UNIT 1 AIR QUALITY IMPACT ANALYSIS

Structure

1.0 INTRODUCTION

Air pollution continues to be one of the serious environmental issues across the world due to its link to human health, ecological toxicity, meteorological changes, precipitation suppression and climate change. Epidemiological investigations carried out world-wide since 1990, had shown a clear association between air pollution and the occurrence of acute respiratory disorders, lung cancer, chronic respiratory and cardiovascular diseases. Recent research also shows a significant link between air pollution and diabetes globally. The study published in *The Lancet Planetary Health* reports that pollution contributed to 3.2 million new diabetes cases (14% of the total) globally in 2016.

According to World Health Organization (WHO) data 2018, more than 90 percent of the global population is breathing in high levels of pollutants, and causing as many as seven million deaths annually. It is observed that every corner of the globe is dealing with air pollution, and the problem is far worse in poorer countries - 90 percent of deaths linked to air pollution occur in low- or middle-income countries, mainly in Asia and Africa. According to the data, 14 Indian cities rank among the list of top 20 global cities that have reached alarming heights of air pollution in terms of PM 2.5 concentrations. Another study namely *State of Global Air – 2018* published by Health Effects Institute, USA, estimates that exposure to "household air pollution" also has a substantial impact on health and is ranked 8th in risk factors for early death, with 2.6 million attributable deaths in 2016 (Figure 1.0). Both individually and collectively, ambient air pollution and household air pollution impose a substantial burden on public health.

Among the air pollutants, the particulate matter (PM) less than 10 microns and 2.5 microns (in aerodynamic size) referred as PM10 and PM2.5 respectively, are serious due to their role in multiple health disorders. In addition, evidences from the climate change studies suggest that the black carbon content of PM absorbs sunlight and contributes to global warming. PM in the atmosphere are subjected to chemical reactions resulting in secondary chemical components, which are transported to long distance and are eventually cleared by deposition processes causing impacts at global and local scales. Particulate matter (PM) by virtue of its complex mixture of different chemical components, categorizing the environmental impact of it, still remains a challenging task. Long residence time of lower size fraction PM in the atmosphere and their long-range transport under favorable meteorological conditions is another intriguing factor in assessing the environmental and ecological impacts.

1.1 OBJECTIVES

After studying this unit, you will be able to:

- understand the pollutants impacting air quality;
- determine the particulate matter based on size classification;
- categorize the gaseous air pollutants and its impact on human health and ecosystem;
- identify the instrument analytical and experimental Methods available for monitoring and assessment of air quality impacts; and
- describe the methods used to predict the air quality impacts through sensor network and modelling approaches.

1.2 PARTICULATE POLLUTION

Among the air pollutants, Suspended Particulate Matter (SPM) refers to the solid or liquid particles or combination of both that remains suspended in the atmosphere. SPM may be further classified into dust, smoke, fumes, mist, fog, haze, etc. Particulate matter (PM) that is 10 µm or less in diameter refers PM 10 or Respirable Suspended Particulate Matter (RSPM). PM 10 is normally subdivided into:

- Fine fraction of particles 2.5 µm or less (PM 2.5)
- Coarse fraction of particles greater than 2.5 µm

The fraction with aerodynamic diameters approximately below 0.15 µm is termed as 'ultrafine particles'.

Particulate matter is further categorised into two groups and they are:

- Primary (discharged directly into the atmosphere)
- Secondary (formed in the atmosphere via physical and chemical transformations)

The principal gases present in secondary particulate formation include:

- Sulphur dioxide (SO_2)
- Nitrogen oxides (NO_x)
- Volatile organic carbons (VOCs)
- Ammonia (NH_3)

Primary particles occur in both fine and coarse fractions, however, secondary particles like nitrates and sulphates mainly occur in fine fraction. Either natural or anthropogenic sources can cause primary and secondary PM.

Ever since the onset of industrialization and urbanization air borne SPM has been a major problem due to its adverse effects such as visibility reduction, soiling of buildings and impact on human health. However, the serious nature of the issue was not realized till a few decades ago.

Once released into the atmosphere, particulate matter of smaller sizes has a longer residence time in the atmosphere. Elimination of these particles happens by both wet and dry deposition mechanisms. In wet deposition incorporation of aerosols occur within cloud or below cloud and its efficiency is dependent on particle size and hygroscopicity of aerosols. The type of cloud and precipitation intensity is also expected to have a major influence. Rain effects about 90% removal of these pollutants than dry deposition mechanisms like gravity settlement, impaction and dispersion. Dry deposition velocities are greatly influenced by local meteorological conditions.

