CHAPTER -2
REVIEW OF LITERATURE

2.1 General

Over the years there has been a tremendous increase in setting up of industries, number of vehicular traffic due to an exponential growth in economic development and consumption habits, throughout the world. Urban air pollution not only represents a threat to human health and the urban environment, but it also contribute to serious regional and global atmospheric pollution problems. Air pollution is experienced in most urban areas and is therefore a worldwide problem and an issue of global concern. Air pollutants are classified as primary or secondary, based on their characteristics at the source of emissions and physical or chemical changes, they undergo while in the atmosphere. Pollutants emitted into the atmosphere directly from the identifiable sources, that remain scattered in the atmosphere in the same chemical form as at the time of emission from the sources, are recognized as the primary pollutants. Pollutants that are formed in the atmosphere by the reactions among two or more primary pollutants are recognized as the secondary pollutants. The sources of air pollutants can be point sources, line sources and non-point sources. The point sources include emissions from domestic sources and industrial sources; whereas, line sources include vehicular emissions, and non-point sources include fugitive emissions, emissions from construction activities and from refuse burning. (Agarwal M 1991)¹

2.2 Major Air Pollutants Related to Industry and Transport

The major industry- and transport-related air pollutants are:

- Sulfur Dioxide
- Oxides of Nitrogen
- Ozone
- Particulate Matter (PM)
- Carbon Monoxide
- Respirable SPM
Lead
Benze
Ammonia

**Sulfur Dioxide**

Sulfur Oxides are emitted in significant quantities from thermal power plants. Smelting process of sulfide ores to produce copper, lead and zinc and also from petroleum refining processes. A large quantity of SO$_2$ emissions from the refinery sector is associated with combustion in boilers of process heaters. Sulfuric acid plant produces significant SO$_x$ emissions through combustion of sulfur containing raw material and subsequent losses during conversion to SO$_3$ and then to sulfuric acid (H$_2$SO$_4$). Sulfur oxides are also produced during paper and pulp manufacturing as a result of combustion of sulfur containing material. Other industries that emit SO$_2$ are aluminum smelter, thermal power plants and steel industry. The diesel-driven vehicles are specific source of Sulfur Dioxide generated during combustion process. (Martin Crawford, 1976)$^{81}$

**Oxides of Nitrogen**

Nitrogen oxides form when fuel is burned at high temperatures, as in a combustion process. The primary sources of NO$_x$ are motor vehicles, electric utilities, and other industrial, commercial, and residential sources that burn fuels. Nitrogen Dioxide (NO$_2$) along with particles in air can be seen as a reddish brown layer over many urban areas. Oxides of nitrogen along with volatile organic compounds (VOCs) result in formations of ground-level ozone, which can trigger serious respiratory problems. (Rao and Rao, 1989)$^{92}$

**Ozone**

Ozone (O$_3$) is the secondary pollutant and is formed through complex chemical reactions between precursor emissions of VOCs and oxides of nitrogen (NO$_x$) in the presence of sunlight. The reactions are stimulated by sunlight and temperature so that peak O$_3$ levels occur typically during the warmer times of the year. Transportation and industrial sources are one of the major sources of VOCs and NO$_x$. VOCs are emitted from sources such as autos, chemical manufacturing,
dry cleaners, paint shops and other sources using solvents. (Martin Crawford, 1976)\textsuperscript{61}

\begin{itemize}
\item \textbf{Particulate Matter (PM)}
\end{itemize}

The primary Particulate Matter consists of carbon (soot) emitted from cars, trucks, heavy equipment, and burning waste- and crustal-material from unpaved roads, stone crushing, construction sites, and metallurgical operations. The secondary Particulate Matter is formed in the atmosphere from gases. Some of these reactions require sunlight and/or water vapor. The secondary Particulate Matter includes sulfates formed from Sulfur Dioxide emissions from power plants and industrial facilities. It also includes nitrates formed from Nitrogen Oxide emissions from cars, trucks, and power plants. Carbon formed from reactive organic gas emissions from cars, trucks, industrial facilities, and biogenic sources such as trees is also part of the secondary Particulate Matter. (Rao and Rao, 1989)\textsuperscript{92}

