

Chapter 2

Air Quality Issues

Abstract Air quality changes from place to place and time to time and so as air quality issues. The air quality issues depend on types of air pollutants, regulatory issues, activity within the region, climate. Pollutants do not respect political boundaries and hence the pollutants from one country can just damage as much or greater than the country of origin. This chapter elaborates air quality issues and possible solutions along with monitoring, inventorisation, and modeling.

Environmental pollution is presence of an agent potentially damaging to either the environment or human health. If such agent is present in air then it is considered as air pollution. Polluting agents are called pollutants which include particles, chemicals, and microorganisms. All the elements in periodic table are found in atmosphere. It is difficult to quantify all the chemicals as about 15,000 new chemicals are updated in Chemical Abstract Service (CAS) every day (CAS 2015). As on May, 2015 more than 96 million chemicals were registered in CAS.

Every substance emitted into the atmosphere removed subsequently so that cycle of elements is established through phenomena called *biogeochemical cycle*. The usual source, pathway and sinks of air pollutants are given in Fig. 2.1.

It is not practical to evolve standard and measure all chemicals known to mankind in the atmosphere. Hence six criteria pollutants were adopted across the world in 1970s: particulate matter, nitrogen dioxide, ozone, sulfur dioxide, carbon monoxide, and lead. Later many countries bifurcated particulate matter into two types: PM₁₀ (Particulate matter < 10 μ), PM_{2.5}(Particulate matter < 2.5 μ) there by increasing the criteria pollutants to seven.

Even though it is known fact that micro-organisms are present in the atmospheric air, estimating the number of species of microbes is not possible with knowledge as on date. Variety of endotoxins can be released from the protoplasm of cells of organisms after death causing potential risks to health and environment. Monitoring of microorganisms and toxins released due to death the micro-organisms is not practiced as part of air quality monitoring.

Air quality continues as important issue for the economy, public health, and the environment. Although Europe has significantly cut emissions of many air pollutants greatly reducing sulphur dioxide (SO₂), benzene (C₆H₆), carbon monoxide

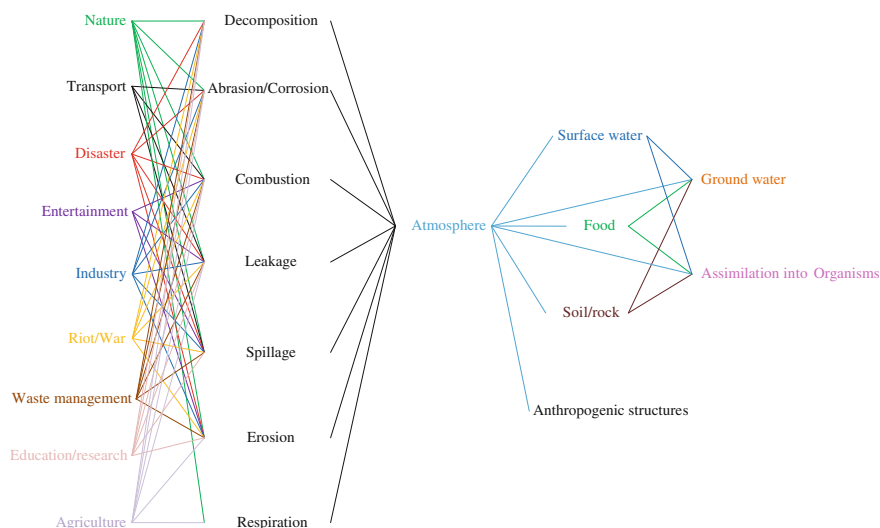


Fig. 2.1 Source, pathway and sinks of air pollutants

(CO), and lead (Pb) air pollution continues to damage human health as well as the environment (EEA 2013).

Emissions of air pollutants originate from all economic as well as societal activities. Some air pollutants are released into atmosphere intentionally (as in fumigation of operation theatre and modern agriculture practice) while other are released as unavoidable byproduct or waste product. There are other situations wherein product (as in cement manufacturing and mining) escapes into atmosphere.

Policies executed at the regional, national as well as sectoral level have resulted in decreased emissions of many air pollutants resulting in acceptable air quality levels. But, road transport, power plants, industry, households as well as agricultural activities continue to emit major amounts of air pollution. Burning of biomass by households is an important source of PM as well as polycyclic aromatic hydrocarbons (PAHs). Agricultural activity is responsible for the major amount of ammonia (NH₃) emissions.

As per EEA 2013, emission from agriculture have either decreased very little from agricultural sources and not decreased from domestic in the past decade (2003–2013) from Europe. The scenario of air quality is not monitored or poorly monitored in case of developing countries due low prioritization of issue related to air pollution.

Average time a species resides in atmosphere is called average life time or average residence time. This definition are useful in calculating some of the air polluting species in the atmosphere by applying principle of conservation of mass, for an imaginary volume, as described below.

$$\begin{aligned}
 \text{Rate of accumulation of given species} = & [\text{Rate of the species flowing in}] \\
 & - [\text{Rate of species flowing out}] \\
 & + [\text{Rate of formation of species}] \\
 & - [\text{Rate of removal of species}]
 \end{aligned}$$

$$\frac{dQ}{dt} = (F_{\text{in}} - F_{\text{out}}) + (P - R)$$

where,

Q Total mass of substance in the imaginary volume;

F_{in} Rate of species flowing in;

F_{out} Rate of species flowing out;

P Rate of introduction of species; and

R Rate of removal of species.

If Q does not change in time than $\frac{dQ}{dt} = 0$

$$\therefore F_{\text{in}} + P = F_{\text{out}} + R$$

The average residence time $\tau = Q/(R + F_{\text{out}})$

If entire atmosphere is taken as reservoir $\tau = \frac{Q}{R} = \frac{Q}{P}$

The Clean Air Act of USA establishes hazardous air pollutants, abbreviated as HAPs and referred to as “air toxics” or “toxic air contaminants”. These are 188 air toxics known or suspected to cause serious health effects even at low exposure levels. Of these 188 air toxics, about two-thirds are VOCs and the majority of the rest are metal compounds.

The dispersion of air pollutants depends on atmospheric chemistry and physics. The major chemical and physical phenomena that predominates air pollutants dispersion are

- Chemical kinetics;
- Atmospheric chemistry and photochemistry;
- Chemistry of stratosphere;
- Chemistry of troposphere;
- Chemistry of atmospheric;
- Properties of the Atmospheric Aerosol;
- Dynamics of aerosol particles;
- Thermodynamics of Aerosols;
- Nucleation;
- Mass transfer in atmosphere;
- Condensation;
- Coagulation;
- Cloud physics;
- Dry deposition;

- Wet deposition;
- General circulation of atmosphere; and
- Biogeochemical cycle.

2.1 Types of Air Pollutants

Types of air pollutants can be categorized as: (1) Natural or anthropogenic based on source of air pollution, (2) Organic or inorganic based on presence/absence of carbon and hydrogen, (3) Gas/Liquid/Solid based on state of the pollutants, (4) Primary/Secondary pollutants based on whether pollutant has come out of source or formed due to interaction of primary pollutants in the air.

Natural air pollutants are generated due to natural phenomena such as erosion of soil, disintegration of rocks/minerals evaporation of droplets of sea water, volcanoes, wild fires, and living organisms. Living organisms can generate gases due to oxidation/reduction of elements/compounds during metabolic process. Living organisms can also generate pollens/spores during the process of reproduction which may spread in air. Sources of air pollutants due to anthropogenic activity include transportation, manufacturing, cooking, waste management, etc.

Organic pollutants are originated due to: (1) incomplete combustion of organic substances like petroleum or wood, (2) manufacturing process of organic products, and (3) biological action like decomposition of organic material. Inorganic pollutants originate from complete combustion of fuel, manufacturing activity, weathering, corrosion and biological action.

Solid and liquid air pollutants occur as particles where as gaseous pollutants occur as molecules in atmosphere.

Secondary pollutants formed due to chemical changes of primary pollutants. Examples of secondary air pollutants are nitrogen dioxide formed due to oxidation of nitric oxide. If the nitrogen dioxide is formed due to combustion or chemical reaction in single stage it is considered as primary pollutant. Formation of ozone produced from nitrogen dioxide and volatile organic compound is of major health concern. Particles, emitted directly into the air are considered primary and particles are formed from other pollutants like sulphates from SO_2 and Nitrates from NO_2 are considered as secondary pollutant.

2.1.1 Natural Air Pollutants

Natural air pollutants enter atmosphere from natural activity like volcano, wild fire, soil re-suspension without anthropogenic intervention, lightening, etc. Some of the common natural air pollutants are discussed in following paragraphs.

Ammonia: Major natural sources of Ammonia are ammonification of humus, animal waste, and emission from soils.

Arsenic: Atmospheric arsenic exists mainly in particulate matter. The main natural sources of arsenic are volcanic activity and, low-temperature volatilization.

Biogenic Hydrocarbons: Vegetation releases organic compounds into atmosphere. Organic compounds emitted by vegetation include Isoprene, Camphene, 2-carene, Δ^3 -carene, d-Limonene, Myrcene, Ocimene, α -Limonene, Myrcene, Ocimene, α -Phellandrene, α -Pinene, β -Pinene, Sabinene, α -Terpinene, γ -Terpinene, Terpinolene, β -Phellandrene, p-Cymene. The Largest biogenic hydrocarbon emissions occur tropics and Isopropene is dominant compound. Emission of biogenic hydrocarbons is more than anthropogenic hydrocarbons on global scale (John and Spyros 2006).

Cadmium: Main source of natural emission of cadmium is volcanic activities.

Hydrogen fluoride: Volcanoes are major natural source of hydrogen fluoride.

Mercury: Degassing of the Earth's crust as well as evaporation from water bodies are major sources of atmospheric mercury.

Methane: Methane is mainly formed due to biological activity during anaerobic degradation of organic matter in waste, marshes, rice fields, wetlands, forests, enteric fermentation etc.,

Methyl Bromide: Methyl Bromide is the most abundant atmospheric bromocarbon. Natural sources of methyl bromide are ocean, salt marshes, rice fields, fungus, wet lands and plants.

Methyl Chloride: Major natural sources of methyl chloride emission are fungi, salt marshes, wetlands, tropical plants, rice field and oceans.

Mineral dust: Mineral dust arises due to wind acting on soil particles. The largest global sources of mineral dust are Sahara-Sahel region and central Asia. Published global estimates of mineral dust vary from 1000 to 2150 Tg/year (John and Spyro 2006).

Oxides of Nitrogen: Nearly 90 % of atmospheric NO_x is produced naturally by biological processes, lightning, volcanic activity, and photochemical destruction of compounds of nitrogen in the upper atmosphere. The important nitrogen containing compounds in atmosphere are nitrogen dioxide (NO_2), nitric acid (HNO_3), nitrous oxide (N_2O), nitric oxide (NO), and ammonia (NH_3). N_2O is emitted by biological sources in soil and water. N_2O is also emitted during biomass burning, degassing of irrigation water and agricultural activities. Nitrogen oxides (NO and NO_2) are usually represented as NO_x . Reactive odd nitrogen (represented as NO_y) is the sum of NO_x and all products of atmospheric oxidation of NO_x . Atmospheric oxidation products in atmosphere include nitric acid (HNO_3), dinitrogen pentoxide (N_2O_5), nitrous acid (HONO), the nitrate radical (NO_3), peroxyntitric acid (HNO_4), peroxyacetyl nitrate (PAN) and its homologs, alkyl nitrates (RONO_2), and peroxyalkyl nitrates (ROONO_2).

Ozone: Major ground level ozone is formed due to atmospheric reaction of VOCs emitted naturally from trees, anaerobic biological process, lightning, and volcanic activity.

Oxides of sulfur: Sulfur is present in the earth's crust and subsequently enters atmosphere in various form. The major sulfur compounds in the atmosphere are hydrogen sulfide, dimethyl sulphide (DMS), carbon disulfide(CS_2), carbonyl sulfide, methyl mercaptan, dimethyl disulfide, sulfur dioxide, bisulfate ion, sulfite ion, sulfuric acid, bisulfate ion, sulfate ion, Methane sulfonic acid (MSA), dimethyl sulfone, Hydroxymethane sulfonic acid (HMSA). Major natural source of oxides of sulfur is from volcano and wild fire. Ocean contributes to DMS produced by marine phytoplankton. Oxidation of DMS is source of MSA and SO_2 . Atmospheric conversion of CS_2 and DMS is one of the sources of carbonyl sulfide (OCS) apart from direct OCS flux from oceans and anthropogenic source.

2.1.2 Anthropogenic Air Pollutants

Anthropogenic air pollutants are of major concern to mankind as major quantity of these pollutants occurs in or near human settlement. Major air pollution sources across the world are: Motor vehicles, Residential wood combustion, glycol dehydrators, solvent use, prescribed burning, dry cleaning, solvent cleaning, coal combustion, gasoline(petrol) distribution, primary aluminium production, manufacture of motor vehicles, plastic foam products, commercial printing gravure, pulp mills, structure fire, waste dump (Fig. 2.2), and soil re-suspension.

Some of anthropogenic air pollutants which are of major concern are discussed in subsequent paragraphs:

Airborne particulate matter: Particulate matters (PM) include all solid/liquid (except pure water) substance with size larger than a molecule but less than microscopic/submicroscopic size (about 500μ). Figure 2.3 shows some of the sources of airborne particulate matter. This includes dust, dirt, soot, smoke, as well as liquid droplets. Airborne particulates may be a mixture of organic as well as

Fig. 2.2 Waste dump like this can emit numerous hazardous chemicals due to vaporisation/reaction





Fig. 2.3 Some of the sources of airborne particulate matter **a** industrial emission, **b** re-suspension on road, **c** re-suspension on unpaved sites, **d** firing litter, **e** street sweeping

inorganic substances. PM exceeding 2.5μ in aerodynamic diameter is defined as coarse particles. Particles smaller than 2.5μ ($PM_{2.5}$) are called fine particles. PM is unique in complexity. Airborne PM not only arises from source but also formed due to condensation/reaction in the atmosphere.

Acetaldehyde: Acetaldehyde is largely used as an intermediate during synthesis of other chemicals. Acute exposure to acetaldehyde leads to irritation of the skin, respiratory tract as well as eyes. Symptoms of chronic intoxication of acetaldehyde

are similar to those of alcoholism. It is considered as probable human carcinogen (USEPA 1987).

Acetamide: Acetamide is used as a solvent and a plasticizer. Acute exposure leads to causes mild skin irritation.

Acetylene: This is a colourless gas which is lighter than air. Acetylen is produced from calcium carbide or from petroleum fractions.

Acetonitrile: Acetonitrile is used in lithium batteries as well as spinning fibres. It is present in air from automobile exhaust as well as manufacturing facilities. Acute exposure causes irritation of mucous membranes. Chronic exposure caused headaches, numbness, as well as tremors.

Acetophenone: Acetophenone is used as a flavoring agent in foods, in soaps and perfumes, and as a solvent for resins and plastics. Acute exposure of this chemical may produce skin irritation as well as transient corneal injury in humans.

Acrolein: Acrolein may be formed from the burning of certain organic matter or fuels such as gasoline(petrol) or oil. Acrolein is used as a biocide or as an intermediate in the production of acrylic acid. Acute inhalation exposure may result in respiratory tract irritation as well as congestion.

Acrylamide: *Acrylamide* is used as an intermediate in the manufacture of organic chemicals and polyacrylamides. An acute and chronic oral exposure leads to damage of the nervous system in animals and humans.

Acrylic acid: Acrylic acid is used in manufacture of various plastics, adhesives, paints, elastomers, coatings, as well as floor polishes. Acrylic acid is irritating and corrosive to the respiratory tract and the skin. Eye contact can result in irreversible injury. high exposure might result in pulmonary edema.

