and the prevention, control or abatement of air pollution;
- Plan and cause to be executed a nation-wide programme for the prevention, control or abatement of air pollution;
- Co-ordinate the activities of the State and resolve dispute among them;
- Provide technical assistance and guidance to the State Boards, carry out and sponsor investigations and research relating to problems of air pollution and prevention, control or abatement of air pollution; and
- Collect, compile and publish technical and statistical data relating to air pollution and the measures devised for its effective prevention, control or abatement and prepare manuals, codes or guides relating to prevention, control or abatement of air pollution;

Functions SPCBs
- To plan a comprehensive programme for the prevention, control or abatement of air pollution and to secure the execution thereof;
- To advise the State Government on any matter concerning the prevention, control or abatement of air pollution;
- To collaborate with the Central Board in organising the training of persons engaged or to be engaged in programmes relating to prevention, control or abatement of air pollution and to organise mass-education programme relating thereto;
- To inspect, at all reasonable times, any control equipment, industrial plant or manufacturing process and to give, by order, such directions to such persons as it may consider necessary to take steps for the prevention, control or abatement of air pollution;
- To inspect air pollution control areas at such intervals as it may think necessary, assess the quality of air therein and take steps for the prevention, control or abatement of air pollution in such areas;
- To lay down, in consultation with the Central Board and having regard to the standards for the quality of air laid down by the Central Board, standards for emission of air pollutants into the atmosphere from industrial plants and automobiles or for the discharge of any air pollutant into the atmosphere from any other source.

The Act has the provisions that no person shall, without the previous consent of the State Board, establish or operate any industrial plant in an air pollution control area.

Every person to whom consent has been granted by the State Board under sub-section (4), shall comply with the following conditions, namely-
- The control equipment of such specifications as the State Board may approve in this behalf shall be installed and operated in the premises where the industry is carried on or proposed to be carried on;
- The existing control equipment, if any, shall be altered or replaced in accordance with the directions of the State Board;
- The control equipment referred to in clause (i) or clause (ii) shall be kept at all times in good running condition;
- Chimney, wherever necessary, of such specifications as the State Board may approve in this behalf shall be erected or re-erected in such premises; .and
- Such other conditions as the State Board, may specify in this behalf,
- The conditions referred to in clauses (i), (ii) and (iv) shall be complied with within such period as the State Board may specify in this behalf.

An umbrella act which covers all components of environment THE ENVIRONMENT (PROTECTION) ACT (referred to as EP Act), 1986 is considered more powerful than other acts (e.g. Air Act, 1981). The Section 3 states that the Central Government, shall have the power to take all such measures as it deems necessary or expedient for the purpose of protecting and improving the quality of the environment and preventing controlling and abating environmental pollution.

The Section 5 states that notwithstanding anything contained in any other law but subject to the provisions of this Act, the Central Government may , in the exercise of its powers and performance of its functions under this Act, issue directions in writing to any person, officer or any authority and such person, officer or authority shall be bound to comply with such directions.

Recently that National Clean Air Program (NCAP) has been launched (Ref…). The NCAP signifies that no additional power or amendments in rules/acts are required; the SPCB/CPCB can achieve the desired air quality standards in various parts of the country.

6.3 Design An Ambient Air Monitoring Network[19]

Air quality monitoring program will depend upon the monitoring objectives, the measuring strategy and the pollutants to be assessed. For the relevant air quality parameters or selected indicators, the concentration of an air pollutant and associated averaging time needs to be specified. Some review of information and a screening study would have to estimate the:

- magnitude and variation of pollutant concentrations in space and time;
- availability of supplementary information, such as topographical data, population density and spatial distribution, background concentrations, air quality standards or guidelines, sources, emission estimates, wind speed and direction distribution, dispersion modelling capacity and others;
- required accuracy of the estimated concentrations.