\begin{itemize}
\item \textbf{Carbon Monoxide (CO)}
\end{itemize}

Carbon Monoxide results from incomplete combustion of fuel and is emitted directly from vehicle tailpipes or silencers. Incomplete combustion is most likely to occur at low air-to-fuel ratios in the engine. These conditions are common during vehicle starting when air supply is restricted, when cars are not tuned properly, and at higher altitude, where thin air effectively reduces the amount of oxygen available for combustion. (Alan Wellburn 1998)\textsuperscript{7}

\textbf{Table 2.1. Carboxy-Hemoglobin Content of Blood for Different Concentrations of Carbon Monoxide in the Atmosphere}

<table>
<thead>
<tr>
<th>Concentration of CO in the Atmosphere(ppm)</th>
<th>Equilibrium of COHb in the Blood (%)</th>
<th>COHb in the Blood after 30 min Exposure (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Rest</td>
</tr>
<tr>
<td>30</td>
<td>4.8</td>
<td>0.27</td>
</tr>
<tr>
<td>50</td>
<td>8.0</td>
<td>0.45</td>
</tr>
<tr>
<td>125</td>
<td>20</td>
<td>1.12</td>
</tr>
<tr>
<td>250</td>
<td>40</td>
<td>2.25</td>
</tr>
</tbody>
</table>

\textit{Source:} Sherwood and Bowers 1970\textsuperscript{109}
Carbon Monoxide is not known to particulate in the secondary atmospheric reactions. Its primary effects on human health are dependent on its great affinity for hemoglobin, the oxygen transporting pigment of the blood. Carbon Monoxide tends to combine with hemoglobin 210 times as readily as does oxygen, thus effectively preventing its important function of Carbon Monoxide with hemoglobin is spontaneously but slowly reversible, and blood tends to be cleared of Carbon Monoxide in exponential fashion with a half time of 3–4 h. (IS: 5182, Part-2. 1976)\textsuperscript{46}

The toxic properties of this gas are due to its ability to react with the hemoglobin in the blood to produce carboxyl-hemoglobin (COHb). The levels of carboxyl-hemoglobin in the blood for different concentrations of Carbon Monoxide in the atmosphere are given in Table 2.1. The toxic effects of Carbon Monoxide as measured by the percentage of carboxyl-hemoglobin in the blood are given in Table 2.1.

\begin{itemize}
  \item \textbf{Respirable SPM (RSPM/PM}_{10}\textsuperscript{)}

PM\textsubscript{10} is the Particulate Matter having aerodynamic diameter <10 μm, and it is a fraction of the Particulate Matter suspended in air and it represents the fraction that is considered to enter the respiratory system. Sources of PM\textsubscript{10} may also be formed from other pollutants (acid rain, NO\textsubscript{x}, SO\textsubscript{x} organics) and from incomplete combustion of any fuel. Monitoring of RSPM is carried out for 24 h with 24-hourly sampling. RSPM is measured gravimetrically with Whatmann filter paper using a high volume air sampler. (Rao and Rao, 1989)\textsuperscript{92}

\textbf{Lead}

The main source of lead in the atmosphere is the automobile exhaust, especially by petrol vehicles. Lead is added to petrol in the form of tetraethyl lead to act as an anti-knocking agent to improve the engine performance. However, the combustion of tetraethyl lead releases tetraethyl lead oxide into the atmosphere producing severe health effects. (Paul 2000)\textsuperscript{84}

\begin{itemize}
  \item \textbf{Benzene}

Benzene is found in the air by emissions from burning coal and oil, petrol service stations, and motor vehicle exhaust and as evaporative emission. Benzene in air exists predominantly in the vapor phase, with residence time varying between
few hours to a few days depending upon environment and climate. Other sources include cigarette smoke, chemical manufacturing, coke ovens, petroleum refineries, etc. It is used as a solvent for fats, waxes, resins, oils, inks, paints, plastics, and rubber. Benzene is also used in the manufacture of detergents, explosives, pharmaceuticals, and dyestuffs. (Warner, C.F., 1976) \[127\]