1.3 GASEOUS POLLUTANTS IN POLLUTION

Pollutants that occur in gaseous state are known as gaseous pollutants. These pollutants are found to be gaseous in nature at normal pressure and temperature. A gas in an atmosphere can be classified as pollutant only in such concentrations when it causes human health impact and ecological effects. Many gaseous pollutants behave like air and do not settle down easily. They include various organic and inorganic gaseous materials.

a. Inorganic gases: These inorganic gases include noxious gaseous pollutants such as oxides of sulphur (SOx), oxides of nitrogen (NOx), hydrogen sulphide (H_2S), chlorine, ammonia, hydrogen chloride, hydrogen fluoride, hydrogen cyanide, oxides of phosphorous, mercaptans, bromine, etc.

b. Organic gases: The organic gaseous pollutants include hydrocarbons (CxHy) such as CH_4, C_3H_8, C_2H_2, C_2H_4, C_6H6, C_8H_{18} and other compounds including acetone, formaldehyde, alcohols, acetone vapours, methyl isocyanate, organic acids, chlorinated hydrocarbons, etc.

Check Your Progress 1

Note: a) Write your answer in about 50 words.

b) Check your progress with possible answers given at the end of the unit.

1. What are the gaseous pollutants?

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2. Define Particulate matter?

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1.4 GREEN HOUSE GASES AND CLIMATE CHANGE

Green house effect is globally well known phenomenon today due to and its significance in global climate change. In this unit we will discuss the about ill effects of unprecedented increase in green house gases (carbon dioxide - CO_2, methane - CH_4 and nitrous oxide-N_2O). Although increased green house gases do not cause any direct human health effects or ecological impairment, it indirectly contributes to global warming. Since the start of the industrial revolution, some of the anthropogenic activities that have contributed significantly to an increased concentration of green house gases include:

1. Usage of fossil fuels: Usage of fossil fuels discharges large amounts of carbon dioxide into the atmosphere.

2. Deforestation and burning of forests and grasslands to transform into cropland: Forests and grasslands are cleared and/or burned to transform them into cropland. Burning of biomass generates large amounts of carbon dioxide (CO_2). Burning and clearing of forests also reduce vegetation which absorbs CO_2 through photosynthesis.

3. Cultivation of rice and paddies and use of inorganic fertilizers: Cultivation of rice and paddies produces methane and usage of fertilizers discharges N_2O into the atmosphere.

1.5 OZONE IN TROPOSPHERE AND ITS IMPACTS

Ozone in stratosphere protects life on earth from sun's ultraviolet (UV) rays. At ground level, greater concentrations of ozone are poisonous to people and plants causing an irritation effect in the respiratory tract and lungs. In the lower atmosphere (troposphere), the chemical reactions occurring between air pollutants from motor gasoline vapours, vehicle exhaust and other emissions create ozone.

High ozone levels and other oxidants including peroxy-acetyl nitrate (PAN) clearly caused threat to human and ecosystem health in several cities of the United States. Cities like Los Angeles and California where inactive meteorological episodes with minimum air exchange are often encountered, were most influenced. This ozone problem has become more extensive because transportation emissions have increased.

Exposure to 50 ppm of ozone for many hours will result in mortality because of pulmonary edema (a condition characterised by accumulation of fluid in lungs). At lower levels, ozone is causing non-lethal accumulation of fluid in lungs and also harming lung capillaries. Young children are at more risk to ozone exposure than adults. Both ozone and PAN produce free radicals.

Ozone is also a greenhouse gas which absorbs infrared radiation and re-emits it as radiation at an energy level which is equal to about 18°C. This indicates that there is a minimal impact of ozone at temperatures encountered at the surface. Ozone is considered as more efficient greenhouse gas at the tropopause, where temperatures ranging between –60° and –80°C are encountered.

1.6 ACID RAIN AND ITS IMPACTS

Acid rain was first observed in 1852 in Manchester, England. Robert Angus Smith was the discoverer of the relationship between atmospheric pollution and acid rain.