The estimates will give some information on the expected air pollution levels, high impacted areas and general air pollution background levels. Once the objective of air sampling is well-defined and results of the screening study are available, an operational sequence has to be followed. In general, there are ten individual items that need to be addressed in designing an ambient air-monitoring network.[20]

- **Set objectives -** included in this item is quality of data needed, what air pollutants should be measured, sampling times and seasons of the year sampling will be performed.
- Choosing the parameters to be measured, in addition to specific pollutants meteorological parameters (i.e., speed, wind direction, temperature and mixing depth) and topographical features may need to be included.
- **Selecting sampling sites -** number and placement based on money and manpower constraints and confidence in the desired results.
- Scheduling sampling and duration - long term or short term.
- **Selecting air sampling methods -** continuous, integrated, grab sampling, intermittent sequential sampling or a combination of these.
- **Equipment selection -** identification of suitable instruments, calibration instruments and shelter design and fabrication.
- **Setting calibration procedures -** preparation of gas mixtures of known air pollutant concentrations along with instrument flow calibrations.
- **Choosing data recording methods -** several methods of recording are available (i.e., strip chart, analog or digital electronic data loggers).
- **Data analysis -** useful types of analysis include spatial distribution of pollutants, concentration frequency distribution, averaging time analysis and regression analysis.
- **Reporting results -** presented results can be in the form of graphs, histograms, pollution roses and isopleth maps.

Summary of CPCB Producers and Protocols of Ambient Air Quality Monitoring

The CPCB has published several documents that describe air quality monitoring, largely for regulatory purposes. The relevant publications in the context of air quality monitoring and summary, protocols, and guidelines described in the CPCB are presented.

CPCB Documents

- Guidelines for manual sampling and analyses (along with sample flow chart and data sheets. CPCB, 2013- National Ambient Air Quality Series:NAAQMS/36/2012-13. Vol - I;
- Guidelines for continuous sampling and real time analyses (CPCB, 2013- National Ambient Air Quality Series: NAAQMS/37/2012-13 Volume-II

19 Haq, Gary & Schwela, Dietrich. (2008). Air Quality Monitoring. 10.13140/RG.2.1.1816.8166.
20 Central Pollution Control Board (2013), Guidelines for Ambient Air Quality Monitoring, Ministry of Environment, Forest and Climate Changes

These documents have described that in national ambient air quality monitoring programme (NAAMP), the air quality monitoring is of two types, manual and through automatic analysers. Monitoring of the some of the pollutants could be manual as well as through automatic analysers (e.g., SO_2, NO_2, PM_{10}, $PM_{2.5}$, CO, NH_3, O_3, C_6H_6) but for all metals and benzo(a) pyrene (BaP), the monitoring has to be manual on filter paper. However, CO can be monitored only through automatic analyser. A summary sheet developed by CPCB for air quality monitoring under NAAMP, site and parameter section and methods to be employed is presented below.

Figure 41: National Ambient Air Quality Monitoring System

NATIONAL AMBIENT AIR QUALITY MONITORING PROGRAM

NATIONAL AMBIENT AIR QUALITY STANDARD PARAMETERS AND METHODS

MANUAL	AUTOMATIC
SO_2, NO_2, PM10, PM2.5, O_3, NH_3, Benzene, B(a)P, Ni, As, Pb	SO_2, NO_2, PM10, PM_2, O_3, CO, NH_3, Benzene