- **Ammonia**

  Ammonia occurs naturally and is found in small quantities in the atmosphere due to putrefaction of nitrogenous animal and vegetable matter. Ammonia and ammonium salts are also found in small quantities in rainwater. It is an important source of nitrogen which is needed by plants and animals. Bacteria found in the intestines can produce ammonia. Ammonia gas can be dissolved in water and is called liquid ammonia or aqueous ammonia. Once exposed to open air, liquid ammonia quickly turns into a gas. Ammonia is applied directly into solid on farm fields, and is used to make fertilizers for farm crops, lawns, and plants. Many household and industrial cleaners contain ammonia. (Homer W., Parkar 1997) \[44\]

2.3 **National Ambient Air Quality Standards (NAAQS)**

The ambient-air quality objectives/standards are pre-requisite for developing a program for effective management of ambient-air quality and to reduce the damaging effects of air pollution. The objectives of air-quality standards are:

- To indicate the levels of air quality necessary with an adequate margin of safety to protect the public health, vegetation and property.
- To assist in establishing priorities for abatement and control of pollutant levels.
- To provide a uniform yardstick for assessing air quality at national level.
- To indicate the need and extent of monitoring program and to create awareness among Industries, Entrepreneur.

The CPCB had adopted the first ambient-air quality standards on November 11, 1982 as per Section 16 (2) (h) of the Air act (Prevention and Control of Pollution) 1981. The air-quality standards have been revised by the CPCB on April 11, 1994 and were notified in Gazette of India, Extraordinary Part-II Section 3, subsection (ii) dated May 20, 1994. These standards are based on the land-use
and other factors of the area, and the guidelines for declaring sensitive areas as recommended by peer/core group of CPCB are as follows:

- 10 km all around the periphery of health resorts that is notified by State Pollution Control Boards in consultation with Department of Public Health of the concerned state.
- 10 km all around the periphery of Biosphere Reserves, Sanctuaries and National Parks, those are notified by Ministry of Environment and Forest or concerned states.
- 5 km all around the periphery of an archeological monument declared to be of national importance or otherwise that are notified by Archeological Survey of India (A.S.I.) in consultation with State Pollution Control Boards.
- Areas which are delicate or sensitive to air pollution in terms of important Agricultural/Horticultural crops grown in that area and accordingly notified by State Pollution Control Boards in consultation with Department of Agriculture/Horticulture of concerned state.
- 5 km all around the periphery of centers of tourism and/or pilgrim due to their religious, historical, scenic or other attractions, which are notified by Department of Tourism of the concerned state in consultation with State Pollution Control Boards. (NAAQS 2003)\textsuperscript{72}

2.4 Air-Quality Monitoring Program

The air-quality monitoring programs are needed for most of the actions taken to prevent air pollution from the initial assessment of existing conditions to the enforcement of current control regulations to the evaluation of the effectiveness of abatement programs and finally to the development of new control measures. The criteria laid down in the WHO publications, 1977, entitled the “Air Monitoring Program, Design for Urban and Industrial Areas”, have been used for establishing the ambient-air quality monitoring network under the NAAQM Program in India. The criteria guidelines as a whole could not be followed at few places keeping in the view, the limitations. The following requirements have also been considered while identifying the status for the monitoring sites.
These stations are more of logistic in nature to cover the maximum representative site which is exposed to the polluted air.