Acid rain is a broad term which is defined as a combination of wet and dry deposition (deposited substance) from the atmosphere containing more than normal amounts of sulphuric and nitric acids. The chemical forerunners of acid rain formation are formed from decaying vegetation and volcanoes and man-made sources. The man made sources include the nitrogen oxide (NOx) and sulphur dioxide (SO2) which are caused out of combustion of fossil fuel.

The major contributors to acid rain are known as 'precursors' and they are the common air pollutants. Some of them include:

Nitrogen oxides (NO_X) - nitric oxide (NO) and nitrogen dioxide (NO_2)

1.7 METEOROLOGICAL FACTORS INFLUENCING AIR QUALITY

Meteorology is an important factor contributing to air quality. The nature and density of emission are influenced by meteorological conditions by their role in dispersion and dilution. It encompasses atmospheric processes that control or influence evolution of emissions, chemical species, aerosols and particulate matter. Weather patterns determine how air contaminants are dispersed and move through the troposphere, and thus determine the concentration of a particular pollutant that is breathed or the amount deposited on vegetation. These processes influence horizontal and vertical transport, turbulent mixing, convection, and dry and wet deposition of air pollutants Wind velocity data are plotted as a wind rose, a graphic picture of wind velocities and the direction from which the wind came. The wind rose in Fig1 shows that the prevailing winds are mainly from the southwest. Relative humidity, solar energy, temperature, and presence of liquid water droplets and clouds affect the rates at which secondary species of aerosols are formed. Horizontal wind motion is measured as wind velocity.

Most of the severe air pollution episodes that resulted in mortality occurred mainly due to the meteorological conditions. Low wind speeds, low mixing heights and accompanying fogs favor the build up of primary pollutant concentrations. Investigations on wet deposition in the San Joaquin Valley of California during winter showed that a typical fog removes 500-2000mg m^3 of sulfate, 2500-6500 mg m^3 of nitrate, and 2000-3500mg m^3 of ammonium. The net reduction of ambient concentrations due to fog deposition accounted to 0.05-0.2 mg m^3, 3-6mg m^3, 1-3mg ^{3} for sulfate, nitrate and total ammonium respectively.

1.8 AIR QUALITY ANALYSIS – INSTRUMENTS AND METHODS

Dear Learners, let us now read about air quality analysis- instruments and methods in the following sentences:

1.8.1 Methods for Monitoring and Assessment of Particulate Matter (PM)

Gravimetric Method

High volume and low volume air samplers are used traditionally to sample air for particulate and gaseous pollutants. It captures more than 1500 cubic metres (m^3) of air for 24-hour period, while low volume air samplers draw about 24m^3 of air. A pre-weighed filter paper traps particulate matter as the air passes through the instrument. After sampling, the filter is re-weighed and the difference in filter weight is the collected particulate matter mass. Later, the particulate matter retained on the filter is analysed to determine the concentration of different pollutants including pollutants including metals and other organic pollutants such as Poly Aromatic Hydrocarbons (PAH), Poly Chlorinated Biphenyls (PCB) etc.

In India, High Volume Air Samplers manufactures by Envirotech, New Delhi is mainly use for air quality impact assessment studies (Figure 1.1). Ambient air enters the sampler through an omnidirectional inlet designed to provide a clean aerodynamic cut-point for particles greater than 10 ìm. Particles in the air stream finer than 10 ìm proceed to a second impactor that has an aerodynamic cut-point at 2.5 ìm. The air sample and fine particulates exiting from the PM 2.5 impactor are passed through a 47-mm-diameter PTFE filters that retain the PM 2.5. The Envirotech APM 550 system allows removal of the PM 2.5 impactor from the sample stream. The sampling rate of the system was held constant at 1 m^3/h by a suitable critical orifice for 24 h.

Cascade Impactors are another version where the aerosol sample passes through a sequence of stages. In each stage, an air jet containing the aerosol reaches the impacting plate and particles larger than the cutoff diameter for the stage are collected. Smaller particles follow the gas flow that surrounds the collection plate and are collected in the next stage, in which the orifices are smaller and have conditions for greater air speed. This process continues until smaller particles are removed in the after-filter.

Fig..1 : PM 10/PM 2.5 sampler of Envirotech, India

Air Quality Impact Analysis

Optical Methods

In the optical detection methods, aerosol particles are lit by a light beam and irradiate this light in all directions (scattering). Part of this light is simultaneously transformed in other energy forms (absorption) and extinction of the light can be calculated by the addition of scattering and absorption. Optical instruments used for measuring particle concentration, in real time, can be based in the principles of scattering, absorption, and light extinction.