Ammonia: This colourless, pungent gas is highly soluble in water to form solutions with up to 29 % NH_3 . Ammonia is used in hydrometallurgy for leaching sulfides of nickel, copper, and cobalt as ammonia forms the ammine complexes with these metals. The ammonia solution is also used in recovery of metals from solid waste (such as E-Waste) by precipitation of metals that reacts with ammonia.

Arsine: Traces of arsenic in ores, scrap, and metallurgical residues will be converted into arsine under certain conditions. This is a toxic gas with strong garlic odour formed when hydrogen is generated in presence of arsenic-bearing solutions.

Arsenic: Arsenic is a metalloid found as arsenides of copper, lead, silver, gold, and some coal. White arsenic (arsenic trioxide), emitted during roasting of sulfide ores. Major part of anthropogenic arsenic emissions are emitted from copper smelting, combustion of coal, and other nonferrous metal industries.

Arsenic Compounds: Most of anthropogenic emissions of arsenic compound origin from metal smelters and the fuel combustion, where arsenic is typically emitted in the form of arsenites (As_2O_3) or arsenates (As_2O_5). Acute high-level exposure of arsenic compound through inhalation leads to gastrointestinal effects; central as well as peripheral nervous system disorders. Chronic inhalation leads to irritation of the skin as well as mucous membranes and affects the brain/nervous system.

Arsenic oxide: Arsenic oxides are two types—the trivalent and the pentavalent. Trivalent oxide is dangerous as it is volatile. It is generated during the oxidation of arsenic-bearing sulfide minerals under restricted supply of air. It should be collected

in the gas filtration system and should be disposed in steel barrels. Since arsenic oxide is soluble in water its storage and disposal should be monitored carefully.

Acrylonitrile: Acrylonitrile is used in the manufacture of acrylic fibres, modacrylic fibers plastics, acrylamide, adiponitrile, and nitrile rubbers from where it may find its way into atmosphere. It is likely to cause headaches, mucous membrane irritation, dizziness, and nausea

Allyl chloride: Allyl chloride is used in the synthesis of compounds such as allyl alcohol, allyl esters, allyl amines, polyesters. Allyl chloride derivatives are found in plastics, varnish, adhesives, pharmaceuticals, perfumes, and insecticides. This pollutant enters into ambient air from production and processing facilities. Acute exposure to this pollutant results in irritation of the eyes and respiratory passages.

Aniline: Aniline is used as a chemical intermediate for manufacturing dye, polymer, and rubber. It is used as a solvent, and as an antiknock compound for gasoline (petrol). It can be formed from the burning of plastics, or tobacco (USEPA 1985). Aniline is highly toxic and carcinogen. Acute exposure to high levels of aniline will result in irritation of upper respiratory tract and congestion.

Antimony Compounds: Antimony is a silvery-white metal mined and then either changed to antimony metal. The concentration of antimony in ambient air ranges from less than 1 to about 170 ng/m³. However, concentrations may be greater than 1000 ng/m³ (0.01 mg/m³) near factories that convert antimony ores into metal, or antimony oxide (ATSDR 1992). Chronic exposure to antimony in humans causes antimony pneumoconiosis, alterations in pulmonary function, inactive tuberculosis, pleural adhesions, chronic bronchitis, chronic emphysema, irritation, cardiovascular effects and gastrointestinal disorders(ATSDR 1992; USDHHS 1993a, b)

Asbestose: Asbestos is a mineral fiber which is mined for commercial use. Due to its fiber strength as well as heat resistance, it has been used in roofing shingles, ceiling and floor tiles, and asbestos cement products, automobile clutch, brake, transmission parts, packaging, heat-resistant fabrics, gaskets, and coatings. Asbestos can be released to air when asbestos-containing objects are disturbed by cutting, sanding etc. Exposure to asbestos causes lung cancer, mesothelioma, and asbestosis.

Beryllium Compounds: This chemical enters air during combustion of coal, fuel oil, tobacco smoke, mining, and industrial activity involving beryllium compound. Acute exposure causes inflammation of the lungs and Chronic inhalation exposure causes chronic beryllium disease and increases risk of lung cancer.

Benzine: Benzene is released due to incomplete combustion of fuels in vehicles, domestic heating, oil refining, and handling/distribution storage of gasoline(petrol). Benzene is a carcinogenic pollutant.

Benzopyrene: Benzopyrene formed mainly from the combustion of organic material like wood, and from vehicle exhaust fumes, especially from diesel vehicles. Benzopyrene is carcinogenic to humans.

Benzotrichloride: Benzotrichloride is used in the dye industry and other chemical industry. Acute exposure to this chemical causes irritation to skin and mucous membranes.

Benzyl chloride: Benzyl chloride is a chemical intermediate in the manufacture of dyes and pharmaceuticals. The acute human exposure through respiratory track leads to severe irritation of respiratory tract, eyes, skin, mucous membranes and lung. Exposure to high concentrations affects the central nervous system.

Biphenyl: Biphenyl is used in dye carriers, heat transfer fluids, food preservatives, and as a fungistat. Acute human exposure to high concentration of this chemical causes eye/skin irritation. It imparts toxic effects on the kidneys, liver, and nervous systems.

Bis(2-ethylhexyl)phthalate (DEHP): This is used in the manufacturing of polyvinyl chloride. It exhibits low toxicity from chronic and acute exposures. Acute oral can cause gastrointestinal distress in humans.

Bis(chloromethyl)ether: In humans, acute human exposure to Bis(chloromethyl) ether may cause skin, mucous membrane, as well as respiratory tract irritation. Chronic human exposure to Bis(chloromethyl)ether causes chronic bronchitis, chronic cough, as well as impaired respiratory function. Bis(chloromethyl)ether is known human carcinogen(ATSDR 1989; USDHHS 1993a, b; USEPA 1999d).

Bromoform: Bromoform is used as intermediate in chemical synthesis, and as cough suppression agent; sedative; laboratory reagent; fluid for mineral ore separation during geological tests, and in quality assurance programs in the electronics industry. The acute effects from inhalation/ingestion of high levels of bromoform are slowing down of brain functions, and injury to the liver/kidney. Chronic effects include effects on the kidney, liver, and central nervous system. Bromoform has been classified as a probable human carcinogen (USEPA 1999c).

1,3-Butadiene: It is used as a monomer in the manufacture of synthetic rubber. Acute exposure to 1,3-butadiene by inhalation results in irritation of the nasal passages, eyes, throat, and lungs. Exposure may also causes cardiovascular diseases, leukemia. It is carcinogenic to humans by inhalation (USEPA 2009).

Calcium cyanamide: Calcium cyanamide is used as a pesticide, fertilizer, as well as in the production of other chemicals. Acute human inhalation exposure may cause rhinitis, pharyngitis, gastritis, laryngitis, and tracheobronchitis. Chronic human exposure can cause chronic rhinitis.

Caprolactam: Caprolactam is used in the production of synthetic fibers. Acute exposure may result in irritation and burning of the throat, eyes, nose, and skin. Chronic human exposure to caprolactam causes peeling of the hands; eye, nose, and throat irritation.

Captan: Captan is used as a fungicide on vegetables, fruits, as well as ornamentals. Acute exposure to captan may cause conjunctivitis as well as dermatitis in humans. It is classified as probable human carcinogen (USEPA 1997).

Carbaryl: Carbaryl is an insecticide. Acute and chronic human exposure will cause cholinesterase inhibition, and neurological effects. Prolonged low-level exposure can cause memory loss, headaches, muscle weakness and cramps, as well as anorexia (Sittig 1985; Budavari 1989; USDHHS 1993a, b)

Carbon disulfide: Carbon disulfide is used in the manufacture of cellophane, rayon, carbon tetrachloride, rubber chemicals and pesticides. Acute inhalation exposure can cause changes in breathing, chest pains, nausea, vomiting, headache, mood

changes, lethargy, dizziness, fatigue, blurred delirium, vision, and convulsions. Chronic exposure can lead to neurologic effects (ATSDR 1996).

Carbon tetrachloride: Carbon tetrachloride is used to make refrigerants as well as propellants for aerosol cans; and as a solvent for lacquers, oils, fats, varnishes, resins, rubber waxes. It is also used as cleaning agent and as a dry as a grain fumigant. Carbon tetrachloride will affect kidneys, liver, and central nervous system (CNS). Acute inhalation and oral exposures causes headache, lethargy, nausea, weakness, and vomiting. Acute exposures to higher levels as well as chronic inhalation or oral exposure leads to liver and kidney damage in humans.

Carbonyl sulphide: Carbonyl sulfide is emitted from oceans, volcanoes as well as deep sea vents. It is used in organic compound synthesis. Acute inhalation of high concentrations of carbonyl sulfide might cause narcotic effects in humans; and irritation of eyes and skin.

Catechol: Catechol is used as a developer for fur dyes; as a photographic developer; in polymerization inhibitors, as an intermediate for antioxidants in rubber as well as lubricating oils; and in pharmaceuticals. Chronic exposure causes eczematous dermatitis, depression of the CNS and a prolonged rise of blood pressure in humans.

Chloramben: Chloramben is used as a herbicide. Acute exposure to high levels of chloramben results in dermal irritation.

Chlordane: It is a pesticide. The acute effects of chlordane in humans are gastrointestinal distress as well as neurological symptoms. Chronic inhalation exposure of humans will affect nervous system and may cause cancer.

Chlorine: This is a pungent gas with greenish yellow colour and irritating odour. This gas which is heavier than air is used to form chlorides from ores as well as concentrates. Main applications of chlorine are in the manufacture of a wide range of industrial/consumer products, disinfection, and bleaching of paper pulp. Chlorine was used as weapon as Chlorine can react with water in the mucosa of the lungs and form hydrochloric acid. Hence chlorine irritates the respiratory system. The element iron can react with chlorine at high temperatures creating a *chlorine-iron fire*.

Carbon dioxide: This is colourless, odourless gas, heavier than air generated during combustion of carbonaceous fuels.

Carbon monoxide: This is colourless, odourless gas slightly lighter than air. This is used as a reducing agent and is a major component of producer gas and BF gas.

Cadmium compounds: Key contributors of cadmium into air is drying of zinc concentrates; and roasting, smelting, refining; waste incineration; production of nickel-cadmium batteries; combustion of fossil fuel; and cement manufacturing (Kazantzis 1987). The main sources of cadmium compounds in the atmospheric air are the combustion of fossil fuels and the incineration of municipal waste. Chronic inhalation to cadmium can cause kidney disease and the acute exposure affects lung.

Chromium Compounds: Chromium naturally occurs in rocks, animals, soil, plants, and volcanic dust. It occurs as trivalent chromium (Cr III), and hexavalent chromium (Cr VI) forms. Chromium is released in the form of small particles or aerosols. The major sources of chromium are from ferrochrome production;

chemical and refractory processing; ore refining; automobile brake lining as well as catalytic converters for automobiles; fossil fuel (oil and coal) combustion; dyes for paints; rubber and plastic products; chrome plating; pharmaceuticals; stone; wood; clay and glass products; electrical/aircraft manufacturing; steam/air conditioning supply services; incineration of solid waste; cement-producing plants; leather tanneries; pulp and paper mills and chrome pigments. Chromium (III) is less toxic than chromium (VI). Acute inhalation exposure to chromium (VI) results in gastrointestinal and neurological effects. Dermal exposure causes skin burns. Chromium VI is a carcinogen.

Cobalt Compounds: Cobalt is found naturally throughout the environment but higher emission may be observed due to industrial activity. Acute exposure results in respiratory effects, like decrease in ventilatory function, edema, congestion, and hemorrhage of the lung. Chronic exposure results in respiratory irritation, asthma, pneumonia, wheezing, and fibrosis. Cadmium also affects liver, kidneys, conjunctiva, and immunological system.

Coke Oven Emissions: Emissions from coke oven comprises variety of chemicals that results in cancer, severe dermatitis, conjunctivitis, lesions of the respiratory system as well as digestive system.

Cyanide Compounds: Cyanide is emitted in vehicle and number of industries. Cyanide compounds are extremely toxic to humans and animals. Chronic inhalation affects central nervous system, cardiovascular system, respiratory system, thyroid gland, eyes and skin.

Carbon disulfide: This is a colourless liquid with unpleasant odour and boiling point of 46.2 °C. The gas is used as solvent for elemental sulfur. It is formed in small quantity when SO₂ reacts with carbon at high temperature.

Cyanogen: This is a colourless gas with distinct odour. This gas is formed when hot air contact carbon under reducing conditions (as in the iron blast furnace). Since Cyanogen is soluble in water, scrubbed water will be contaminated with Cyanogen.

Chloroacetic acid: Chloroacetic acid is used in the making of cellulose ethers, synthetic caffeine, glycine, thioglycolic acid, dyes, as well as organic chemicals. Acute inhalation or dermal exposure may damage/irritate eyes, respiratory tract, mucous membranes, skin, and cause depression of the central nervous system.

2-Chloroacetophenone: 2-chloroacetophenone is used in tear gas as well as in chemical Mace as it is a strong throat, eye, and skin irritant.

Chlorobenzene: Chlorobenzene is used as degreasing agent, solvent, and chemical intermediate. Chronic exposure of humans to this chemical affects the central nervous system.

Chlorobenzilate: This is a pesticide not currently used in the USA and Europe. It is a non-systemic pesticide that works through contact and as a neurotoxin. USEPA has classified it as a, probable human carcinogen (USEPA 2015).

Chloroform: Sources of Chloroform include hazardous waste sites, pulp and paper mills, and sanitary landfills. It may be formed during chlorination of drinking water, wastewater as well as swimming pools. Acute inhalation exposure to chloroform may cause central nervous system depression. Chronic exposure by inhalation in humans can affects the liver and may result in hepatitis, as well as central nervous

system effects. USEPA (1999e) has classified chloroform as a probable human carcinogen.

Chloromethyl methyl ether: Chloromethyl methyl ether is used in manufacturing of some chemicals. Acute inhalation exposure can cause severe irritation of the eyes, skin, mucous membranes, pulmonary edema, respiratory tract, and pneumonia in humans. Chronic inhalation exposure can cause chronic bronchitis in humans. USEPA has classified this chemical as known human carcinogen (USEPA 1999n).

Chloroprene: Acute human exposure to chloroprene include headache, irritability, giddiness, dizziness, insomnia, respiratory irritation, cardiac palpitations, fatigue, chest pains, gastrointestinal disorders, dermatitis, nausea, temporary hair loss, conjunctivitis, as well as corneal necrosis. Symptoms of chronic exposure are fatigue, chest pains, dermatitis, irritability, giddiness, and hair loss.

Cresols/Cresylic acid (isomers and mixture): Ambient air contains small quantity of cresols from power plants, automobile exhaust, as well as oil refineries. Acute inhalation exposure to mixed cresols results in respiratory tract irritation and dermal irritation. USEPA has classified *o*-cresol, *m*-cresol, as well as *p*-cresol as Group C, possible human carcinogens (1999a, b, f).

Cumene: Cumene is used as lacquers, thinner for paints, enamels as well as a component of high octane fuels. It is also used in the manufacture of acetone, phenol, acetophenone, as well as methylstyrene. Acute inhalation exposure to cumene is skin and eye irritant. It may cause dizziness, drowsiness, headaches, slight incoordination, as well as unconsciousness in humans. It has a potent central nervous system depressant action.

2,4-D, salts and esters: 2,4-D, (2,4-dichlorophenoxyacetic acid), is a herbicide available as free acid, salts and ester. It generally has low acute toxicity via the oral/dermal/inhalation routes of exposure. At dose levels above the threshold of saturation for renal clearance, it is toxic to the thyroid, kidney, adrenals, eye, and ovaries/testes.

1,1-Dichloro-2,2-bis(p-chlorophenyl) ethylene (DDE): DDE is a breakdown product of DDT. EPA has classified DDE as a probable human carcinogen (USEPA 1999o).