- Availability of space for monitoring.
- Availability of water, infrastructure, electricity in the field.
- Sampling and preservation of samples collected.
- Height of the site 3–5 m to be maintained to get exact representative of sample.
- Stations are fixed at sited locations and they are manually operated.

The monitoring of meteorological parameters such as wind speed and direction, relative humidity and temperature was also integrated with the monitoring of air quality. The monitoring of pollutants is carried out for 24 h. (NAAQS 2003)\(^{72}\).

### 2.5 Air Quality Standards Specified by Various Agencies

Ambient-air quality standards specified by the Environment Protection Agency (EPA) are presented in Table 2.2.

\(^{(i)}\) Final rule signed October 15, 2008. The 1978 lead standard (1.5 as a quarterly average) remains in effect until one year after an area is designated for the 2008 standard, except that in areas designated non-attainment for the 1978, the 1978 standard remains in effect until implementation plans to attain or maintain the 2008 standard are approved.

\(^{(ii)}\) The official level of the annual NO\(_2\) standard is 0.053ppm, equal to 53 ppb, which is shown here for the purpose of clearer comparison to the 1-h standard.

\(^{(iii)}\) Final rule signed March 12, 2008. The 1997 ozone standard (0.08ppm, annual fourth-highest daily maximum 8-h concentration, averaged over 3 years) and related implementation rules remain in place. In 1997, EPA revoked the 1-h ozone standard (0.12ppm, not to be exceeded more than once per year) in all areas, although some areas have continued obligations under that standard (“anti-backsliding”). The 1-h ozone standard is attained when the expected number of days per calendar year with maximum hourly average concentrations above 0.12 ppm is \(\leq 1\).
<table>
<thead>
<tr>
<th>Pollutant [final rule cite]</th>
<th>Primary/secondary</th>
<th>Average time</th>
<th>Level</th>
<th>Form</th>
</tr>
</thead>
<tbody>
<tr>
<td>Carbon Monoxide [76 FR 54294, August 31, 2011]</td>
<td>Primary</td>
<td>8-h</td>
<td>9 ppm</td>
<td>Not to be exceeded more than once per year</td>
</tr>
<tr>
<td></td>
<td></td>
<td>1-h</td>
<td>35 ppm</td>
<td></td>
</tr>
<tr>
<td>Lead [73 FR 66964, November 12, 2008]</td>
<td>Primary and secondary</td>
<td>Rolling 3-month average</td>
<td>0.15 μg/m³(1)</td>
<td>Not to be exceeded</td>
</tr>
<tr>
<td>Nitrogen Dioxide [75 FR 6474, February 9, 2010] [61 FR 52852, October 8, 1996]</td>
<td>Primary</td>
<td>1-h</td>
<td>100 ppb</td>
<td>98th percentile, averaged over 3 years</td>
</tr>
<tr>
<td></td>
<td>Primary and secondary</td>
<td>Annual</td>
<td>53 ppb(2)</td>
<td>Annual mean</td>
</tr>
<tr>
<td>Ozone [73 FR 16436, March 27, 2008]</td>
<td>Primary and secondary</td>
<td>8-h</td>
<td>0.075 ppm(3)</td>
<td>Annual fourth-highest daily maximum 8-h concentration, averaged over 3 years</td>
</tr>
<tr>
<td>PM₂.₅ Pollutant, December 14, 2012</td>
<td>Primary</td>
<td>Annual</td>
<td>12 μg/m³</td>
<td>Annual mean, averaged over 3 years</td>
</tr>
<tr>
<td></td>
<td>Secondary</td>
<td>Annual</td>
<td>15 μg/m³</td>
<td>Annual mean, averaged over 3 years</td>
</tr>
<tr>
<td></td>
<td>Primary and secondary</td>
<td>24-h</td>
<td>35 μg/m³</td>
<td>98th percentile, averaged over 3 years</td>
</tr>
<tr>
<td>PM₁₀ Pollutant, December 14, 2012</td>
<td>Primary and secondary</td>
<td>24-h</td>
<td>150 μg/m³</td>
<td>Not to be exceeded more than once per year on average over 3 years</td>
</tr>
<tr>
<td>Sulfur Dioxide [75 FR 35520, June 22, 2010] [38 FR 25678, September 14, 1973]</td>
<td>Primary</td>
<td>1-h</td>
<td>75 ppb(4)</td>
<td>99th percentile of 1-h daily maximum concentrations, averaged over 3 years</td>
</tr>
<tr>
<td></td>
<td>Secondary</td>
<td>3-h</td>
<td>0.5 ppm</td>
<td>Not to be exceeded more than once per year</td>
</tr>
</tbody>
</table>