Scattering photometer is another type in which the scattering light is measured by employing a photometer detector. Among the scattering photometers, Respirable Aerosol Monitor (RAM) is a kind of instrument in which the aerosol was aspirated with the help of a pump, and then passed through a cyclone that separated the respirable aerosol fraction. The aerosol entered the optical sensor zone, where the infrared light scattered in an angle of 45° to 90°, and the aerosol was detected by a photodiode.

The Condensation Particle Counters (CPCs) are also classified as light scattering counters. These counters are employed to measure the concentration of small particles. These particles do not scatter light sufficiently, in a way that conventional optical counters cannot detect this scattering.

Spotmeters are the equipments also known as reflectometers or smoke filter meters, in which the concentration of particles is obtained by filtering the exhaust gas in a paper filter, and recording of the ratio between the light reflected by this exposed spot and a non-exposed spot. Aethalometer are the instruments used to determine BC concentrations.

Microbalance Methods

When the particles are collected, over the surface of an oscillatory microbalance element, those microbalances use the alteration of the resonance frequency to determine the PM. There are two main measurement instruments that use the microbalance method: Tapered Element Oscillation Microbalance (TEOM) and Quartz Crystal Microbalance (QCM).

Mobility Analyzer

Among the Mobility analyzers, the Electrical Aerosol Analyzer (EAA) as the oldest mobility analyzer, and the DMA as the most recent model. DMA uses bipolar diffusion charging to bestow a well-defined charge distribution in the aerosol. After loading, particles are inserted into an electrostatic classifier, allowing particle passage in a narrow range of electrical mobility. Classified particles are measured by an electrometer or CPC.

Differential Mobility Spectrometers (DMS)

Among the spectrometers based on particle mobility, the most known are the Differential Mobility Spectrometers (DMS) and the Fast Mobility Particle Sizer (FMPS). Scanning Mobility Particle Sizer (SMPS) and Twin Differential Mobility Particle Sizer (TDMPS) are also widely used**.** SMPS is an analytical instrument that measures the size and number concentration of aerosol particles with diameters from 2.5 nm to 1000 nm. This method is based on the physical principle that the ability of a particle to traverse an electric field (electrical mobility). In a Differential Mobility Analyzer (DMA), an electric field is created, and the airborne particles drift in the DMA according to their electrical mobility.

Aerodynamic Particle Sizer (APS), Particle Size Distribution (PSD) and Aerosol Mass Spectrometer (AMS) are the equipment used to measure aerodynamic size. APS is a spectrometer in which working principle is based on the acceleration of aerosol sample flow through an accelerating orifice. The particle aerodynamic size determines its acceleration rate. Larger particles accelerate slowly due to larger inertia. At the nozzle exit the particles cross each other through two laser beams partially overlapped, in the detection area. The light is scattered when each particle passes through overlapped beams. One elliptical mirror, placed 90 degrees in relation to the laser beam axis, collects and concentrates the light over an avalanche photodetector (APD). Next, the APS converts light pulses in electrical pulses.

1.8.2 Methods for Gaseous Pollutants

NO_x and SO_2

To analyse the impacts of Oxides of Nitrigen (NO_x) and Sulphur dioxide (SO_2) concentration, high volume air samplers discussed elsewhere are used in which air is passed through absorbent solutions kept in impinger tubes seated in the gas sampling assembly. The solutions are kept cool by cold water bath. The absorbent solution to collect NOx was 0.002 N NaOH and for SO_2 it is 0.03 N H_2O_2. The concentration gaseous pollutants in the corresponding absorbent solutions are determined following standard methods (IS:5182, 1973, IS:2720, 1972). Modified West & Gaeke Method (IS 5182 Part 2 Method of Measurement of Air Pollution: Sulphur dioxide).

1.8.3 Choosing sampling location

Air sampling location needs to be chosen with additional care depending upon the objective of measurement campaign. The altitude of sampling location should be identified depending upon the type of study region (roadways, industrial area, disposal sites, residential area, etc). Generally it is kept at a height of about 3m to 10m from the ground level and sufficiently away from the disturbance of direct obstacles from the source under consideration. The regular monitoring campaign of national ambient air quality includes measurement of particulate matter typically for 24 hours at least twice a week making about 104 samples a year. For routine sampling to determine compliance with the National Ambient Air Quality Standards (NAAQS), CPCB guidelines shall be considered. Before selection of sampling location, point and non-point sources of pollution should be analyzed visually and the monitoring should be done at outside the zone of influence of sources. Tall and large buildings, trees and other structures extending above the height of the monitor may present barriers or deposition surfaces for PM. 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. Certain trees may also be sources of PM in the form of detritus, pollen, or insect parts. These can be avoided by locating samplers by placing them > 20 m from nearby trees.