Diazomethane: Diazomethane is used as a methylating agent. It is a strong respiratory irritant. Acute inhalation exposure of humans to diazomethane can cause irritation of the eyes, wheezing, asthmatic symptoms, cough, pulmonary edema, pneumonia, weakness, dizziness, headache, and chest pains.

1,2-Dibromo-3-chloropropane (DBCP): This chemical is used as an intermediate in chemical synthesis. Acute exposure to DBCP in humans results in depression of the central nervous system and pulmonary congestion. Chronic exposure affects male reproductive effects. USEPA has classified DBCP as probable human carcinogen (EPA 1997).

Ethylidene dichloride (1,1-Dichloroethane): Ethylidene dichloride is mainly used as an intermediate in chemical production. Acute inhalation exposure to high levels of these chemical results in central nervous system depression as well as a cardiostimulating effect. USEPA has classified ethylidene dichloride as possible human carcinogen (USEPA 1999g).

Fine mineral fibers: Fine mineral fibers include rockwool, glasswool, glass filaments, slagwool, and ceramic fibers. Chronic exposure to rockwool, glasswool, and slagwool will cause fibrosis. As per IARC, glass fibers and ceramic fibers are classified as Group 2B (possibly carcinogenic to humans), whereas glass wool, slag wool, glass filaments, and rock wool, is classified as Group 3, (not classifiable as to their carcinogenicity to humans) (IARC 1988).

Formaldehyde: Formaldehyde is an organic compound also known as methanal. A colorless gas at room temperature, it has characteristic pungent, irritating odor. It is a common precursor to more complex compounds. Formaldehyde in water, commonly called formalin or formol are used for preservation of biological specimens. It is also used in nail hardeners as well as nail varnish. It is known to be a human carcinogen.

Fluorine: This is a highly corrosive, colourless gas with a distinct odour which is heavier than air. This gas is produced by the fused electrolysis of Hydrogen Fluoride and Potassium Fluoride bath at 100 °C. Fluorine is used mainly for uranium isotopic enrichment and to produce uranium hexafluoride from uranium tetrafluoride.

Glycol ethers: Uses of Glycol ethers include use as solvents as well as an ingredient in liquid soaps, cleaning compounds, and cosmetics. Acute exposure to high levels of this chemical by humans results in narcosis, pulmonary edema, severe liver and kidney damage. Chronic exposure to the glycol ethers by humans may result in neurological as well as blood effects, including tremor, fatigue, nausea, and anemia.

Heptachlor: Heptachlor was used as an insecticide. Acute inhalation exposure to this chemical may result in nervous system effects. Chronic inhalation may lead to neurological effects including salivation, irritability, as well as dizziness.

Hexachlorobenzene: Hexachlorobenzene was widely used as a pesticide till 1965. Chronic oral exposure to hexachlorobenzene results in a liver disease with skin lesions.

Hexamethylene diisocyanate: This chemical is used as a polymerizing agent in polyurethane paints/coatings. Acute exposure to high concentrations of hexamethylene diisocyanate can cause pulmonary edema, coughing, as well as shortness of breath. This chemical is also extremely irritating to the eyes, nose, and throat. Chronic exposure may cause chronic lung problems.

Hexamethylphosphoramide: hexamethylphosphoramide is used as a solvent in research laboratories. The International Agency for Research on Cancer (IARC) has classified it as a Group 2B, possible human carcinogen (IARC 1987).

Hexane: Hexane is used as a special-use solvent, to extract edible oils from seeds/vegetables and as a cleaning agent. Acute inhalation exposure to high level hexane causes mild central nervous system effects. Chronic exposure to hexane in air is linked with polyneuropathy in humans.

Hydrazine: Small amount of hydrazine is present in tobacco smoke. Acute exposure to high levels of hydrazine can cause irritation of the nose, eyes, and throat. Acute exposure can also cause dizziness, headache, seizures, nausea, pulmonary edema,

coma in humans and can also damage the liver, kidneys, as well as central nervous system. USEPA (1999e) has classified hydrazine as a probable human carcinogen. *Hydrogen chloride*: This is a colourless gas forms dense white fumes in air due to reaction with atmospheric moisture forming hydrochloric acid. This gas may be formed accidentally in industry when gaseous chlorides leak and react with moisture in the air.

Hydrochloric acid: Hydrochloric acid is used in the manufacture of fertilizers, chlorides, dyes. It is used electroplating, textile, and rubber industries. It is corrosive to the eyes, skin, as well as mucous membranes. Acute inhalation exposure may cause irritation of nose, eye, and respiratory tract. Accute exposure can also cause inflammation as well as pulmonary edema in humans. Chronic occupational exposure to hydrochloric acid can cause chronic bronchitis, dermatitis, gastritis, and photosensitizations.

Hydrogen cyanide: This is a colourless gas with an odour resembling bitter almonds. This gas which is lighter than air may be formed during cyanidation process of gold ores. This gas is formed only at pH below 10 which may happen due to absorption of carbon dioxide in the air.

Hydrogen fluoride (Hydrofluoric acid): This gas is colourless, with penetrating odour, which is lighter than air. It is prepared commercially by reaction of concentrated H_2SO_4 and fluorspar (CaF_2). This gas is used in the fluorination of oxides. The Hydrofluoric acid, a solution of hydrogen fluoride in water is a fuming liquid with boiling point of 19.5°C .

Hydrogen sulfide: This is a colourless gas with odour of rotten eggs. It occurs in natural gas, and must be removed before using. The gas is used in hydrometallurgy for precipitation of copper, nickel, as well as cobalt from solution.

Hydroquinone: It is used as a developing agent in photography as well as as an antioxidant in rubber/food. Hydroquinone is a skin irritant in humans and chronic exposure can result in corneal effects, eye irritation, as well as impaired vision.

Isophorone: This chemical is a widely used solvent as well as chemical intermediate. The acute effects of this chemical due to inhalation include eye, nose, as well as throat irritation. Chronic exposure to isophorone in can cause fatigue, dizziness, and depression. Isophorone has been classified as a Group C, possible human carcinogen by USEPA (1999d).

Lead Compounds: Lead is used in batteries, metal products as well as ammunition. Mining, smelting, and processing of lead containing metal ores as well as lead are major sources of lead emissions from anthropogenic sources in addition to the combustion of wastes with lead. Lead can cause effects nervous, immune, renal, blood, as well as cardiovascular systems. Early childhood/prenatal exposures leads to learning deficits, slow cognitive development, and other effects. Exposure to high quantities of lead can cause gastrointestinal symptoms, damage the brain and kidneys. Exposure to higher amounts lead may cause reproductive effects and cancer.

Lindane: Lindane is used as an insecticide. The acute effect of lindane through inhalation leads to irritation of the nose and throat. Chronic exposure affects blood, liver, nervous, cardiovascular, as well as immune systems. USEPA (1997) has classified lindane as a Group B2/C, possible human carcinogen.

Maleic anhydride: Acute inhalation of maleic anhydride will cause irritation of the respiratory tract and eye. Chronic exposure to maleic anhydride will cause, asthma-like attacks, chronic bronchitis and irritation of upper respiratory tract as well as eye.

Methanol: Methanol is released to the atmosphere during industrial uses as well as naturally from vegetation, volcanic gases, and microbes. Acute/chronic exposure to methanol may result in headache, dizziness, blurred vision, and nausea.

Methoxychlor: Methoxychlor is a pesticide and may enter air during manufacture/use. Dermal contact to this chemical is slightly irritating to skin. Chronic oral exposure can affect liver, kidneys, as well as nervous system.

Methyl bromide (Bromomethane): Methyl bromide from anthropogenic activity includes fumigation, leaded fuel additive, biomass burning. Because its toxicity it is used for control of wide range of pests.

Methyl chloride: Methyl chloride is used in the production of methylate silicon, agricultural chemicals, quaternary amines, methyl cellulose, butyl rubber and tetramethyl lead. Apart from emission from manufacturing these products dichloromethane is also emitted from coal combustion and biomass burning. Acute exposure of methyl chloride causes severe neurological effects. It also effects heart rate, liver, blood pressure, and kidneys. Chronic exposure affects liver, spleen, kidney, and central nervous system.

Methyl chloroform (1,1,1-Trichloroethane): This chemical is used as a solvent as well as in many consumer products. Acute inhalation leads to hypotension, mild hepatic effects, as well as central nervous system depression.

Methyl ethyl ketone (2-Butanone): This section is used as a solvent. Acute inhalation exposure in humans results in irritation to the nose, eyes, and throat. Chronic inhalation results in slight neurological, liver, kidney, as well as respiratory effects.

Methylene chloride (Dichloromethane): Dichloromethane is a colourless liquid that easily evaporates to vapour. It is non-flammable. Dichloromethane are used as paint removers; as a flame retardant after mixing with some propellants; as aerosol solvents; manufacture of steroids, antibiotics and vitamins; in the electronics industry and as an extracting/degreasing agent.

Methyl isocyanate: Methyl isocyanate is used to in production of carbamate pesticides. This chemical is extremely toxic that lead to death of about 3800 people as well as adverse health effects on 170,000 survivors in Bhopal, India.

4,4'-Methylene diphenyl diisocyanate (MDI): The commercial form of MDI is used to manufacture polyurethane foams. Acute inhalation of high concentrations of MDI can cause sensitization as well as asthma in humans. Acute dermal contact can cause dermatitis and eczema. Chronic inhalation exposure to MDI can cause asthma, dyspnea, as well as other respiratory impairments.

4,4'-Methylenedianiline (MDA): This chemical is mainly used to produce 4,4'-methylenedianiline diisocyanate as well as other polymeric isocyanates. Acute oral/dermal exposure to MDA causes liver damage. MDA can irritate the skin as well as eyes in humans. IARC has categorized MDA as a Group 2B, possible human carcinogen (USDHHS 1993a, b).

Nitric oxide: It is formed in trace amounts when a fuel is burnt with air and hence will be present flue gases. This colourless gas reacts readily with atmospheric oxygen to form brownish red Nitrogen dioxide.

Nickel carbonyl: This is an odourless and colourless gas formed during nickel refining process when impure nickel reacts at high temperature and pressure with Carbon monoxide. The Nickel carbonyl need to be decomposed at atmospheric pressure and high temperature to form nickel and Carbon Monoxide for recycling.

Nitrogen dioxide: This is an orange-red gas formed during oxidation of atmospheric nitrogen in furnaces, boilers, incinerators etc., This gas is also formed when nitric acid and minerals react with each other.

Ozone: This colourless gas with peculiar odour is heavier than air. It is sometimes used as oxidizing agent. Motor vehicles, chemical industries and combustion activities are major source of ground level ozone. Ozone may be formed due to reaction of oxides of nitrogen and VOC under the influence of sunlight.

Oxides of nitrogen: Only about 10 % of all oxides of nitrogen emissions come from anthropogenic sources. Combustion of fossil fuel, waste and chemical manufacturing are major anthropogenic sources of oxides of nitrogen.

Phosgene: Phosgene which is also known as carbonyl chloride is a colourless volatile liquid below 8.2 °C which was used as a toxic gas in World War I. It is formed during the chlorination of metal oxides under certain conditions.

Phosphine: Phosphine which is also known as hydrogen phosphide is a colourless gas with odour resembling decayed fish. Acetylene, generated in metallurgical industry contains traces of phosphine. Phosphine is formed due to presence of small quantities of phosphorus in the raw materials.

Polycyclic Organic Matter: These compounds are formed normally from combustion and occur in the form of particulate matter. Sources vehicle exhaust, include cigarette smoke, laying tar, home heating, and grilling meat. These pollutants can cause cancer.

Manganese Compounds: Manganese occurs naturally in many rock and soil thereby entering during re-suspension of soil and dust during agricultural and constructional activities as well as vehicular movement. Manganese can also be released by power plants, iron and steel plants as well as coke ovens. Chronic exposure to manganese by inhalation in humans may cause central nervous system effects and a syndrome named manganism. Manganism is characterized by weakness and lethargy, a mask-like face, tremors, and psychological disturbances.

Mercury compounds: Major sources of atmospheric mercury due to anthropogenic activity are fossil fuel combustion, mercury-cell chlor-alkali production, coke ovens, and incineration of waste with mercury and recovery of gold by the amalgamation process (now not practiced in most parts of the world). Mercury exists in the form of elemental mercury, inorganic mercury compounds, and organic mercury compounds. Chronic exposure to elemental mercury results in erethism (increased excitability), excessive shyness, irritability, and tremors. Acute exposure to high levels of elemental mercury results in mood changes, tremors, as well as slowed sensory and motor nerve function. Acute exposure to inorganic mercury orally may result in vomiting, nausea, and severe abdominal pain. Chronic exposure to

inorganic mercury leads to kidney damage. Exposure of experimental animals to mercuric chloride resulted in thyroid, forestomach, and renal tumors. Chronic exposure to methyl mercury results in paresthesia, speech difficulties, blurred vision, malaise, as well as constriction of the visual field. Acute exposure methyl mercury results in deafness, blindness, and impaired level of consciousness. Children born to women who consumed high levels of methyl mercury show ataxia, mental retardation, blindness, constriction of the visual field, and cerebral palsy (ATSDR 1999; USEPA 1999h, i, p).

Nickel Compounds: Nickel is found in ambient air at very low levels as a result of releases from oil and coal combustion, nickel metal refining, sewage sludge incineration, manufacturing facilities, and other sources (ATSDR 1997). Nickel dermatitis is the common effect in humans due to chronic exposure. Nickel refinery dust as well as Nickel subsulfide are human carcinogens, and nickel carbonyl is probable human carcinogen (USEPA 1986, 1999q, r, s, t).

Radionuclides: Radiation from naturally-occurring radioactive materials, like uranium, thorium and radon are harmful to health. The radon gas comes from the decay of radium present in almost all soils. Quantity of radon varies place to place. Radon migrates into buildings from the soil through cracks/holes in foundations/walls. Accumulated radon, inside the buildings, can be a health hazard. Radon in the air decays into polonium, which, can damage lung cells and can lead to lung cancer.

Selenium Compounds: Selenium naturally occurring substance which is toxic at high concentrations. Acute exposure to hydrogen selenide, elemental selenium, as well as selenium dioxide by inhalation results irritation of the mucous membranes, severe bronchitis, pulmonary edema, as well as bronchial pneumonia. Chronic exposure to Selenium compounds leads to discoloration of the skin, loss of hair, deformation and loss of nails, lack of mental alertness, excessive tooth decay and discoloration, and listlessness.

Sulfur chlorides: Sulfur dichloride (SCl_2) is a reddish brown liquid with boiling point of 59°C while Sulfur monochloride is a yellow liquid with a boiling point of 138°C . These chlorides are formed during the treatment of concentrates of sulfide with chlorine.

Sulfur dioxide: This is a colourless gas with characteristic pungent odour. All fossil fuel contain sulfur. Sulfur dioxide is generated due to combustion of fuels with sulfur and melting/roasting of sulfur/suphide bearing ores.

2,4,6-Trichlorophenol: 2,4,6-Trichlorophenol is used as an antiseptic; pesticide; as an anti-mildew treatment; and manufacture of other chemicals. It is not used in USA now (ATSDR 1990). Inhalation of this chemical is likely to cause respiratory effects, such as chronic bronchitis, chest wheezing, cough, altered pulmonary function, as well as pulmonary lesions. It is a probable human carcinogen (USEPA 1999k).

Triethylamine: Triethylamine is used as an accelerator activator for rubber; as a catalytic solvent in syntheses of chemical; as a corrosion inhibitor; as a propellant; as a curing and hardening agent for polymers; in the manufacture of wetting/penetrating/waterproofing agents of quaternary ammonium compounds; as

well as for the desalination of seawater. Acute exposure to triethylamine vapor causes corneal swelling, eye irritation, halo vision, skin irritation and irritation of mucous membranes in humans. Chronic exposure to triethylamine vapor can cause reversible corneal edema (USDHHS 1993a, b).