Source: website: http://www.epa.gov/(NAAQM 2007)^73

(iv) Final rule signed June 2, 2010. The 1971 annual and 24-h SO₂ standards were revoked in that same rulemaking. However, these standards remain in effect until one year after an area is designated for the 2010 standard, except in areas designated non-attainment for the 1971 standards, where the 1971 standards remain in effect until implementation plans to attain or maintain the 2010 standard are approved.
The ambient-air quality standards for India specified by the CPCB, New Delhi are presented in Table 2.3. The air-quality standards given by the World Health Organization (WHO, 2004) are given in Table 2.4. The recently revised November 2009, NAAQS are depicted in Table 2.5.

Table 2.3. Air-Quality Standards Given by World Health Organization

<table>
<thead>
<tr>
<th>Average Time</th>
<th>Pollutant Concentration</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>CO (µg/m³)</td>
</tr>
<tr>
<td>1-h</td>
<td>4000</td>
</tr>
<tr>
<td>3-h</td>
<td>–</td>
</tr>
<tr>
<td>8-h</td>
<td>10,285</td>
</tr>
<tr>
<td>24-h</td>
<td>–</td>
</tr>
<tr>
<td>Annual average</td>
<td>–</td>
</tr>
</tbody>
</table>


Table 2.4. National Ambient Air Quality Standards-2001

<table>
<thead>
<tr>
<th>Pollutant</th>
<th>Time weighted Average</th>
<th>Industrial Area (µg/m³)</th>
<th>Residential rural and other areas (µg/m³)</th>
<th>Sensitiv e Area (µg/m³)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sulfur Dioxide (SO₂)</td>
<td>Annual average*</td>
<td>80</td>
<td>60</td>
<td>15</td>
</tr>
<tr>
<td></td>
<td>24-haverage**</td>
<td>120</td>
<td>80</td>
<td>30</td>
</tr>
<tr>
<td>Oxides of Nnitrogen as NO₂</td>
<td>Annual average*</td>
<td>80</td>
<td>60</td>
<td>15</td>
</tr>
<tr>
<td></td>
<td>24-haverage**</td>
<td>120</td>
<td>80</td>
<td>30</td>
</tr>
<tr>
<td>SPM</td>
<td>Annual average*</td>
<td>360</td>
<td>140</td>
<td>70</td>
</tr>
<tr>
<td></td>
<td>24-haverage**</td>
<td>500</td>
<td>200</td>
<td>100</td>
</tr>
<tr>
<td>Respirable PM (size &lt;10µm) (RPM)</td>
<td>Annual average*</td>
<td>120</td>
<td>60</td>
<td>50</td>
</tr>
<tr>
<td></td>
<td>24-haverage*</td>
<td>150</td>
<td>100</td>
<td>75</td>
</tr>
<tr>
<td>Lead (Pb)</td>
<td>Annual average*</td>
<td>1.0</td>
<td>0.75</td>
<td>0.50</td>
</tr>
<tr>
<td></td>
<td>24-haverage**</td>
<td>1.5</td>
<td>1.00</td>
<td>0.72</td>
</tr>
</tbody>
</table>

Source: Guide lines, Manual, CPCB (2011)
Table 2.5. National Ambient Air Quality Standards—November 2009