Finally the results obtained from the aforesaid experiments are compared with prescribed standards (National Ambient Air Quality Standards) to assess the impacts (Table 1).

Table 1.1 National Ambient Air Quality Standards-2009

National Ambient Air Quality Standards - 2009

Sl. No	Pollutant	Time Weighted Average	Concentration in Ambient Air	
			Industrial, Residential, Rural and Other Area.	Ecologically Sensitive Area (Notified by Central Govt.)
1.	Sulphur Dioxide (SO_2) µg/m^3	Annual * 24 Hours **	50 80	20 80
2.	Nitrogen Dioxide (NO_2) µg/m^3	Annual * 24 Hours **	40 80	30 80
3.	PM_{10} µg/m^3	Annual * 24 Hours **	60 100	60 100
4.	PM2.5 µg/m^3	Annual * 24 Hours **	40 40	40 60
5.	Ozone (O^3) µg/m3	8 Hours ** 1 Hours **	100 180	100 180
6.	Lead (Pb) µg/m3	Annual * 24 Hours **	0.50 1.00	0.50 1.00
7.	Carbon Monoxide (CO) µg/m^3	8 Hours ** 1 Hours **	02 04	02 04
8.	Ammonia (NH3) µg/m^3	Annual * 24 Hours **	100 400	100 400
9.	Benzene (C4H4) µg/m^3	Annual *	05	05
10.	Benzo Pyrene (BaP) µg/m^3	Annual *	01	01
11.	Arsenic (As) µg/m^3	Annual *	06	06
12.	Nickel (Ni) µg/m^3	Annual *	20	20

[* File contains invalid data | In-line.JPG *]

Source: National Air Quality Index, 2009

1.8.4 Air Quality Index (AQI)

To minimize the complexity of understanding the impacts of multiple air pollutants, Air Quality Index (AQI) has been formulated for monitoring the quality of air in major urban centres across the country on a real-time basis and enhancing public awareness for taking mitigatory action.

The Index consists of five chief pollutants: Particulate Matter, Ozone, Nitrogen Dioxide and Carbon Monoxide.

- The unit of measurement is microgram (or milligram in the case of CO) per cubic meter.
- The AQI has been at present launched for 10 cities — Delhi, Agra, Kanpur, Lucknow, Varanasi, Faridabad, Ahmedabad, Chennai, Bangalore and Hyderabad.
- The AQI has been developed by the Central Pollution Control Board in consultation with other expert group comprising medical, air-quality professionals and other stakeholders.

- India has joined the global league of countries like the US, China, Mexico and France that have implemented smog alert systems.

India has set standards for a particular level of pollutant and the AQI codes are given below in table 1.2.

Table 1.2 AQI Codes and associated health impacts

AQI	Associated Health Impacts
Good (0–50)	Minimal Impact
Satisfactory (51–100)	May cause minor breathing discomfort to sensitive people.
Moderately polluted (101–200)	May cause breathing discomfort to 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
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 impact even on healthy people, and serious health impacts on people with lung/heart disease. The health impacts may be experienced even during light physical activity.

Source: National Air Quality Index, 2009

1.8.5 Sensor Network for Air Quality Monitoring

Globally several research projects are exploring the possibility of collecting air quality data using low-cost sensor platforms. Examples include OpenSense (www.opensense.ethz.ch) and Citi-Sense-MOB that use mobile platforms to monitor air pollution levels and its changes in cities. Everyaware is another agency (www.everyaware.eu) that helps citizens collect and share noise and air pollution data. Similarly Citi-Sense (www.citi-sense. eu) empowers people to use low-cost air quality platforms in 8 cities across Europe.

These air pollution sensors can be classified into two groups; those that measure gas phase species and those that measure particulate matter. Commercially available gas sensors operate by measuring either the electrochemical interaction between the sensing material and the pollutant (i.e., electrochemical or metal oxide technologies) or the absorption of light at the visible range.