Trifluralin: Trifluralin is used mainly as an herbicide. Acute animal tests on animals have shown trifluralin to have moderate acute toxicity by inhalation. (USDHHS 1993a, b).

2,2,4-Trimethylpentane: 2,2,4-Trimethylpentane is used, as a solvent, thinner, in organic syntheses, and in determining octane numbers of fuels, in spectrophotometric analysis. It is released to the environment through the production, use, and disposal of products associated with petroleum/gasoline(petrol) industry. Exposure to 2,2,4-Trimethylpentane can cause necrosis of the skin and tissue, irritation of the lungs, edema, as well as hemorrhage(USDHHS 1993a, b; Clayton and Calyton 1981).

Vinyl acetate: Vinyl acetate is used as a monomer in the manufacture of polyvinyl acetate, polyvinyl alcohol, other chemicals, adhesives, nonwoven textile fibers, water-based paints, paper coatings, textile sizings/finishes, inks, films, and lacquers. Acute inhalation can result in eye irritation as well as upper respiratory tract irritation.

Vinyl bromide: Vinyl bromide is mainly used in the production of flame retardant synthetic fibers. Acute and chronic exposure will damage liver. In high concentrations, it may cause disorientation, dizziness, and sleepiness in humans.

Vinyl chloride: Vinyl chloride is used in production of polyvinyl chloride as well as vinyl products. Acute exposure to high levels of vinyl chloride can result in central nervous system effects like dizziness, drowsiness, as well as headaches in humans. Chronic exposure through inhalation/oral exposure can damage liver and cause cancer.

Vinylidene chloride (1,1-Dichloroethylene): Vinylidene chloride is used in chemical synthesis as an intermediate to manufacture polyvinylidene chloride copolymers. The acute effects in humans due to exposure are on the central nervous system. Low-level, chronic inhalation exposure of vinylidene chloride may affect the liver kidneys, central nervous system and lungs.

Xylenes: Xylene is an aromatic hydrocarbon comprising of a benzene ring with two methyl substituents. Representing around 0.5–1 % of crude oil, xylenes are found in small quantities in gasoline as well as airplane fuels. Xylenes are used in solvent, paints, coatings, and gasoline(petrol).

Xylene are released from refineries during the production, transport as well as processing of petroleum. It can also enter the environment from automobile exhaust, during the use of certain solvents, as well as from hazardous waste landfills. It can also enter the environment from accidental spill/leak. Symptoms of xylene poisoning include drowsiness, excitement, tremor, headache, dizziness, nausea, vomiting, irregular heart rhythm, inflammation and fluid in the lungs, liver and kidney damage, loss of muscle coordination, and coma. Vapours of xylene are mildly irritating to the skin, but repeated/prolonged contact can cause skin to crack/peel.

2.2 Regulatory Issues

Regulations are important but effective only if implemented. Member states of United Nations published many acts, rules to protect environment and control pollution since 1972 after The United Nations Conference on The Human Environment. The effectiveness of implementation these legislations are still questionable as these laws are enforced by government institutions which are obedient to ruling parties. The legislations which came across the globe to satisfy international relationship have not met with the goals in many regions. The failure may be due to inherit weakness within the law which do not stipulate basis to calculate manpower, action against erring officers, and time bound action to curb air pollution. The implementation usually deviates from published legislation due to difference in communication from people in power which is rather oral.

Figure 2.4 shows issues affecting legal efficiency at regional level. Despite of several environmental legislations supplied to citizens by nations across the world

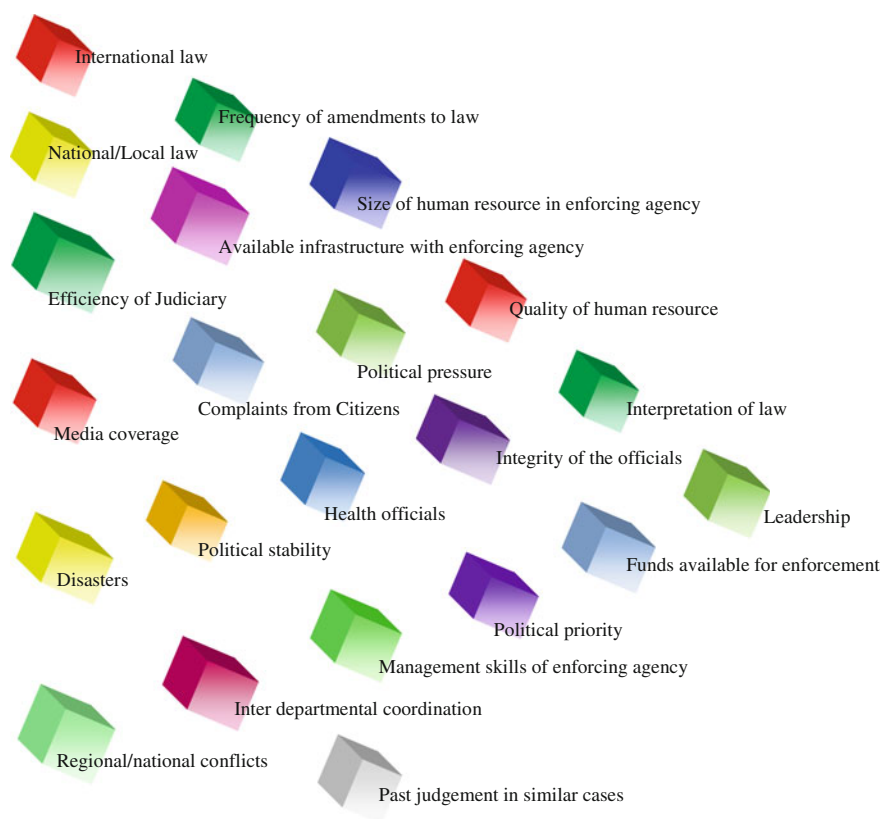


Fig. 2.4 Issues affecting legal efficiency at regional level

quality of environment has deteriorated since 1972. The reasons are due to weak institutions without skill, sufficient manpower, commitment and funds. Corruption has been part of these institution and legislations are used to generate personal and political funds by people in the power.

In theory the legislation to control Air pollution combines several approaches to prevent air pollution. One of the approaches is stipulating National Ambient Air Quality Standards that fix maximum concentration of pollutants in the atmosphere. Once the ambient air quality is fixed it is the duty of executive wing of the government to attain the goals. Some of the approached to be achieve ambient air quality standards are: (1) allowing only nonpolluting industries where a region has already been polluted, (2) insisting clean fuel, (3) regulating/restricting number of vehicles in a region, (4) sustainable urban design, (5) fixing maximum population density in any area, (6) extending tax benefits and other economic benefits to non polluting industry, (6) proper solid waste management, (7) stipulating vehicular emission standards, (8) stipulating industrial emission standards, (9) banning fuels which are harmful to environment, (10) providing sustainable transportation, (11) restricting movement of vehicles with old technology which do not comply with new standards, (12) closing the polluting industry/mines, (13) paving the unpaved roads, (14) carrying out afforestation, (15) extinguishing forest fires, (16) maintaining parks in urban area, (17) banning crackers, (18) restricting industries in valleys and adjacent to hills where dispersion of air is minimal, and (16) research and development.

Most of the legislation to protect environment are so stringent that in theory converts all the entrepreneurs into criminals. Neither the ambient air quality standards nor emission standards can be achieved by the industry. Hence the regulators turn away with blind eye or issue notices and drag the case or makes false monitoring and manipulate the analysis reports. In a system where in corruption plays major role in recruitment it is hard to get any fair officers. Further in a system, wherein political leaders raise questions in assembly and parliament, officers often fear discharging duty fairly against politicians. The fear of officers also suppress discharging duty against system where in officers are subordinate to corrupt politicians.

Impractical laws, and practical difficulties leads to poor implementation of laws.

2.3 Standards and Consents

The word ‘consent’, ‘authorisation’ and ‘registration’ are preferred instead of ‘licence’ for the permit granted by agencies designated for protecting environment. Standards are stipulated while consent to industries. The standards with respect to air are either ‘emission standards’ or ‘ambient standards’ or both. The occupier is responsible for maintaining these standards even though the occupier of unit hardly has control on ambient air quality in an area which has many air pollution source like vehicular emission, wild fires and/or volcanic eruption.

2.3.1 Ambient Air Quality Standards

Ambient air quality standards are set at national level to attain the same by policies, permits and regulation. It is the duty of executive wing of government to make policies and advice legislature/judiciary wing as required to attain the ambient air quality.

Some of the policies/permits/regulation that would help quality of air within the limits are: (1) urban planning, (2) fuel quality, (3) industrial development, (4) mass transportation, (5) permitting only non polluting industry in the area where quality of air has already exceeded standards, (6) permitting roadways considering air quality of the area, and (7) regulating product capacity of the industry in case ambient air quality exceeds the limits.

2.3.2 Emission Standards

Emission standards are limits set for the pollutants emitted from outlet of source. The outlets in mobile sources are exhaust pipe and outlet in stationary source is normally chimney or stack. These standards can be set uniformly though out the country for the activity (like thermal power plant, cupola furnace or diesel generator) or can be set case to case after considering quality of ambient air.

Emission standard helps manufacturer of vehicle and equipment to design the product to suit standards. If the ambient air is already polluted then regulatory authority usually makes standards stringent to maintain better air quality.

2.4 Agriculture and Air Pollution

Agriculture contributes to emissions of GHGs and other pollutants. The emission occur due to emissions from livestock, decay of organic matter in agricultural fields, use of agro chemicals etc., Unsustainable agriculture and associated activity could generate substantial air pollutants. The major air pollutants from agriculture and associated activity are given in Table 2.1.

About 80 % of the ammonia used as fertiliser ends up in the soil and atmosphere. Ammonia is also produced in natural setup due to biodegradation of organic matter in soil. Modern agriculture has increased ammonia emission more than 20 altering the natural nitrogen cycle resulting in eutrophication of waters and increasing tropospheric ozone due to atmospheric chemical reaction. Over application, exposure of fertilizer granules to atmosphere after application is usual reasons from ammonia emission from atmosphere which needs prudent use and education of farmers. Sustainable use of these fertilizers by loosening the soil prior to application and properly covering manure by soil help in reduction of ammonia into

Table 2.1 Major activity and pollutants released

Sl. No	Activity	Pollutants
1	Application of nitrogenous fertilisers	Ammonia
2	Spraying agrochemicals	Agrochemicals
3	Slash and burn agriculture	CO, SO ₂ , NO _x , particulate matter, hydrocarbons, methyl chloride, methyl bromide
4	Curing of tobacco	CO, SO ₂ , NO _x , particulate matter, hydrocarbons
5	Paddy fields and sugar cane fields	Methane , Methyl chloride, Methyl Bromide
6	Cattle rearing	Methane
7	Poultry	Methane
8	Fumigation for grain protection, structure protection, green house	Aluminum phosphide, chloropicrin, magnesium phosphide, methyl bromide, sulphuryl fluoride, acrylonitrile , acetaldehyde , azobenzene, chloroform , dichloronitroethane, ethylene chlorobromide, methyl allyl chloride, methylene chloride, nicotine, propylene dichloride, sulphur dioxide, methyl chloroform (1,1,1-trichloroethane)
9	Fumigation for ripening banana	Ethylene
10	Soil fumigation	Chemicals containing chloropicrin, methyl bromide, 1,3-dichloropropene, and iodomethane

atmosphere. Testing the soil prior to fertilizer application to assess the exact requirement will also help in reduction of ammonia emission from agriculture. Application of fertilizer through drip irrigation after dissolving in water also avoids excess application of fertilizers. Apart from fertilizer, fumigation is also major source of pollution.

Aluminum phosphide, chloropicrin, and magnesium phosphide are major fumigants used pesticides in the form of gases for pest control. These gases are used as they are slightly heavier than air can seep into the smallest of cracks as well as crevices. Hence they have become a popular solution to rodent infestations/insect in stored grain. But these gases are highly toxic and ultimately escape to atmosphere.

Bananas are generally ripened in rooms with 2–3 exposures to ethylene gas 6 hourly applications for 1–4 days or at 1:1000. Post-ripening storage in air with 10–100 ppm ethylene accelerates softening and fruits will remain clear yellow with attractive with few or no surface brown specks.

Apart from fumigation, spraying agrochemicals for controlling fungus, insects/pests also pollutes air affecting human/animal health.

2.5 Indoor Air Pollution

The quality of air inside homes, office and other work place has become a matter of growing concern as homes and work places are not fully safe. Our knowledge of indoor air quality has been increasing increasingly in recent years (Maroni et al. 1995). The concentration of air pollutants inside living or work space depends on a numerous of factors: (1) volume of air contained, (2) rate of release of the pollutant into the space, (3) rate of elimination of the pollutants due to filtration, reaction and/or settling, (4) rate of formation of new air pollutants die to reaction within the space, and (5) concentration of the pollutant entering from outdoors.

Indoor air pollution at homes/offices/restaurants/hotels can occur due to array of sources that include: (1) heating, (2) cooking, (3) smoking of tobacco, (4) evaporation of solvents from paints/varnishes, (5) biological aerosols arising due to coughing/sneezing and treatment of patients, (6) disintegration of building, (7) emission from office automation equipments, (8) mercury evaporation during accidental spillage, (9)spraying chemicals, (10) fumigation, (11) decaying organic matter, (12) animal hair and dandruff, (13) cosmetic/personal care products, (14) adhesives, (15) cleaning and waxing, (16) Automotive products, (17) hobby supplies(photographic chemicals, clay, wood fillers, chalk dust etc.), and (18) contaminated water/sewage.

Indoor air at foundries, assembly lines, laboratories, chemical industries, garages, waste handling units, food making/packaging industry, plastic molding, health care establishments, slaughter houses, printing, paper making, metallurgical industries, cutting/polishing of stones, timber cutting etc., will have different indoor air quality which are much more dangerous than at homes and offices. Health care establishments of humans/animals are sources of nosocomial infections which have been reason for disease spreading to doctors/visitations/staff/patients.

Emissions are complex and quantity varies at each source and time in a different manner. Studies on three dimensional printers suggest caution should be taken when operating in unfiltered or insufficiently ventilated indoor environments. Moldy surfaces in household can release volatile compounds which induce symptoms typical with Parkinson disease (Samhita 2014).

Combustion sources are the chief indoor generators of particles which contain organic and inorganic material. Sprays and cooking aerosols also contribute to particles in addition to biological contaminants such as viruses, bacteria, fungal spores, pollens, fragments of feces, dried animal secretions (e.g., urine, saliva) as well as animal dander. Coarse-mode fractions consist largely outdoor dusts, insect fragments, animal hair etc. Emissions from stoves and fireplaces vary depending on the design/operation of the unit. Emission from cooking also varies depending on the ingredients and method of preparation.

Indoor air can also have Radon (Rn) a radioactive noble gas. Radon can easily leave the place of generation (soil, rock and building material) and enter living space. The radon gas comes from the decay of radium present in almost all soils and migrates into buildings from the soil through cracks/holes in foundations/walls.

2.6 Air Pollution Management for Wildlife Conservation

Air pollution can occur in gas/liquid/solid forms. It can be highly toxic or low toxic. The wild life can react to air pollution in intricate way. It can show resistance or perish. Air pollution management to protect wild life is not a priority to air pollution managers who usually dwell in urban areas.

Air pollutants can enter wild by air pollution due to wild fire, volcano etc., and dispersion of anthropogenic emission.