PARAMETERS

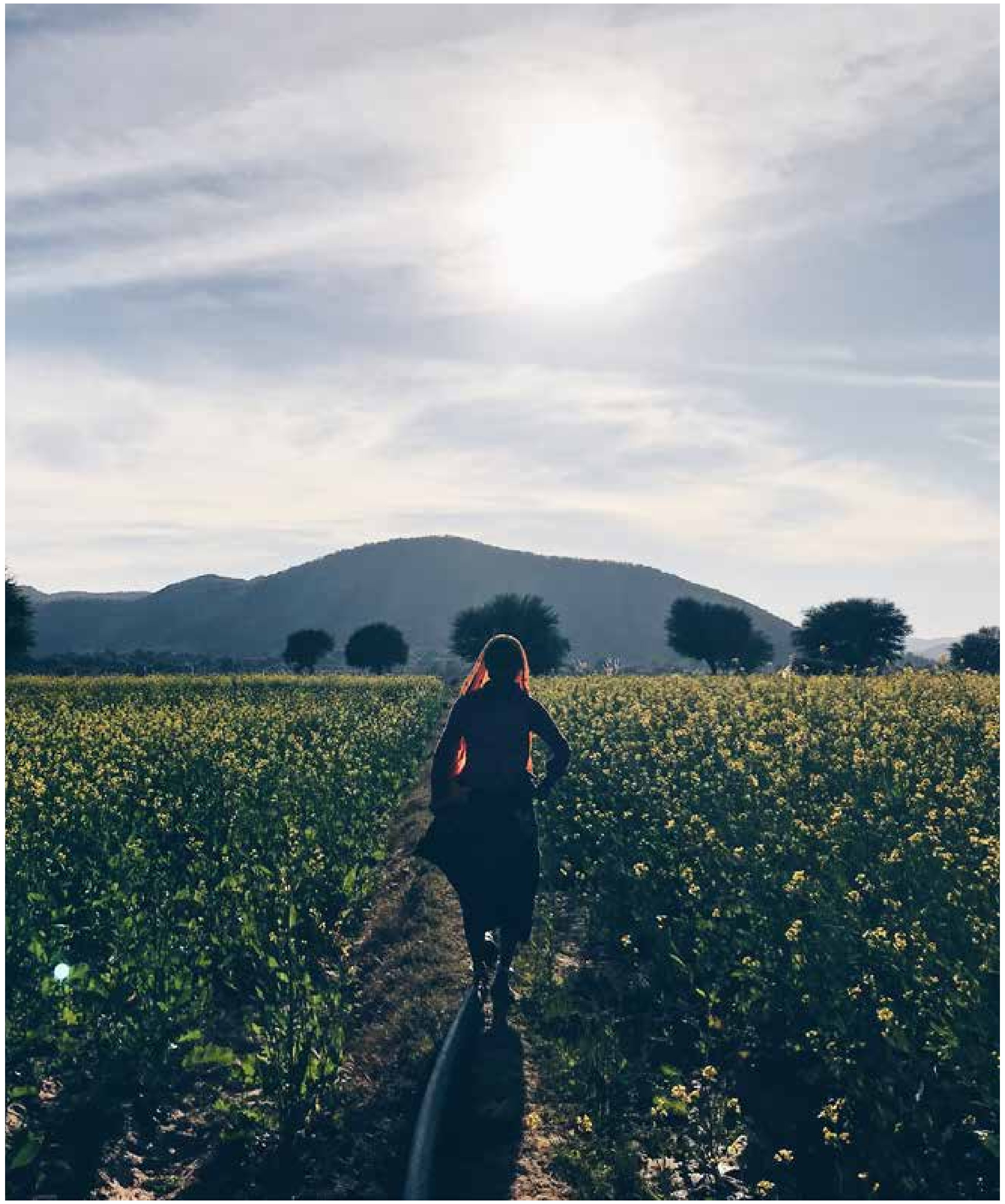
Manual	Parameter	Automatic
Improved West & Geake Method	SO_2	Ultra-violet flourescence
Modified Jacob & Honchheiser Method	NO_2	Chemiluminescence
Chemical (Buffered Ki) Method	O_3	UV-Photometric, Chemiluminiscence
Indo-Phenol Method	NH_3	Chemiluminescence
	CO	Non-dispersing infrared Spectroscopy
Gravimetric Method	PM2.5	TEOM, Beta Attenuation
Adsorption - desorption followed by GC	Benzene	GC Based Continuous Analyzer
Gravimetric Method	PM10	TEOM, Beta Attenuation
AAS/ICP after sampling using EPM 2000 ED-XRF using Teflon filter	Pb	
AAS/ICP after sampling using EPM 2000	Ni As	
Solvent Extraction followed by HPLC/GC Analyses	B(a)P	

Figure 42: Parameters and Methods – National Ambient Air Quality Monitoring System

The above mentioned publications of CPCB provide the guidelines for sampling and analysis of the pollutants under NAAMP (both for manual and automatic sampling).