Particulate matter is measured by light scattering or absorption, using algorithms to relate the attenuated signal to the particle size and/or composition. These individual sensors need to be integrated into a sensor platform or node. The sensor node contains a sensor board, the sensors, and control board that integrates all the required electronics (e.g., signal conditioning, GPS, communication ports, data storage). The number and type of commercially available sensor platforms is increasing at a rapid pace. Whereas the price of individual gas sensors ranges from Rs. 2000 - 15000, the cost of a commercial sensor node that includes several sensors can reach Rs. 40,000 to 4,00,000.

Low cost sensor platforms can play an important role in air quality monitoring. Sensor nodes can be deployed as dense networks (ubiquitous monitoring) or mounted on vehicles, facilitating the elaboration of high-resolution air quality maps. The reduced size of the low-cost platforms also allows new research in personal exposure. 'Wearable' platforms are able to consider changes in exposure due to changes in location and activities and provide new capabilities to evaluate health risk from air pollution.

1.9 AIR QUALITY MODELLING

Air pollution modelling is another approach to study the impact of air pollution by using mathematical theory to understand, or predict the way pollutants behave in the atmosphere. ***Modelling*** considers terrain conditions, environmental lapse rates, different emission rates, weather and development scenarios theories while attempting to understand the ***environmental*** impact of air pollution. Initially, a simple model known as the ***Gaussian Plume Model*** was developed to understand the diffusion properties of plumes emitted from the industrial chimneys. The Gaussian plume model determines the horizontal and vertical spread of the plume, measured by the standard deviation of the plume's spatial concentration distribution. Assuming a homogenous, steady-state flow and a steady-state point source, Gaussian plume distribution equation is formulated as follows.

$$c(x,y,z) = \frac{Q}{2\pi\sigma_y\sigma_z u}\exp\left(\frac{-y^2}{2\sigma_y^2}\right)\left[\exp\left(\frac{-(z-h)^2}{2\sigma_z^2}\right)+\exp\left(\frac{-(z+h)^2}{2\sigma_z^2}\right)\right]$$

where c is a concentration at a given position, Q is the source term, x is the downwind, y is the crosswind and z is the vertical direction and u is the wind speed at the h height of the release. The σ_y, σ_z deviations describe the crosswind and vertical mixing of the pollutant, thus they are constructed from the K_h, K_z values of equation. Gravitational settling and chemical or radioactive decay are neglected.

1.9.1 Advanced Gaussian models

AERMOD is an open-source Gaussian air dispersion model developed by the *US Environmental Protection Agency* (EPA). It has incoroporated Monin–Obukhov-theory which is based turbulence parameterization. Many features such as built-in models to handle complex terrain and urban boundary layer has been included in the model. It also uses the *Plume Rise Model Enhancements* (PRIME) algorithm that gives a hard approximation of complicated turbulent processes like the downwash effect near the source. Although AERMOD uses the steady-state approximation for the flow and the source, it can be used within 10–100 km distance as a long-term statistical tool through its meteorological pre-processor (AERMET). AERMET assimilates detailed surface and meteorological data from both surface measurements and upper air soundings and enables the model to perform several model runs from which time averaged concentrations can be estimated through a certain period. AERMOD is a powerful tool to carry out impact studies of planned or existing industrial sites as well as to estimate the average load on environmental protection or agricultural areas.

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UK Met Office and *Cambridge Environmental Research Consultants* (CERC) also developed the ADMS-Urban module that aims to provide air quality forecasts for cities. The basic idea behind ADMS-Urban is to create the complex concentration field of a city as a superposition of plumes from different point, line and field sources based on emission estimates and a built-in chemistry model. (AERMOD: http://www.epa.gov/scram001/dispersion_prefrec.htm#aermod)

There are several other Gaussian models available like CALINE3 for highway air pollution, OCD for coastal areas, BLP and ISC for industrial sites or ALOHA for accidental and heavy gas releases. They are widely used by authorities, environmental protection organizations and industry for impact studies and health risk investigations. They are often coupled with GIS software to create an efficient decision support tool for risk management.

CALPUFF is a non-steady state Lagrangian puff dispersion model. The advantage of this model over a Gaussian-based model is that is can realistically simulate the transport of substances in calm, stagnant conditions, complex terrain, and coastal regions with sea/land breezes. CALPUFF is particularly recommended for long-range simulations (e.g., more than 50 miles) and studies involving the assessment of the visual impact of plumes. With the development of the VISTAS Version 6 model2, CALPUFF can use sub-hourly meteorological data and run with sub-hourly time steps. This version of CALPUFF is appropriate for both long-range and short-range simulations.