2.7 Zoning Atlas for Urban Development

As the population of human settlements changed rural areas around the world gradually turned to urban areas. Most of the cities have been developed due to historic reasons. Urban settlements have been pool for tradable skills and business and holds population with particular skills like diamond trading in Antwerp; Software development in Bangalore; manufacturing skills in cities of China etc. Over the years urban development has been done keeping demands for housing and trade. Some of the cities have been developed by real estate business establishments keeping interest of their business. Most of the developing countries which are keen to industrialise gave away lands at the outskirts for industries. Location of industries adjacent to sensitive area has been cause for adverse impact on sensitive ecological setup.

Hence zones of areas is essential to limit ambient air quality by allowing proper lungspace for dispersion of pollutants.

2.8 Air Pollution Management in Urban Settlement

Air pollution management in urban settlement is complex situation which needs case to case approach as size and activities of urban area varies widely. While Geneva can be crossed within 10 min in bicycle, it needs half to one day in Bangalore to do the same task. The population, traffic, discipline among the citizens, industries, commercial activity, quality of roads, conflicts on roads, waste management, drilling borewells (Fig. 2.5), construction and demolition etc., add to urban air pollution. The source and management approach for air pollution is given Table 2.2.

There are many success stories and failure stories with respect air pollution management. The curbing of air pollution from industries have been failed due to low staff in agencies responsible for inspecting polluting industries. Many of polluters operate the polluting activities during holidays and night to avoid penal action or huge bribe to be given to inspectors. The corruption has also weakened the spirit

Fig. 2.5 Air pollution during drilling borewell



of air pollution management in many countries. In many circumstances polluter will transfer his favourite officer in the location desirable to polluter.

Certification of vehicles by private agencies recognized by government department has been in failure in many parts of the world due to nexus between these agencies and departments. The quality checking of fuel in gasoline(petrol) refilling stations across the city lead to agitation and resistance by all the gasoline(petrol) bunks in Bangalore resulting in public inconvenience. Pollution checks followed by restriction to entry the city resulted in entry of vehicles in night times in Bangalore when emission checking was not carried out by officials. An attempt to catch culprits of fuel adulteration resulted in murder of government official in India.

Covering of trucks carrying soil has been not satisfactory in many parts of the world due to corruption and resistance from truck owners association. Action to scrap aged vehicle with inappropriate pollution control technology has also been cause for agitation and strike by truck owners association in some parts India.

The covering of buildings completely so as to curb dust is inefficient due to nexus between real estate owners, politicians and government officials. Proper pavement to avoid re-suspension of dust is not priority in many parts of the world.

Table 2.2 Air pollution management approach in urban settlement

Sl. No.	Activity	Air management approach
1	Traffic	• Adopt national policy for emission and allow manufacture of vehicles with Best Available Technology (BAT) with respect to emissions
		• Switch over to green fuel (natural gas/ CNG/ electricity / hydrogen) driven vehicles
		• Create infrastructure for mass transportation
		• Discourage horizontal growth of cities and immigration of rural population to cities
		• Impose traffic congestion tax by collecting tax from the vehicles entering city
		• Provide ring road to divert the vehicles
		• Earmark Low Emission Zones in urban areas to restrict entry of most polluting vehicles
		• Adopt lower urban speed limits as movement of vehicles with higher speeds consumes more fuel and generates more pollutants
		• Restricting car access to sensitive/polluted areas
2	Industries	• Dissipate knowledge of clean technology
		• Insist continuous emission monitoring
3	Commercial activity	• Ensure installation of pollution control equipments in commercial establishments like restaurants
4	Quality of roads	• Improve quality of roads to reduce re-suspension of dust
		• Adopt sprinkling
5	Conflicts	• Provide good governance to avoid riots
		• Manage conflict earliest
		• Extinguish fire during riots earliest
		• Make conflict management plan
6	Waste management	• Avoid burning of waste and litter
		• Avoid re-suspension of dust during sweeping roads
		• Avoid littering and rotting of waste
		• Use of methane generated from landfill
7	Disaster management	• Manage air pollution causing disaster in shortest period
		• Mitigate air pollution from disaster prone site in earliest possible time
		• Foresee possible natural and anthropogenic disaster and prepare Emergency Preparedness Plan, and Disaster Management Plan
8	Fuel adulteration	• Take proper samples from fuel shops
		• Adopt proper investigation methodology including secrete investigation as adopted in crime
9	Land use	• Avoid encroachments of lung spaces (Fig. 2.6) like gardens and open spaces
		• Plan the land use change
		• Avoid cutting trees
		• Grow more trees

(continued)

Table 2.2 (continued)

Sl. No.	Activity	Air management approach
		• Fence and protect free spaces of government before it is converted into slums or occupied illegally by influential people
		• Provide dedicated pedestrian ways (Fig. 2.7)
10	Mass transportation	• Encourage car sharing • Consolidation of goods and optimization of urban freight transport • Encourage mass transportation by subsidizing the bus/metro/tram services
11	Restriction of certain fuel	• Ban wood/coal fired boilers and stoves for domestic/commercial heating/cooking
12	Energy management	• Enhance energy efficiency during transmission • Increase dependency on solar/wind/tidal energy • Phase out thermal power plants and nuclear power plants
13	Harbour management	• The use of electric power for ships anchored in port • Reduce speed near cities
14	Green public procurement	• All government agencies should buy less polluting vehicle
15	Airport management	• Green approaches wherein pilot depends on communication between the airplane's computers as well as the air traffic control system to compute the aircraft's landing time and glide the aircraft during the final stage of landing using less fuel • Connect airport with electric train and vehicles with renewable/hybrid fuel

**Fig. 2.6** Lung space

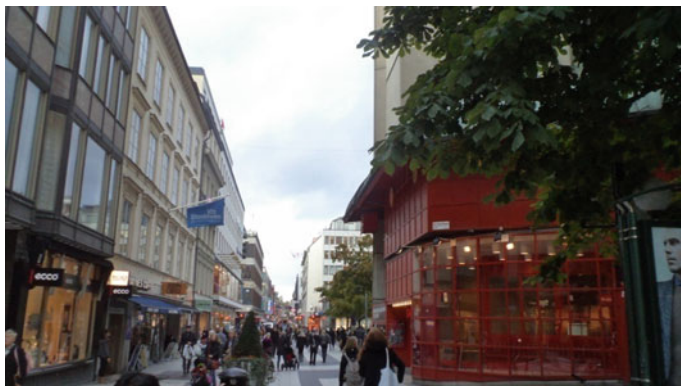


Fig. 2.7 Dedicated pedestrian way

Copying the practices of developed countries in developing countries is not possible due to various reasons. Figure 2.8 shows electric cars in Sweden which cannot be used in developing countries due to nonavailability recharging facility across the developing countries and availability/affordability of such cars. Presence of slums in the centre of cities of developing countries that contribute to air pollution act as vote banks the elected politicians. Hence developing countries usually avoid decisions and policies that affect harmony of citizens in slums. Ultimately the emissions due use of coal, kerosene, combustible waste (like waste cotton from workshops, paper cartoon box, coconut shells) in the centre of city will not be eliminated. Combustion of waste by homeless people, slum dwellers, truck drivers during winter to warm themselves is a scenario often not seen in developed countries.



Fig. 2.8 Electric cars parked in Sweden

Box 2.1 Case studies

Beijing

The government implements of Euro IV emission standards between the year 2000–2008 (pre-Olympic). The government banned diesel cars in the year 2003. The city restricted Euro III heavy duty vehicles and restricts movement of Euro I cars. The city introduced 20,000 buses, metro and light railway. The city adopted a system under which different days were fixed for allowing cars with odd or even number plates on roads. The city implemented stringent checks on industries. After the year 2008 (post Olympic period) the city capped the number of cars to be sold in a year and introduces Euro v emissions standards and fuel with 10 ppm sulphur for buses and municipal fleet in February 2013. The government introduced vehicle inspection using remote sensing technology. The city increased parking fee in February 2011. The city improved subway and light railway network. The government hiked subsidy on scrapping vehicle and promoted CNG and electric vehicles (CSE 2014).

Delhi

The city enforced Euro II emission standards in 2000 and Euro III in 2005. Further the city mandated pre-mix gasoline(petrol) to two/three wheelers and introduced unleaded gasoline(petrol). The city buses and three-wheelers switched over to CNG. Delhi phased out 15-year old commercial vehicles and banned open burning. The city expanded the metro rail network and introduced 6000 new buses. Delhi introduced Euro IV standards in 2010. The city upgraded tests for pollution certificates and starts Air Ambience Fund in 2009 for promoting clean air policies. The city also constructed 40 km of cycle tracks with new footpaths in 2010 (CSE 2014).

There are three major issues linked to air pollution in Delhi. First is natural sources such as soil dust and road dust. Secondly, local emissions from transport and industries and thirdly the pollution transported from nearby states. During 1990s, diesel driven buses were the major source of air pollution in Delhi city. But after the Supreme Court decision, the buses were run on CNG which gave a relief to the citizens of Delhi. However, at present, Delhi is victim of trans-boundary pollution from nearby states such as Uttar Pradesh, Haryana and Punjab. Hundreds of brick kiln units have come up in National Capital Region which are strong source of trans-boundary pollution in Delhi. During winters of 2014, Delhi had the worst air quality due to these sources. Crop residue burning and outside heavy duty vehicles entering into the city are also important external sources affecting air quality in Delhi. Hence, in order to solve the air pollution problem of Delhi, one joint task force involving Delhi, UP, Haryana and Punjab governments needs to be developed which will be looking for a joint action. While comparing the air pollution scenario of Delhi and Beijing, we have to consider the difference in

topographical and meteorological conditions between two cities. Air pollution in Delhi gets dispersed very soon except few localities. Delhi is probably blessed with very high natural dispersion of pollution where pollution cannot stagnate more than a few days which is not the case of Beijing. The fact is that Delhi or any city in India especially the north India, atmospheric dust and black carbon are the two major pollutants which create haze reducing the visibility. So far gaseous pollution is concerned, the situation is almost controlled except carbon monoxide and sometimes ozone.

Stockholm

The city adopted congestion tax and environmentally efficient mass transport. The city was planned and incorporated open space within the city. Building under construction will be completely covered. The construction of building in the city by prefabricated components has reduced emission and solid waste. Stockholm-Arlanda has shown preference to eco taxis. These taxis can often leave the holding area immediately to separate queue for renewable or hybrid fuel powered taxis outside the terminals. Green approaches were introduced at Stockholm-Arlanda air port in the year 2006 wherein pilot depends on communication between the airplane's computers as well as the air traffic control system to compute the aircraft's landing time and glide the aircraft during the final stage of landing, with engines running at lower speed avoiding waiting time in the air thereby reducing fuel consumption, noise and air pollution. Each green approach saves up to 150 kg of fuel.

2.9 Air Pollution in Rural Areas

The main source of air pollution in rural areas depends on which part of the world is rural area. The emission depends on the activity. The rural activities usually do not include industrial emissions. Apart from natural emissions like volcanic eruption and wild fire, emission from rural area include:

- Emission from marshes and paddy fields;
- Emission from cattle;
- Emission from waste dumping/management;
- Emissions from cooking;
- Emissions from pot making activity;
- Emissions from burning in fields;
- Emissions from dehulling and grain separation processing;
- Spraying of agrochemicals;
- Pollen grains; and
- Re-suspension of Soil in tilled land.

2.10 Air Quality Deterioration

Emissions of air pollutants originate from almost activities. Population living in/around urban area are normally exposed to deteriorated air. The quality of air in urban will usually have more pollutants compared to its outskirts with some exception like region with wild fires. Policies implemented national and sectoral level have resulted in reduction in emission of many air pollutants (e.g., Pb and CO) in Europe. But road transportation, power plants, industry, agricultural activities as well as households continue to release significant quantities of air pollution. Combustion of wood and coal by households is an important source of PM as well as polycyclic aromatic hydrocarbons (PAH). Agriculture is major ammonia source emissions. Emissions from agriculture have decreased very little and emissions from domestic activity have not decreased. Biomass combustion has become more important as wood burning is cheap, renewable and carbon-neutral source of energy. Many air pollutants are transported from other countries and continents. Trans-boundary air pollution is a major challenge in Europe as less than 50 % of PM_{2.5} concentrations originate from their own emissions (EEA 2013).

Air pollutant emissions in East Asia is responsible around 36, 29, and 36 % to worldwide emissions of SO₂, NO_x, and PM_{2.5} respectively which is more than those of the USA and Europe (Cofala et al. 2012; Wang et al. 2014). NO_x emissions in China have increased during 1995–2010, with growth rate ranging from 5.5 to 7 % (Zhao et al. 2013; Zhang et al. 2007, 2012a, b) degrading regional air quality (Wang and Hao 2012) and human health.

There have also been considerable efforts to avoid air quality deterioration. In Japan, best available technologies have been put in use to control SO₂, (NO_x, as well as PM for most power generation. The use of wet- flue gas desulfurization (FGD), Low NO_x Burner (LNB) and Selective Catalytic Reduction (SCR) and high efficiency deduster (HED) has increased air pollution slightly between 2005 and 2010 (Klimont et al. 2009). LNB was the main NO_x control technology in coal-fired power plants of China by 2010. In the 12th Five-Year Plan, Government of China aims to reduce the national NO_x emissions by 10 % of the emission in 2010 by the year 2015, and the main measures to accomplish this target is use of SCR and Selective Non-Catalytic Reduction (SNCR) facilities.

2.11 Air Quality Monitoring and Inventorization

Air quality evaluation is necessary for developing plans for air quality management to safe guard environment and public health. One of the important functions of the monitoring is estimating the level and distribution of pollutants. Air quality is assessed at source (like chimney and vehicle exhaust) or at recipient (Ambient air quality).

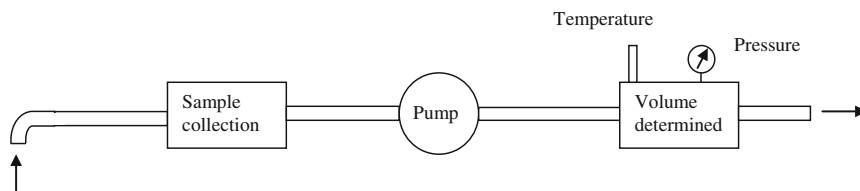


Fig. 2.9 Sampling train

2.11.1 Sampling

A typical sample train for monitoring chimney is shown in Fig. 2.9. In some systems the components might be combined. Care need to be exercised to assure that no leaks occur in the train. It is necessary to ensure components of the train are identical for sampling and calibration. The pump used for monitoring stack must be oil-less and leakproof.

Usually operating curves are provided along with sampling equipment if the sampling train is assembled in factory. Otherwise operating curves shall be prepared before taking the sample train to the test site.

Some of the useful operating curves include (1) velocity versus pressure at different temperatures, (2) flow versus pressure drop, and (3) probe tip velocity versus flowmeter readings at different temperatures.

Pollutants in stack will have very different characteristics from the carrying gas stream. It is therefore important to collect sample maintaining same velocity in the probe tip as it exists in the adjacent gas stream. This type sampling is known as *isokinetic* sampling.

For sampling of gases, the sample can be collected by any of several devices. Some commonly used manual methods include Orsat analyzers, absorption systems, adsorption systems, bubblers, reagent tubes, condensers, and traps. Continuous analyzers are now more widely used than manual methods. Some types of continuous analyzers include infrared and ultraviolet instruments; flame ionization detectors; mass spectrometers; colorimetric systems; gas, liquid, and solid chromatography; colometric and potentiometric systems; chemiluminescence; and solid-state electronic systems. Since gases undergoing analysis do not need to be sampled isokinetically, it is only necessary to insert a probe and withdraw the sample.

Continuous air quality monitoring system (air pollutants from chimney will continuously enter the system and get analysed) can be used for both ambient air quality monitoring and emission monitoring from stack (Fig. 2.10).