<table>
<thead>
<tr>
<th>Pollutants</th>
<th>Time Weighted Average</th>
<th>Concentration in Ambient Air</th>
<th>Methods Of Measurement</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sulfur Dioxide (SO₂), µg/m³</td>
<td>Annual* 24 h**</td>
<td>Industrial, Residential, Rural And Other Areas: 50 80</td>
<td>Ecologically Sensitive Area (Notified By Central Government): 20 80</td>
</tr>
<tr>
<td>Nitrogen Dioxide (NO₂), µg/m³</td>
<td>Annual* 24 h**</td>
<td>40 80</td>
<td>30 80</td>
</tr>
<tr>
<td>PM(size &lt;10µm) or PM₁₀, µg/m³</td>
<td>Annual* 24 h**</td>
<td>60 100</td>
<td>60 100</td>
</tr>
<tr>
<td>PM(size &lt;2.5µm) or PM₂.₅, µg/m³</td>
<td>Annual* 24 h**</td>
<td>40 60</td>
<td>40 60</td>
</tr>
<tr>
<td>Ozone (O₃), µg/m³</td>
<td>8 h* 1 h**</td>
<td>100 180</td>
<td>100 180</td>
</tr>
<tr>
<td>Lead (Pb), µg/m³</td>
<td>Annual* 24 h**</td>
<td>0.50 1.0</td>
<td>0.50 1.0</td>
</tr>
<tr>
<td>Carbonmonoxide (CO), mg/m³</td>
<td>8 h* 1 h**</td>
<td>02 04</td>
<td>02 04</td>
</tr>
<tr>
<td>Ammonia (NH₃), µg/m³</td>
<td>Annual* 24 h**</td>
<td>100 400</td>
<td>100 400</td>
</tr>
<tr>
<td>Benzene (C₅H₆), µg/m³</td>
<td>Annual*</td>
<td>05</td>
<td>05</td>
</tr>
<tr>
<td>Benzo(a)Pyrene (BaP) particulate phase only, µg/m³</td>
<td>Annual*</td>
<td>01</td>
<td>01</td>
</tr>
<tr>
<td>Arsenic (As), ng/m³</td>
<td>Annual*</td>
<td>06</td>
<td>06</td>
</tr>
<tr>
<td>Nickel (Ni), ng/m³</td>
<td>Annual*</td>
<td>20</td>
<td>20</td>
</tr>
</tbody>
</table>

Source:CPCB (November 2009)³³⁷.
Whenever two consecutive values exceed the limit specified above for the respective category, it would be considered an adequate reason to institute regular/continuous monitoring and further investigations. The State Government/State Board shall notify the sensitive and other areas in the respective states within a period of 6 months from the date of notification of NAAQS.

Note: Whenever monitoring results on two consecutive days of monitoring exceed the limits specified above for the respective category, it shall be considered adequate reason to institute regular or continuous monitoring and further investigations.

* Annual arithmetic mean of minimum 104 measurements in a year at a particular site taken twice a week 24 hourly at uniform intervals.

** 24 hourly or 8 hourly or 1 hourly monitored values, as applicable, shall be complied with 98% of the time in a year. 2% of the time, they may exceed the limits but not on two consecutive days of monitoring.

2.6 Toxic Air Pollutants and Health Effects

Toxic air pollutants, also called as hazardous air pollutants, are those pollutants that are known or suspected to cause cancer or other serious health effects, such as reproductive effects or birth defects, or adverse environmental effects. Examples of air toxics include benzene, per-Chloro-Ethylene, Methylene Chloride, Dioxin, Asbestos, Toluene, and metals such as cadmium, mercury, chromium, and lead compounds. The health effects of air pollutants are described in Table 2.6.