1.9.2 Photochemical Modeling

Photochemical air quality models have become widely recognized and routinely utilized tools for regulatory analysis and attainment demonstrations by assessing the effectiveness of control strategies. These photochemical models are large-scale air quality models that simulate the changes of pollutant concentrations in the atmosphere using a set of mathematical equations characterizing the chemical and physical processes in the atmosphere. These models are applied at multiple spatial scales from local, regional, national, and global (http://www.epa.gov/asmdnerl/CMAQ/index.html).

The primary goals for the Models-3/Community Multiscale Air Quality (CMAQ) modeling system are to improve 1) the environmental management community's ability to evaluate the impact of air quality management practices for multiple pollutants at multiple scales and 2) the scientist's ability to better probe, understand, and simulate chemical and

physical interactions in the atmosphere. The newest Models-3/CMAQ version 4.5 is now available for download from the CMAS. (Website: http://www.cmascenter.org/)

CAMX (The Comprehensive Air quality Model with extensions) is a publicly available open-source computer modeling system for the integrated assessment of gaseous and particulate air pollution. Understanding that air quality issues are complex, interrelated, and reach beyond the urban scale, CAMx is designed to simulate air quality over many geographic scales. CAMx is appropriate for simulating hourly ozone, CO, and PM concentrations from the urbanscale to regional-scale; the hourly concentration estimates can be used to generate mean ozone, CO, and PM concentrations at longer than hourly time-scales, including 8-hour, daily, monthly, seasonal, and annual.

The Urban Airshed Model® (UAM®) modeling system, developed and maintained by Systems Applications International (SAI), is the most widely used photochemical air quality model in the world today. Since SAI's pioneering efforts in photochemical air quality modeling in the early 1970s, the model has undergone nearly continuous cycles of application, performance evaluation, update, extension, and improvement. Other photochemical models have been developed during this long period, but no model today is more reliable or technically superior.

1.9.3 Meteorological Models

CALMET, CALPUFF

CALMET is a meteorological diagnostic model that combines data from surface stations, upper-air stations, over-water stations, precipitation stations, with geophysical data like land use, terrain elevations, albedo, etc., to produce a fully 3-dimensional diagnostic gridded wind field for the duration of the CALPUFF simulation. This wind field is then passed into CALPUFF and is used to transport the emitted substances.

http://www.src.com/html/calpuff/calpuff1.htm

The PSU/NCAR mesoscale model (known as MM5) is a limited-area, nonhydrostatic, terrain-following sigma-coordinate model designed to simulate or predict mesoscale atmospheric circulation. The model is supported by several pre- and post-processing programs, which are referred to collectively as the MM5 modeling system. The MM5 modeling system software is freely provided and supported by the Mesoscale Prediction Group in the Mesoscale and Microscale Meteorology Division, NCAR.

RAMS, the Regional Atmospheric Modeling System, is a highly versatile numerical code developed by scientists at Colorado State University for simulating and forecasting meteorological phenomena, and for depicting the results (software utilities. • RAMS: http://rams.atmos.colostate.edu/rams-description.html).

1.9.4 Source Apportionment and Receptor Models

Source apportionment (SA) is the determination of the contribution (fraction, percentage or portion) of air pollution sources at a location of interest. Air pollution originates from sources such as industries, power plants, cars, buses, trucks, boats, windblown dust and open burning. The development of effective control strategies to protect public health and the environment from exposure to air pollution requires knowledge of emission sources that contribute to the pollutant concentrations at the receptor. Pollutant concentrations are obtained from ambient air samples collected at a receptor location.

Two essentially different approaches are used in source apportionment:

1. source-oriented approach; and 2.receptor-oriented approach

The *source-oriented approach* starts from an emissions inventory and uses dispersion models in the form of chemical transport models (CTMs) to estimate the contribution of each source at a receptor location. Transport calculations use emission and source characteristics (stack height, exit velocity of stack gas, pollutant concentrations in exhaust gas) and known meteorological parameters (wind speeds, wind directions, temperature, mixing heights and atmospheric stability classes) to predict pollutant concentrations at specific receptor air monitoring locations. This type of models can be validated by comparison of the predicted spatial and temporal distribution of pollutant concentrations with measured concentrations.