The ambient air monitoring network includes three types of monitoring stations:

- **Continuous stations**—these stations monitor air quality by drawing air in through a tube and analyses air pollutants.
- **Noncontinuous stations**—these stations collect air pollutants on filters and in that are collected by technicians in the field and sent to laboratory for analysis.

Fig. 2.10 Online monitoring equipment



- **Mobile monitors**—these consist of a numerous instruments installed in a vehicle/airplane for monitoring air pollutants.

It is good practice to monitor air quality at numerous locations which includes areas industrial area, kerbside, residential areas, parks and rural areas.

The monitoring station should be located it a place where interferences are not anticipated/present. The station should be away from chimneys; absorbing surfaces; obstructions. All the sides of monitoring station should be open, and intake should not be located in a confined space.

Criteria for selection of sites are usually published by designated organisation in each country. Following guidliens suggested by CPCB for siting the monitoring station (CPCB 2003).

- (i) The sampler must be more than 20 m from trees.
- (ii) Height of the inlet must be 3–10 m above the ground level.
- (iii) Distance of the sampler to any air flow obstacle must be greater than two times the height of the obstruction above the sampler.
- (iv) There should be no nearby furnace/incinerator fumes.
- (v) There should be unobstructed airflow in three of four quadrants.

Sampling intake is done usually at a height of 3 m above the street level for traffic pollution monitoring to prevent re-entrainment of particulates from the street.

2.11.1.1 Passive Sampling

Nearly century years after the first use of passive monitoring of atmospheric Ozone (O_3) concentrations (Fox 1873), there has been an growing interest to use passive samplers to monitor gaseous air pollutants (Namiesnik et al. 1984; Cao and Hewitt 1991).

New methods for monitoring air quality are being developed in recent years (Tremolada et al. 1996; Peters et al. 2000; Harner et al. 2003). Passive air sampling is one of the methods presently considered as suitable for cheap and versatile monitoring programs. Scientists use this technology for quantifying ambient air pollutants in remote wilderness areas. Demands have resulted in the development of different passive air samplers (Bartkow et al. 2004). Passive samplers are capable of being installed in many places at the same time (Krupa and Legge 2000).

Air pollution estimations are done either by calibration based on parallel passive and active samplings or using the permeation reference chemicals (Ockenden et al. 2001; Soderstrom and Bergqvist 2004).

Passive air sampling use semi-permeable membrane devices (SPMDs), poly-urethane foam disks (PUFs) and XAD resins which can be exposed over several weeks or months. Use of passive samplers have following advantage over active sampling using high volume samplers: (1) No moving parts and no maintenance, (2) No need for person to change sample after four to eight hours, (3) no need to change motor brushes, and (4) no need for electric power.

Table 2.3 gives list of adsorbents used for passive sampling. The adsorbed samplers are analyzed in lab to determine the concentration of pollutants in the atmosphere.

2.11.2 Source Apportionment Study

Ambient air quality data analyses as well as receptor techniques are important component of successful air quality management. Identifying the emission sources, and their relative contributions to air pollution helps to control air pollution. Chemical Mass Balance (CMB) techniques are adopted when a prior knowledge of main sources in area are known. The Factor Analysis and Positive Matrix Factorization use ambient measurement data.

Emission factors facilitate estimation of emissions from known sources of air pollution. These factors are averages of all available data of satisfactory quality.

The equation for emissions estimation is:

Table 2.3 Adsorbents used to monitor some of the air pollutants

1	Air pollutant	Adsorbent
2	Ammonia	Oxalic acid
3	Carbon monoxide	Y-type zeolite of which sodium ion was partially exchanged with Zn ion
4	Formaldehyde	2,4-dinitrophenylhydrazine
5	Hydrogen sulfide	Silver nitrate
6	Nitric oxide	2-phenyl-4,4,5,5-tetramethylimidazole-3-oxide-1-oxyl
7	Nitrogen dioxide	1. Sep-Pak C18 cartridge impregnated with triethanolamine-potassium hydroxide 2. Triethanolamine (TEA) 3. Sodium iodide + sodium hydroxide
8	Nitrous oxide	Molecular sieve
9	Ozone	1. 1,2-di-(4-pyridyl)ethylene (DPE) 2. 10,100-dimethyl-9,90-biacridylidene 3. Indigo 4. Indigo carmine (5,50-disulfonate salt of indigo) 5. Nylon-6 polymer, potassium iodide 6. Sodium nitrite, 3-methyl-2-benzothiazolinone acetone azine (MBTH), p-acetamidophenol (p-ATP), indigo carmine 7. Sodium nitrite
10	Photochemical oxidants	Curcumin, indigo carmine, 1-methyl pyrimidine, phenoxazine
11	Polychlorinated biphenyls	Triolein containing semipermeable membrane
12	Sulfur dioxide	1. Sep-Pak C18 cartridge impregnated with triethanolamine-potassium hydroxide 2. Sodium carbonate 3. Sodium hydroxide 4. Triethanolamine (TEA)

(continued)

Table 2.3 (continued)

13	Volatile organic compounds	1. Activated charcoal
		2. Graphitic carbon black
		3. Carboxen 1000 + carbotrap B
		4. Tenax GA
		5. Tenax GC
		6. Tenax-GR, Tenax-TA, Carbotrap and Chromosorb 106

Source Based on Krupa and Legge (2000), Adema et al. (1993), Sommer et al. (1996), Schjoerring (1995), Lee et al. (1992), Levin et al. (1985, 1986), Mulik et al. (1989), Grosjean and Williams (1992a), Larsen et al. (1992), Shooter et al. (1995), Mulik et al. (1991), Nishikawa et al. (1986), Nishikawa and Taguchi (1987), Palmes (1981), Cadoff and Hodgeson (1983), Hangartner et al. (1989), Atkins et al. (1990), Hewitt (1991), Krochmal and Górski (1991), Campbell et al. (1994), Lee et al. (1995), Sickles et al. (1990), Gair et al. (1991), Ayers et al. (1998), Ferm and Sjödin (1992), Ferm and Svanberg (1998), Bishop and Hossain (1984), Hauser and Bradley (1966), Monn and Hangartner (1990), Surgi and Hodgeson (1985), Werner (1989), Runeckles and Bowen (1999), Grosjean and Hisham (1992), Grosjean and Williams (1992b), Grosjean et al. (1995), Scheeren and Adema (1996), Kanno and Yanagisawa (1992), Zhou and Smith (1997), Koutrakis et al. (1990), Liu et al. (1994, 1995), Brauer and Brook (1995), Manning et al. (1996), Grosjean et al. (1992), Ockenden et al. (1998a, b), Tang et al. (1998), Krochmal and Kalina (1997), Begerow et al. (1995), Otson (1989), Pérez Ballesta et al. (1992), Shields and Weschler (1987), Bertoni et al. (1990), Uchiyama et al. (1999), Roche et al. (1999), Beveridge and Duncan (1981), Coutant (1985), Lewis et al. (1985), Cao and Hewitt (1993, 1994a, b)

$$E = (A)(EF) \left(1 - \frac{ER}{100} \right)$$

where:

E emissions;

A activity rate;

EF emission factor;

ER overall efficiency of emission abatement system (%).

Key objectives of source apportionment are:

- To quantitatively relate pollution source to receptor site;
- To assess the effectiveness of control strategies;
- Strengthening environmental management; and
- To improve and validate emission inventories.

Source apportionment studies using positive matrix factorization method in Beijing was studied by Yu et al. (2013) wherein seven sources (Secondary sulphur, vehicle exhaust, soil dust, road dust, biomass burning, metal processing) with their contributions to the total PM_{2.5} were identified and quantified.

Factor analysis is a statistical method employed to describe variability among observed, related variables in terms of a prospective lower number of unobserved variables. These unobserved variables are called factors. To assess the pollution released from sources it is necessary to identify pollutants resulting from the activity. The measured pollutants are then correlated to sources. Factor analysis depends on the internal variability of the data. Samples from many locations over a long time period are employed this method.

Positive Matrix Factorization is a group of algorithms where in one matrix is factorized into two matrices. All three matrices have only positive elements. Since the problem is not precisely solvable it is usually approximated numerically.

2.11.3 Remote Sensing and Geographic Information System

Remote sensing of air quality by Satellite has evolved radically over the last decade. Global observations are available for a broad range of air pollutants that include aerosols, CO, tropospheric O₃, tropospheric NO₂, HCHO, as well as SO₂ (Martin 2008). Satellites can measure the majority of important air pollutants, and provide timely, spatially explicit, information on distribution of pollutants in a cost-effective manner. Citizens in some cities of developed countries are already provided with air pollution alerts via mobile phone text messages, email, or via websites.

New generation Earth-observing satellites have been able to detect tropospheric air pollution since the mid-1990s at increasingly high spatial and temporal resolution. The satellite measures radiation from the ultraviolet to the visible in the range of

$\sim 0.23\text{--}0.9\text{ }\mu\text{m}$ as well as in the infrared from ~ 4 to $50\text{ }\mu\text{m}$. Chemical species are detected by the absorption, of radiation of particular wavelengths along the path.

The advantages of remote sensing air pollutants are many which include flexibility of deployment as well as avoidance of extractive sampling. It gives overall scenario of the region which would have been not measured or wrongly measured in the field. It gives the direction in which air pollutants are travelling and possible destination over a period of time. The technology is boon wherein pollution in multiple countries are monitored and recorded and hence can be shared with least developed countries which do not have skills and capabilities to monitor air pollution.

Observations are made at wavelengths from 260 nm in the ultraviolet through to radar wavelengths (0.1–10 cm) as the capability to see through clouds exists at radar wavelengths. Cloud cover is a major limitation of satellite observations for air quality. Strong absorption by ozone in the stratosphere obscures lower tropospheric measurements of several UV wavelength-absorbing gases. Bright surfaces like deserts, snow, urban areas confuse the ability to distinguish scattered light from the atmosphere. There are now active instruments in space that generate the radiation identified by the satellite after scattering (Hoff and Christopher 2009).

Atmospheric SO_2 can be measured by sensing of scattered sunlight using its unique absorption property in the ultraviolet region. But, the sensitivity of the SO_2 measurement depend very much on surface albedo, spectral interference, and varies with wavelength as Rayleigh scattering (elastic scattering of electromagnetic or light radiation by particles smaller than the wavelength of the radiation) increases at shorter wavelengths. The monitoring of aerosols by near the surface in situ measurements as well as column integrated satellite observations are useful tool for better understanding their impact on human health as well as climate (Gupta et al. 2013).

Processing of satellite measurements for oxides of nitrogen usually involves three or more steps. Calibrated Level 1 satellite data include high-resolution solar as well as earthshine spectra for each individual measurement. In order to linearize the NO_2 retrieval problem Earthshine radiances are divided by a reference solar irradiance spectrum. Two CO spectral bands, the thermal infrared essential at $4.6\text{ }\mu\text{m}$ as well as the near infrared overtone band at $2.3\text{ }\mu\text{m}$, can be used for passive remote sensing (Edwards et al. 1999). Methane can be retrieved from measurements of solar backscatter in the shortwave infrared and of terrestrial radiation in the thermal infrared.

2.11.4 Air Quality Modelling

Atmosphere is a complex reactive system in many physical, chemical and biological processes occur simultaneously. Ambient air quality measurement provides snap shot of air pollution at particular location, time and atmospheric conduction. Models use available data to predict concentration at future time.

Models can be physical or mathematical. Physical models are used to simulate physical representation of actual system in small scale. In physical model a replica of area of interest can be created within a wind tunnel to study possible pollution dispersion. In a mathematical model a set of mathematical equations are used to simulate the area of interest.

The easiest example to explain use of mathematical model is its use for decision making about upcoming thermal power plant by government authority. The project proponents normally prepare an Environmental Impact Assessment (EIA) in which mathematical model would be integral part. The proponents monitor the project location as well as surrounding and add the outcome of the mathematical modelling to compare with national ambient air quality standards to prove the pollution level after project would be within the ambient air quality standards.

The accuracy of the model output depends on data input and equations used within the model. Since most of the equations used in mathematical models are nonlinear in nature, a small deviation in input can give an output favourable to proponents. Hence team which prepare/scrutinises the EIA should have proper knowledge of the limitations of mathematical model and should have utmost integrity to protect the environment.

Figure 2.11 shows schematic diagram of mathematical model. Sophisticated mathematical model considers topographical data, emission data and weather data.

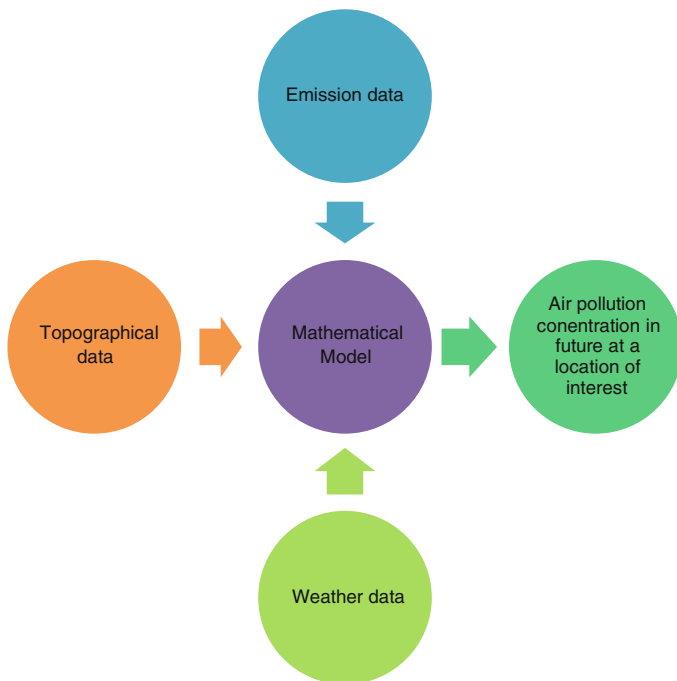


Fig. 2.11 Schematic diagram of mathematical model

There are three main types of air pollution emission plumes: Buoyant, dense and passive. Buoyant plumes are lighter than air since they are at a higher temperature or lower density than surrounding ambient air. Dense gas plumes are heavier than air since they have a higher density than the surrounding ambient air. Passive or neutral plumes are neither lighter nor heavier than air.

Pollutant emission sources are normally characterized point, line, area or volume sources. A point source is a single, identifiable source of air pollutant emissions like emissions from a flue gas stack. A line source is one-dimensional like emissions from vehicular traffic on a roadway. An area source is a two-dimensional source like emissions from a forest fire or landfill. A volume source is an area source with a third dimension (e.g.: the fugitive gaseous emissions from equipment at various heights in industrial facilities).

Other emission/source characterizations of air pollutants are: stationary, mobile, urban, rural, surface, near surface, elevated, puff and continuous. Flue gas stacks are examples of stationary sources and ships are examples of mobile sources. Urban areas are characterized by *heat island* that results in more turbulence above urban area compared to atmosphere above a rural area. Puff or intermittent sources are short term sources (e.g.: accidental release due to explosion of fuel tank). Continuous or long term source emit air pollutants for long term (e.g.: emission from flue stack emissions).

Mathematical models can be used for variety of decision making which include: (1) urban design, (2) New industry/project, (3) fuel specification, and (4) population policy.

Considering population growth of an urban settlement in developing countries, policy can be made to curb population influx and hence air pollution into city. But in reality this may not happen as people in power usually buy land at cheaper rate and influence government to permit them to develop the area.

2.11.5 *Scale of Model*

The domain of the atmospheric model varies from micro scale to global scale. Figure 2.12 shows spatial and temporal scales of variability. The computational domain normally contains an array of computational cells where pollution concentration is assumed to be uniform. Scale of model used for analyzing air pollution depends on the pollutants as the certain species live longer compared to others.

2.11.5.1 Global

Typical domain scale for global model is $65,000 \text{ km} \times 65,000 \text{ km} \times 20 \text{ km}$ with typical resolution of $5^\circ \times 5^\circ$. Motions of whole weather systems need to be considered while analyzing air pollution in this scale.