Manual Sampling

- Sulphur dioxide in ambient air (Improved Westand Gaeke Method)
- Nitrogen dioxide in ambient air (Modified Jacob and Hochheiser Method)
- Particulate Matter (PM_{10}) in ambient air Gravimetric Method)
- $PM_{2.5}$ in ambient air (Gravimetric Method)
- Ozone in ambient air (Chemical Method)
- Ammonia in ambient air (Indophenol Method)
- Benzo(a) pyrene & other PAHs in Ambient Air (Solvent Extraction & GC Analysis)
- Lead, Nickel and Arsenic in ambient air (Atomic Absorption Spectrophotometer Method)
- Data sheets



Automatic Analysers

- Sulphur Dioxide in ambient air (UV Fluorescence Method)
- Particulate Matter (PM_{10} and $PM_{2.5}$) in ambient air (Beta Attenuation Method)
- Carbon Monoxide (CO) in ambient air (Non-Dispersive Infrared Method)
- Oxides of Nitrogen (NO – NO_2 - NO_X) and Ammonia (NH_3) (Chemiluminescence Method)
- Ozone (O_3) in ambient air (UV Photometric Method)
- Benzene Toluene and xylene (BTX) in ambient air (Gas Chromatography Methods)
- Data Formats

The following publication of CPCB describes some important aspects of air quality monitoring objectives, NAAMP, monitoring locations, number of monitoring locations, sampling duration and frequency, measurement methods laboratory requirement quality assurance and operation of air quality monitoring equipment.

CPCB document

Guidelines for Ambient Air Quality Monitoring: NATIONAL AMBIENT AIR QUALITY MONITORING SERIES : NAAQMS/ ... /2003-04:- http://www.indiaairquality.info/wp-content/uploads/docs/2003_CPCB_Guidelines_for_Air_Monitoring.pdf

Some important points from the above publication of CPCB regarding air quality monitoring are reproduced below.

Selection of Monitoring Location[21]

Principal factors governing the locations of the sampling stations are the objectives, the particular method of instrument used for sampling, resources available, physical access and security against loss and tampering. Air quality monitoring should be done in areas where pollution problem exists or is expected i.e. mainly in industrial areas, urban areas, traffic intersections etc. Selection of site is very important as an incorrect location may result in data that may not meet the objectives of monitoring and will be of limited value. In general, the following requirements should be satisfied for site selection.

(a) Representative Site
A site is representative if the data generated from the site reflects the concentrations of various pollutants and their variations in the area. It is not easy to specify whether the location of the station is satisfactory or not, however it may be checked by making simultaneous measurements at some locations in the area concerned. The station should be located at a place where interferences are not present or anticipated. In general, the following conditions should be met:

- The site should be away from major pollution sources. The distance depends upon the source, its height and its emissions. The station should be at least 25 m away from domestic chimneys, especially if the chimneys are lower than the sampling point; with larger sources the distance should be greater.
- The site should be away from absorbing surfaces such as absorbing building material. The clearance to be allowed will depend on the absorbing properties of the material for the pollutant in question, but it will normally be at least I m.
- The objective of monitoring is often to measure trends in air quality and measurements are to be conducted over a long time; thus the site selection should be such that it is expected to remain a representative site over a long time and no land use changes, rebuilding etc. are foreseen in near future.

The instrument must be located in such a place where free flow of air is available. The instrument should not be located in a confined place, corner or a balcony.