Source-oriented: Emissions Inventory Analysis, Chemical Transport Models (CTMs), forward estimation, Chemical Transport Models (CTMs), backward estimation and Single tracer estimation model

Receptor-oriented: Linear Statistical Models, Chemical Mass Balance (CMB) Model, Bi-Linear Statistical Models, Principal Component Analysis, Factor Analysis, Positive Matrix Factorization, Empirical Orthogonal Functions, Hybrid Statistical Model, Chemical Mass Balance with Factor Analysis of Residuals, Target Transformation Factor Analysis (TTFA).

Check Your Progress 2

Note: a) Write your answer in about 50 words.

b) Check your progress with possible answers given at the end of the unit.

1. Describe air quality modeling.

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1.10 AIR QUALITY IMPACT ASSESSMENT OF DEVELOPMENT PROJECTS

To understand the impacts of development projects such as new industrial operations (including expansion), mining, highway, harbour, power plants, metallurgy etc., various stages of the projects are categorized and air quality impact assessment is carried out all stages of the project to suggest appropriate mitigatory measures. Generally impact assessment studies are carried out at pre-construction stage, construction stage, operation stage and post operation stage. Worst-case impacts (i.e. based on the preliminary Preferred Development Option) will also be carried out using air quality models. The major sources of air pollution have to be identified during construction and operation stage The sources of air pollutants at the different phases of the development are categorized as follows:

i) Construction Phase: Construction works include site clearance, site formation, building works, infrastructure provision and any other infrastructure activities. The major temporary air pollution is dust generated as a result of these construction works.

ii) Operational Phase: The major permanent sources of air pollutants such as chimney emissions, vehicular emission from traffic on major roads and the air pollutants emitted from the vicinity of the industrial stationary sources are studied. Chimneys emissions associated with nearby industrial premises are the stationary air pollutant sources.

iii) Meteorology and Topography: The topography and terrain conditions of the study area, airshed and the meteorological parameters play a crucial role in determining the air quality. The wind direction at a given time determines the general area into which a mass of gas or a cloud of particles will move. The wind speed closely relates to how rapidly the contaminant will advance into that area. Hills may deflect the air flow either horizontally or vertically or both, the amount of deflection depending on the vertical stability of the atmosphere. In valleys the wind carrying a pollutant tends to flow either up or down valley, following its meanderings. The deeper the valley the more pronounced this channeling effect.

1.11 LET US SUM UP

This unit discussed about the particulate pollution and its effects to human health. The gaseous pollutants in the atmosphere, green house gases and climate change were also described. A brief account of ozone in troposphere and its impacts and acid rain and its impacts were explained. The unit also discusses the meteorological factors influencing air quality, air quality analysis methods and modelling techniques. Finally the air quality impact assessment of development projects has also been outlined.

1.12 KEY WORDS

Acid rain : It is a broad term referring to a mixture of wet and dry deposition (deposited material) from the atmosphere containing higher than normal amounts of nitric and sulphuric acids.

Green house effect : It occurs when more amount of outgoing long wave radiation is retained than required amount. It results in greater warming of the atmosphere than normal.

Photochemical compounds : It is a condition that develops when oxides of nitrogen and VOCs (volatile organic compounds) interact in the presence of sunlight to produce a mixture of hundreds of hazardous chemicals, which have a major toxic effect on environment and bio-organisms.

PM 10 : Particulate matter (PM) that is 10 µm or less in diameter refers PM 10 or Respirable Suspended Particulate Matter (RSPM).

SOx : These compounds include all air pollutants that contain sulphur atom in their molecular structure. For example, SO_2, SO_3, H_2S, mercaptans, etc.

NOx : These compounds include all the air pollutants that contain nitrogen atom in their molecular structure. For example, NO, NO_2, NH_3 etc.

1.13 REFERENCES AND SUGGESTED FURTHER READINGS

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Understanding environmental Pollution, Second edition, Marquita K. Hill, Cambridge University Press, New Delhi 2004.

1.14 ANSWERS TO CHECK YOUR PROGRESS

Answers to Check your progress 1

1. Your answers should include the following points:
   - Inorganic gases
   - Organic gases
2. Particulate matter (PM) that is 10 µm or less in diameter refers PM 10 or Respirable Suspended Particulate Matter (RSPM).

Answers to Check your progress 2

1. Your answers should include the following points:
   - Refer to section 4.9