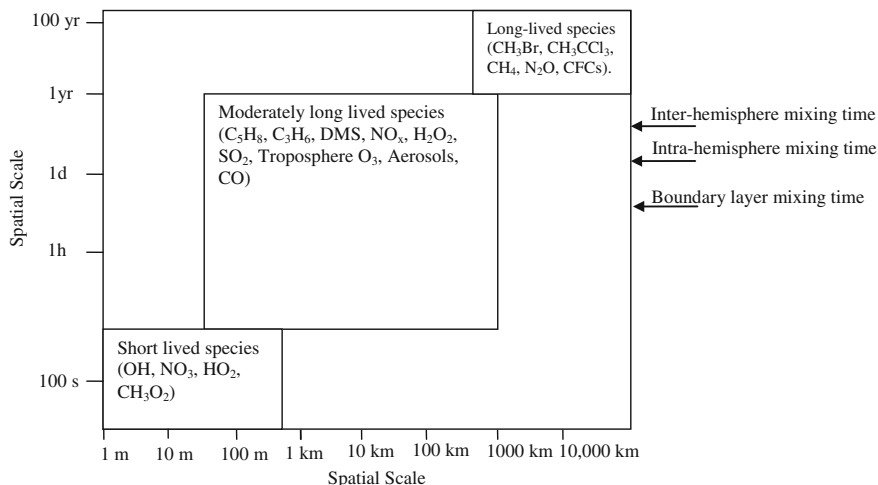


Fig. 2.12 Spatial and temporal scales of variability

2.11.5.2 Continental

Typical domain scale for global model is $3,000 \text{ km} \times 3,000 \text{ km} \times 20 \text{ km}$ with typical resolution of 80 km. Motions of whole weather systems need to be considered while analyzing air pollution in this scale.

2.11.5.3 Regional

Typical domain scale for regional model is $1000 \text{ km} \times 1000 \text{ km} \times 10 \text{ km}$ with typical resolution of 20 km. Motions of whole weather systems need to be considered while analyzing air pollution in this scale.

2.11.5.4 Mesoscale

Some of the countries like Singapore or Luxembourg are as big as cities of third world. Typical domain scale for mesoscale model is $100 \text{ km} \times 100 \text{ km} \times 5 \text{ m}$ with typical resolution of 4 km. Air pollution in city/county is studied/analyzed in this scale. Phenomena to be considered in this scale are land-sea breezes, migratory high/low pressure front, mountain valley winds.

2.11.5.5 Microscale

Typical domain scale for microscale model is $200 \text{ m} \times 200 \text{ m} \times 100 \text{ m}$ with typical resolution of 5 m. Phenomena such as meandering and dispersion of plume and flow regime in small area like street canyons are studied/analyzed in this scale.

2.11.6 Trajectories

Trajectories are the paths of substance in the atmosphere as they move through time as well as space. Substance ‘marked’ at a certain point at a given time in space can be traced backward or forward in time along their trajectory. Figure 2.13 shows example of output of typical trajectory model. Backward trajectories indicate the past path of a substance and forward trajectories indicate the future path of a substance. Models of trajectories are used track pollutants to know where they are coming from or where they are going to. These models are particularly useful if the monitoring stations shows abnormal concentrations of pollutants especially when it is sure that no such pollutants are emitted in the vicinity.

Trajectory models can be used to investigate air flow around mountains; identify pathways of desert dust; water vapor transport; establish relationships between source and receptor of air pollutants; pollen measurements to track locations of marijuana cultivation; track source of radioactive elements entering the territory of country; track pollutants due to war and accidents in nuclear reactor etc.

Theoretically wind velocity vector can be represented as

$$\frac{d\mathbf{X}}{dt} = \bar{\mathbf{V}}$$

where,

$\mathbf{X}$ the position vector in a time step dt resulting due to the wind velocity $\mathbf{v}$;

$\bar{\mathbf{V}}$ Wind velocity vector

Hence,

$$\mathbf{X}(t) = \mathbf{X}(\mathbf{X}_0, t)$$

Position of a parcel of air or pollutant can be identified by

$$\mathbf{X}(t) = \mathbf{X}(t_0) + (\Delta t) \left. \frac{d\mathbf{X}}{dt} \right|_{t_0} + \frac{1}{2} (\Delta t) \left. \frac{d^2\mathbf{X}}{dt^2} \right|_{t_0} + \dots$$

Errors in trajectory model can occur due to wind field errors, starting position errors, amplification of errors, truncation errors, interpolation errors, errors due to assumption regarding vertical wind. Wind field errors can be due to analysis or

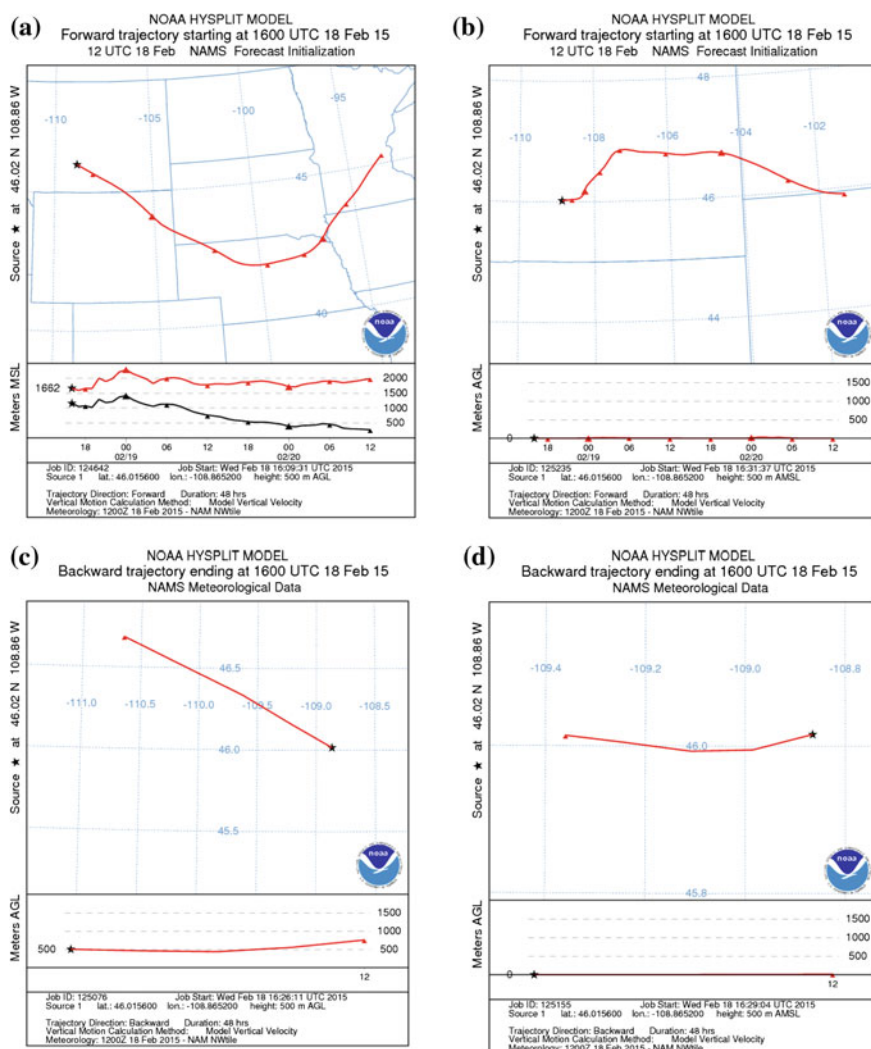


Fig. 2.13 Trajectories calculated for duration: 48 h, Date 18 Feb 2015 using HYSPLIT—Hybrid Single Particle Lagrangian Integrated Trajectory Model on internet <http://ready.arl.noaa.gov/HYSPLIT.php>. **a** Forward trajectory of particle moving from Lat.: 46.015600 (46°0'56"N), Lon.: 108.865200 (108°51'55"W), 500 m above ground level. *Black line* indicates ground level. **b** Forward trajectory of particle moving from Lat.: 46.015600 (46°0'56"N), Lon.: 108.865200 (108°51'55"W), 500 m above mean sea level. **c** Backward trajectory of particle moving to Lat.: 46.015600 (46°0'56"N), Lon.: 108.865200 (108°51'55"W), 500 m above ground level. **d** Backward trajectory of particle moving to Lat.: 46.015600 (46°0'56"N), Lon.: 108.865200 (108°51'55"W), 500 m above mean sea level. [The authors gratefully acknowledge the NOAA Air Resources Laboratory (ARL) for the provision of the HYSPLIT transport and dispersion model and/or READY website (<http://www.ready.noaa.gov>) used in this publication]

forecast errors. Starting position errors can occur as starting point of the trajectories are not exactly known. Start positions may not be exactly entered into model due to the differences between the real topography and the model topography. Truncation errors come from the solution to trajectory equation which is approximated in computer. Interpolation errors occur due to the availability of limited wind data due to which wind speed must be calculated by estimation at the trajectory position.

2.11.7 Mathematical Principles

A fluid flow may be described in two ways: (1) the Eulerian approach (named after a Swiss mathematician Leonhard Euler), and (2) the Lagrangian approach (named after the Joseph Louis Lagrange a French mathematician). In the Lagrangian approach, a parcel is selected and is followed as it travels through space with time. In the Eulerian approach flow are given at rigid points in space as time varies.

Eulerian description is a field description that is easy to apply. The velocity, pressure, density can be mathematically represented as: $v(x, t)$, $p(x, t)$, $\rho(x, t)$.

Lagrangian description is harder to apply. Here the quantities of the flow are vary with times. The velocity, pressure, density, can be mathematically represented as: $v(t)$, $p(t)$, $\rho(t)$.

2.11.7.1 Box Model

Box model assumes that the airshed is in the shape of a box and air pollutants inside the box are homogeneously distributed. This model is very limited in its capability to accurately forecast dispersion of air pollutants.

2.11.7.2 Gaussian Model

The Gaussian model assumes air pollutants from plume disperse as a Gaussian distribution (Fig. 2.14). This model is most often used for forecast the dispersion of uninterrupted, buoyant air pollution plumes.

Gaussian model can be represented by following equation

$$C_{x,y} = \frac{Q}{\pi u \sigma_z \sigma_y} \exp \left[-\frac{1}{2} \left(\frac{H}{\sigma_z} \right)^2 \right] \exp \left[-\frac{1}{2} \left(\frac{y}{\sigma_y} \right)^2 \right]$$

where

C pollutant concentration, g/m³

Q pollutant emission rate, g/s

π pi, 3.14159

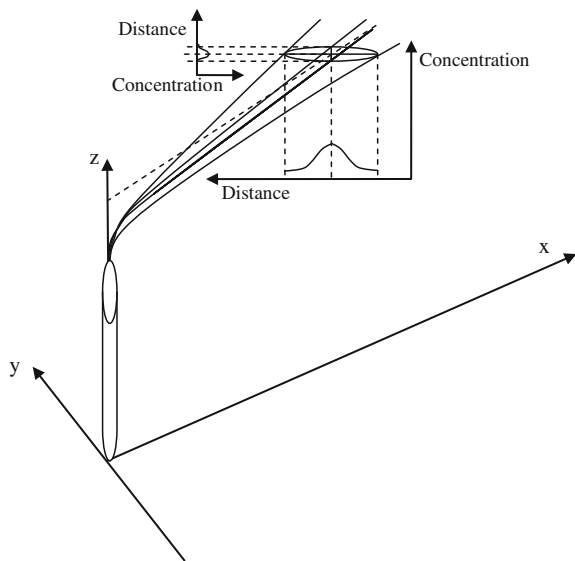


Fig. 2.14 Schematic diagram of air pollution desparation with Gaussian distribution of pollutants

- u mean wind speed, m/s
- σ_y standard deviation of horizontal plume concentration, evaluated in terms of downwind distance x , m
- σ_z standard deviation of vertical plume concentration, evaluated in terms of downwind distance x , m
- $\exp$ base of natural logs, 2.71828183
- H effective stack height, m
- x downwind distance along plume meancontreline from point source, m
- y cross wind distance from centreline of plume, m

2.11.7.3 Eulerian Model

The Eulerian model focuses on particular position in the space through which the fluid flows with time. Eulerian modeling framework remains fixed in the space and pollutant enters and leaves the cells through wall. Eulerian model make use of a

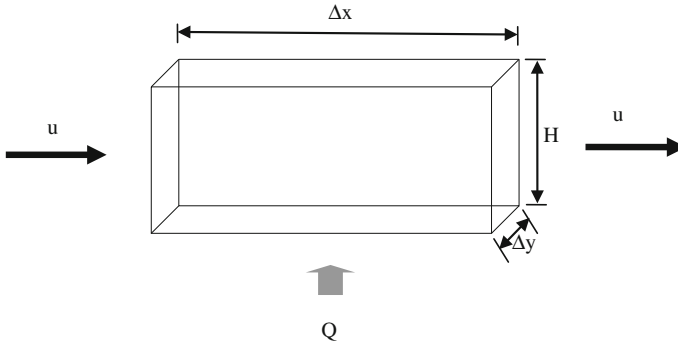


Fig. 2.15 Schematic diagram for single box for Eulerian model

fixed three-dimensional Cartesian grid as a frame of reference. An Eulerian dispersions model also tracks the movement of numerous pollution plume parcels.

A mass balance for Fig. 2.15 for concentration c_i of species i can be expressed as

$$\frac{d}{dt}(c_i \Delta x \Delta y H) = Q_i + R_i \Delta x \Delta y H - S_i + u H \Delta y (c_i^0 - c_i)$$

where,

Q_i mass emission rate of i

S_i removal rate of i

R_i chemical production rate

c_i^0 background concentration of i

u wind speed

Figure 2.16 shows Schematic diagram for Eulerian model for area spread over large area by splitting area into boxes of convenient sizes. Outgoing emission from once box will act as input to adjacent cell

2.11.7.4 Lagrangian Model

Lagrangian model make use of a three-dimensional moving frame of reference and individual fluid parcels are followed through time. In the Lagrangian model, the flow is described by a function $X(a, t)$ for defining position of the parcel ' a ' at time ' t '.