Table 2.6. Health Effects of Different Air Pollutants

<table>
<thead>
<tr>
<th>Air Pollutants</th>
<th>Health Effects</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sulfur Dioxide</td>
<td>Sulfur Dioxide can aggravate existing lung diseases, especially bronchitis, causes wheezing, shortness of breath, and coughing. Long-term exposures to Sulfur Dioxide and PM lead to higher rates of respiratory illness. (Samakovlis et al., 2005)¹⁰³</td>
</tr>
<tr>
<td>Nitrogen</td>
<td>Oxides of Nitrogen react readily with common organic chemicals, and even ozone, to form a wide variety of toxic products. Some of</td>
</tr>
<tr>
<td><strong>Dioxide</strong></td>
<td>which may cause biological mutations. NO\textsubscript{x} and Sulfur Dioxide react with other air pollutants in the air to form acids which fall to the earth as acid rain, fog, snow, or dry particles. Nitrogen Dioxide irritates the nose and throat, and it appears to increase susceptibility to respiratory infections.\cite{Richard1994}^{99}</td>
</tr>
<tr>
<td>---</td>
<td>---</td>
</tr>
<tr>
<td><strong>PM</strong></td>
<td>Long-term exposures to PM, such as those experienced by people living for many years in areas with high particle levels, are associated with problems such as decreased lung function, development of chronic bronchitis, and premature death \cite{USEPA2005}^{120}. Short-term exposures to particle pollution (hours or days) are associated with a range of effects, including decreased lung function, increased respiratory symptoms, cardiac arrhythmias (heartbeat irregularities) heart attacks, hospital admissions or emergency room visits for heart or lung disease, and premature death \cite{USEPA2005}^{123}</td>
</tr>
<tr>
<td><strong>Benzene</strong></td>
<td>Short-term acute inhalation of benzene may cause drowsiness, dizziness, headaches, as well as eye, skin, and respiratory tract irritation, and, at high levels, unconsciousness. Chronic (long-term) inhalation exposure has caused various disorders in the blood, including reduced numbers of red blood cells and a-plastic anemia, in occupational settings. Long-term exposure to benzene in air causes leukemia in human beings. Exposure to benzene is linked to genetic changes, increased proliferation of bone marrow cells and occurrence of certain chromosomal aberrations in humans and animals. Other effects of benzene include, disorders of blood, harmful effect on bone marrow, anemia and reduced ability of blood to clot, damage to the immune system and a reproductive and development toxicant.\cite{ArthurAtkisson1970}^{11}</td>
</tr>
<tr>
<td><strong>Carbon Monoxide</strong></td>
<td>Carbon Monoxide enters the bloodstream through the lungs and forms carboxyl-hemoglobin, a compound that inhibits the blood’s capacity to carry oxygen to organs and tissues. Persons with heart</td>
</tr>
<tr>
<td>Disease</td>
<td>Description</td>
</tr>
<tr>
<td>---------------</td>
<td>-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------</td>
</tr>
<tr>
<td>Carbon Monoxide poisoning</td>
<td>People are especially sensitive to Carbon Monoxide poisoning and may experience chest pain if they breathe the gas while exercising. Infants, elderly persons, and individuals with respiratory diseases are also particularly from cardiovascular disease, particularly those with angina or peripheral vascular disease and exposure to elevated CO levels can cause impairment of visual perception, manual dexterity, learning ability and performance of complex tasks. (Erisaikawa et al., 2009) (^{30})</td>
</tr>
<tr>
<td>Lead</td>
<td>Lead can cause damage to the brain and other parts of the body's nervous system. Children are most susceptible to the effects of lead. (Noel De Nevers 1995) (^{78})</td>
</tr>
<tr>
<td>Ozone</td>
<td>Exposure to O(_3) for several hours at relatively low concentrations has been found to significantly reduce lung function and induce respiratory inflammation in normal, healthy people during exercise and this decrease in lung function generally is accompanied by symptoms including chest pain, coughing, sneezing and pulmonary congestion. (USEPA, 2005) (^{123})</td>
</tr>
<tr>
<td>Ammonia</td>
<td>Exposure to ammonia may occur by breathing or consuming food or water containing ammonia. No health effects have been found in humans exposed to typical environmental concentrations of ammonia. Exposure to high levels of ammonia in air may be irritating to skin, eyes, throat, and lungs and cause coughing and burns. Lung damage and death may occur after exposure to very high concentrations of ammonia. (Wark K Warner 1976) (^{127})</td>
</tr>
</tbody>
</table>