(b) Comparability
For data of different stations to be comparable, the details of each location should be standardised. The following is recommended in IS 5182 (Part 14) 2000

- On all the sides it should be open, that is the intake should not be within a confined space, in a corner, under or above a balcony.
- For traffic pollution monitoring the sampling intake should be 3 m above the street level. The height of 3m is recommended to prevent re-entrainment of particulates from the street, to prevent free passage of pedestrians and to protect the sampling intake from vandalism.
- Sampling in the vicinity of unpaved roads and streets results in entrainment of dust into the samplers from the movement of vehicles. Samplers are therefore to be kept at a distance of 200 m from unpaved roads and streets.

21 Central Pollution Control Board (2003), Guidelines for Ambient Air Quality Monitoring, Ministry of Forest and Environment

(c) Physical requirement of the monitoring site

The following physical aspects of the site must be met
- The site should be available for a long period of time
- Easy access to the site should be there anytime throughout the year.
- Site sheltering and facilities such as electricity of sufficient rating, water, telephone connection etc. should be available.
- It should be vandal proof and protected from extreme weather

Highest concentrations and concentration gradients of carbon monoxide are likely to be in the vicinity of roads, highways. The gradients vary in both time and space on the micro and on the neighbourhood scale. The recommended criteria for siting monitoring stations for CO is given IS 5182 (Part 14): 2000.

Topographical and meteorological factors must also be considered for selecting a monitoring site. The topographical factors that must be considered are mountains, valleys, lakes, oceans and rivers. These factors cause a meteorological phenomenon that may affects air pollutants distribution.

Winds caused by daytime heating and night time cooling may affect pollutant transport causing either build-up of pollutants or dilution. Canyons or valleys may channel the local winds into a particular direction resulting in increase in wind speed. The presence of large water bodies may cause a land-sea breeze wind pattern which may determine pollutant transport. The mountain or hilly terrain may cause precipitation that may affect pollutant concentration. A minimum distance of the sampler from road for measurement of Ozone and NO_X is given in Table 4.4 (Source: ETC. Canada). These criteria are for reference only, actual criteria followed at site must be based on compromise between available resources and site specific parameters such as nearby sources, concentration gradients of the pollutants, topographical features etc.

In general, the following requirement may be met for siting the monitoring station.

- Height of the inlet must be 3 – 10 m above the ground level.
- The sampler must be more than 20 m from trees.
- (Distance of the sampler to any air flow obstacle i.e. buildings, must be more than two times the height of the obstacle above the sampler.
- There should be unrestricted airflow in three of four quadrants
- There should be no nearby furnace or incinerator fumes.

Once a area has been selected for locating a monitoring stations, the site can be selected by finding maximum concentration using air quality modelling.

CPCB has published another useful document that provides specifications of various components of CAAQMS and analyzers

- Housing/Container for CAAQM Station including: sampling system, internal fittings, instrument racks, electrical and gas line fittings, tools (electrical & mechanical), etc.
- General Specification for all Analysers
  - Ambient SO_2, Analyser
  - Ambient NO-NO_2-NO_X, Analyser
  - Ambient NH_3, Analyser (standalone independent analyzer)
  - Ambient CO, Analyser
  - Ambient O_3, Analyser
  - Ambient BTEX, Analyser
  - Continuous PM_{10} Monitoring Analyser (β-RAY)
  - Continuous $PM_{2.5}$ Monitoring Analyser (β-RAY)
- Multi Point Gas Calibration System
- Meteorological, Flow and Electronics Calibration
- Meteorological System comprising of sensors for (A) Wind Speed, (B) Wind Direction, (C) Ambient Temperature, (D) Relative Humidity, (E) Solar Radiation & (F) Rainfall,
- Typical Architecture for Data Connectivity
- Data acquisition and handling system at stations
- Work Station Computer at stations (for AQI Preparation)
- Manageable CISCO Switch (Rack Mountable)
- Remote Monitoring Tool/Software (For Stations and Central locations).