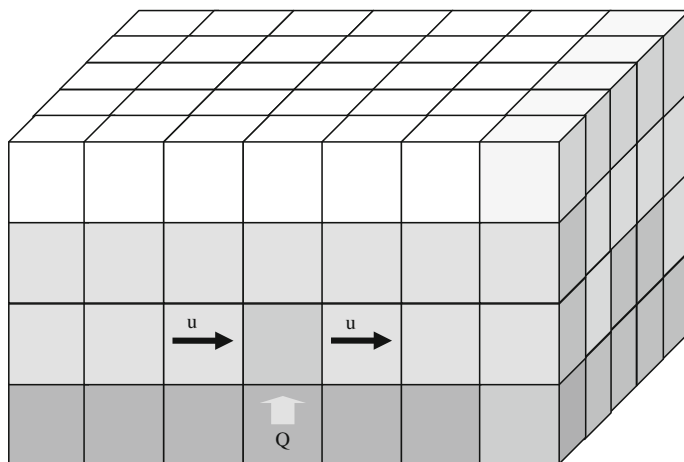


Fig. 2.16 Schematic diagram for Eulerian model for area spread over large area by splitting area into boxes of convenient sizes. Outgoing emission from once box will act as input to adjacent cell

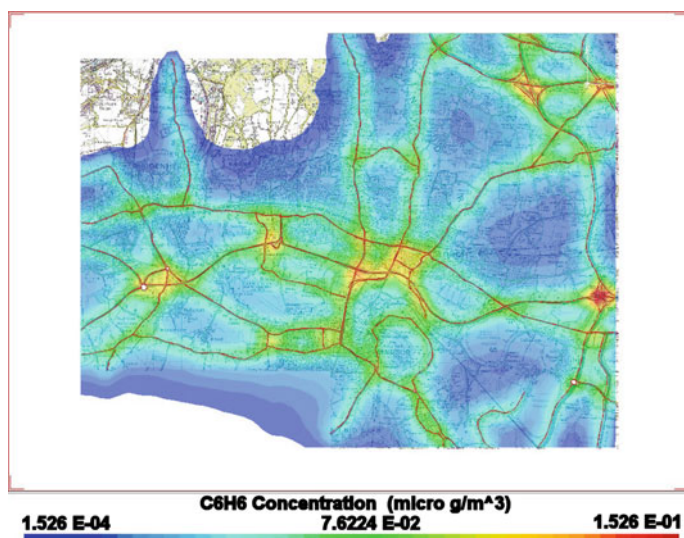


Fig. 2.17 Simulation of C₆H₆ dispersion in road network (*Courtesy Transoft international*)

In the Lagrangian frame, concentration fields as well as its turbulent flux are defined by the statistics of collection of dispersing marked fluid parcels as well as the strength and spatial distribution of sources sinks. This approach is applicable as

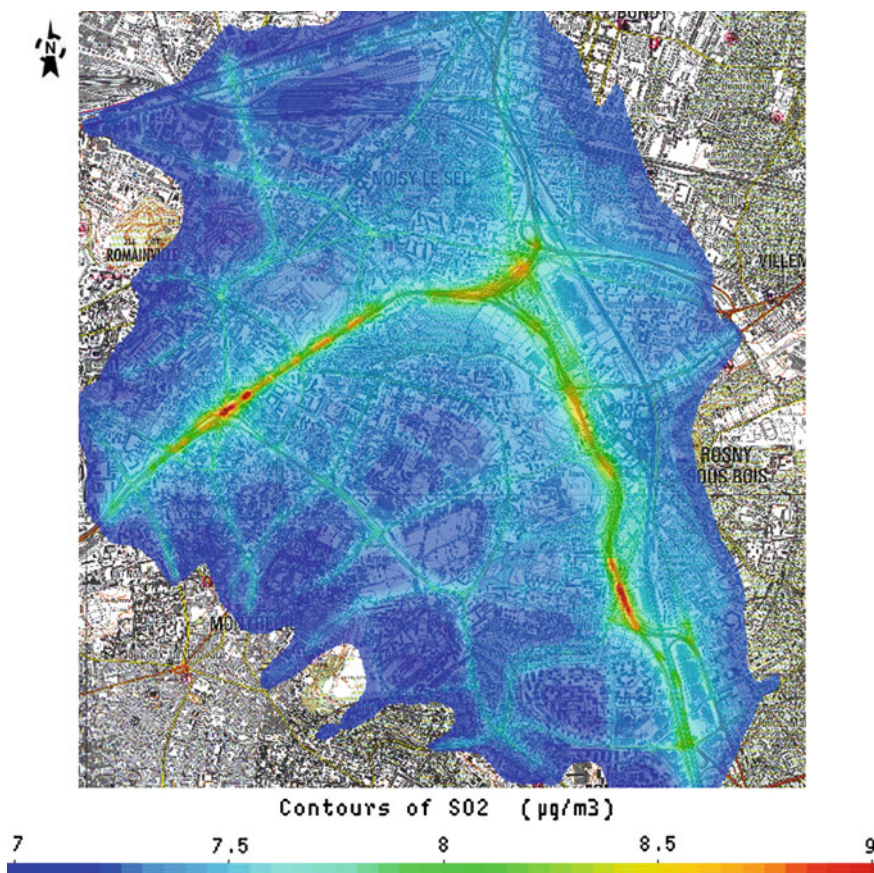


Fig. 2.18 Simulation of SO₂ dispersion in road network (*Courtesy Transoft international*)

long as the molecular diffusion within a fluid parcel is negligible compared to its turbulent diffusion.

Figures 2.17, 2.18, 2.19, 2.20, 2.21, 2.22, 2.23, 2.24 and 2.25 show different output of analysis of dispersion using mathematical models.

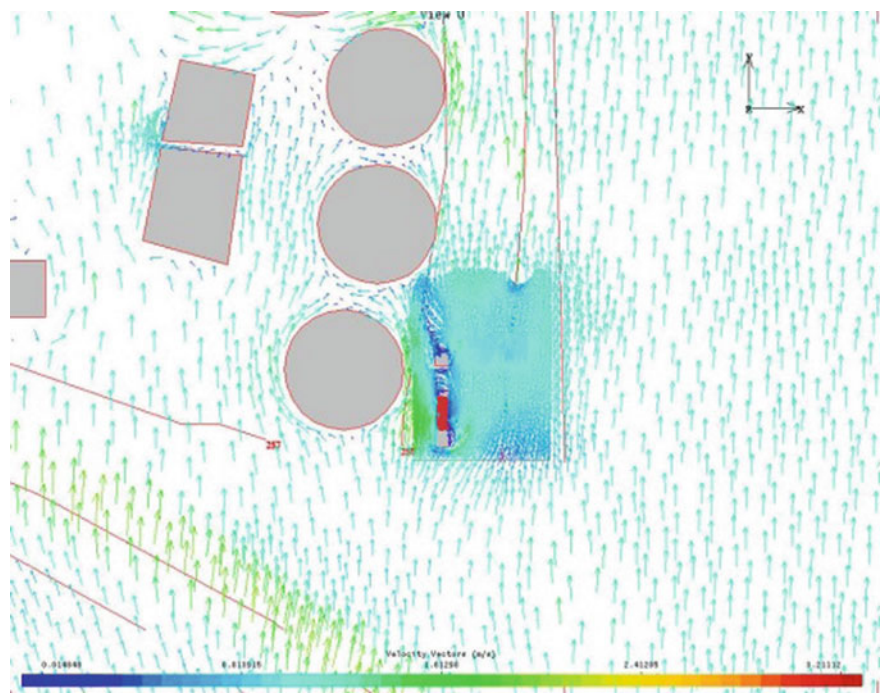


Fig. 2.19 Wind flow around the obstacles (Courtesy Transoft international)

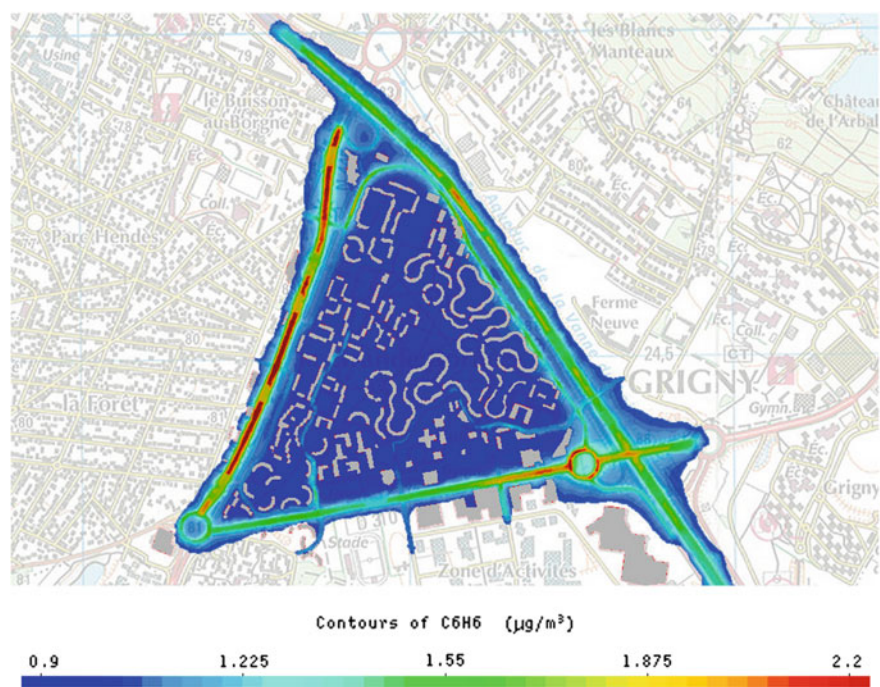


Fig. 2.20 Modelling of urban region (Courtesy Transoft international)

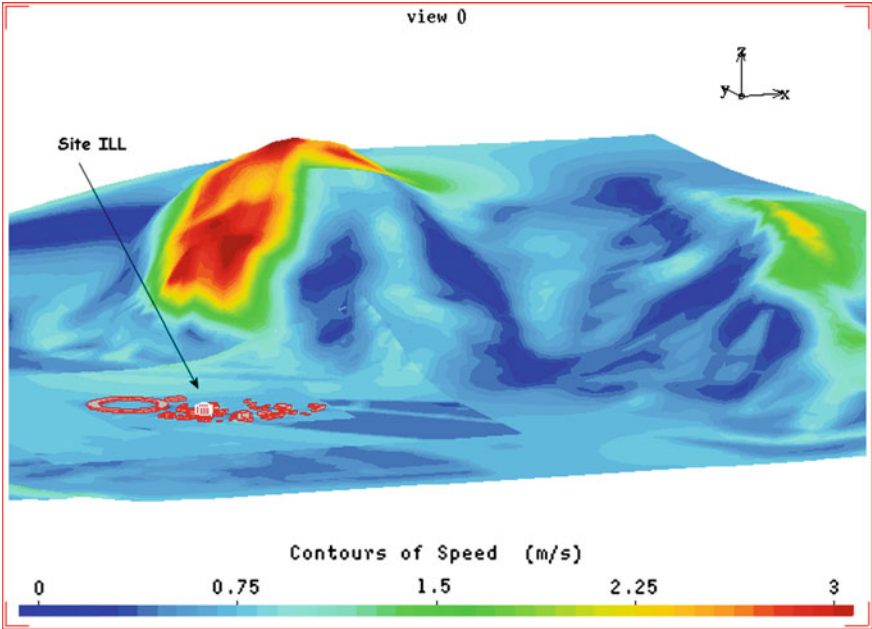


Fig. 2.21 Flow contours over and around hilly region (Courtesy Transoft international)



Fig. 2.22 Wind flow inside a building (Courtesy Transoft international)

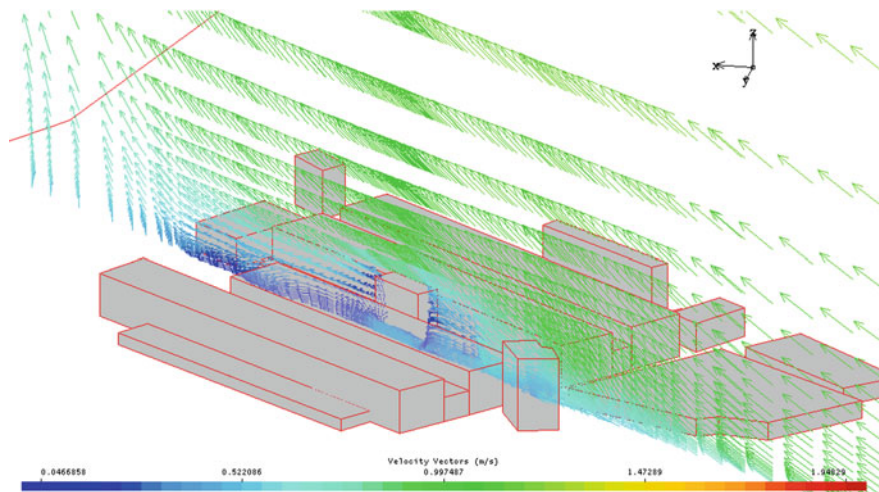


Fig. 2.23 Wind patters (*Courtesy Transoft international*)

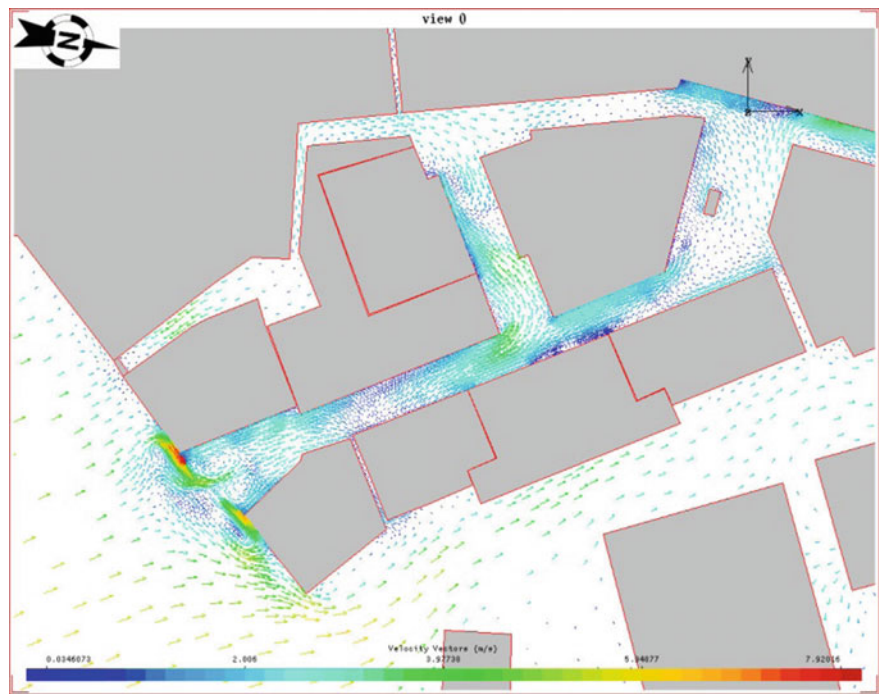


Fig. 2.24 Wind flow showing flow pattern stagnant (*Courtesy Transoft international*)

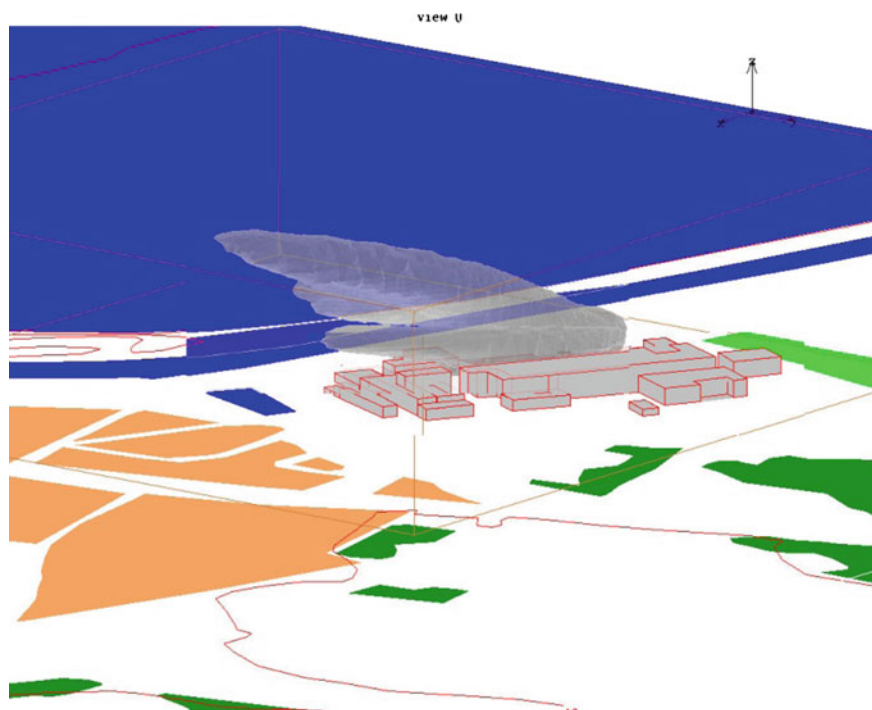


Fig. 2.25 Model of three dimension pollutants plume in a industrial complex (Courtesy Transoft international)

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