*Source: Rajgopal and Kapoor (2001)\(^{94}\)*

People exposed to toxic air pollutants may have an increased chance of getting cancer or other serious health effects. The health effects include neurological damage, immune system damage, developmental problems, and respiratory and other health problems. Some toxic air pollutants such as mercury can deposit on soils or surface of water, from where they are taken up by plants and animals and eventually enter the food chain. (Gopalan H N B 2003) \(^{39}\)
2.7 Air Quality Index

AQI is an index for reporting daily air quality. It tells how clean or polluted the air is, and the associated health effects. AQI focuses on the health effects that may be experienced within a few hours or days after breathing the polluted air. EPA calculates the AQI for five major air pollutants regulated by the Clean Air Act: ground-level ozone, particle pollution (also known as Particulate Matter), Carbon Monoxide, Sulfur Dioxide, and Nitrogen Dioxide. For each of these pollutants, EPA has established NAAQS to protect the public health. Table 2.7 shows the category of levels. AQI ranges from 0 to 500. The higher the AQI value, the greater the level of air pollution, and the greater is the health concern. For example, an AQI value of 50 represents a good air quality with little potential to affect the public health, while an AQI value over 300 represents the hazardous air quality.

**Table 2.7. Rating of Air Quality Index**

<table>
<thead>
<tr>
<th>AQI values</th>
<th>Levels of health concern</th>
<th>Colors</th>
</tr>
</thead>
<tbody>
<tr>
<td>When the AQI is in this range:</td>
<td>Air-quality conditions are:</td>
<td>As symbolized by this color:</td>
</tr>
<tr>
<td>0–50</td>
<td>Good</td>
<td>Green</td>
</tr>
<tr>
<td>51–100</td>
<td>Moderate</td>
<td>Yellow</td>
</tr>
<tr>
<td>101–150</td>
<td>Unhealthy for sensitive group</td>
<td>Orange</td>
</tr>
<tr>
<td>151–200</td>
<td>Unhealthy</td>
<td>Red</td>
</tr>
<tr>
<td>201–300</td>
<td>Very unhealthy</td>
<td>Purple</td>
</tr>
<tr>
<td>301–500</td>
<td>Hazardous</td>
<td>Maroon</td>
</tr>
</tbody>
</table>

*Source: [www.airnow.gov](http://www.airnow.gov)*

An AQI value of 100 generally corresponds to the NAAQS for the pollutant, which is the level that EPA has set to protect the public health. AQI values below 100 are generally thought of as satisfactory. When AQI values are above 100, the
air quality is considered to be unhealthy—at first for a certain sensitive group of people, then for everyone as AQI values get higher.

AQI is divided into six categories, each category corresponds to a different level of health concern and is designated by different colour codes.

2.8 Air-Pollution Studies around the World

Ronald., (1977)\textsuperscript{100} carried out air pollution studies to determine the validity of regression models. A comparison of results with theoretical model calculations, and data splitting or cross-validation in which a portion of the data is used to estimate the model coefficients and the remaining data is used to measure the prediction accuracy of the model. The work concluded that data splitting is an effective method of model validation when it is not practical to collect new data to test the model.

Romieu et al., (1990)\textsuperscript{101} carried out a limited number of epidemiological studies to determine the potential health effects of air pollutants in Latin America. To obtain a rough estimate, a scenario was hypothesized in which subjects living in cities would be exposed to a given level of air pollutant, using data from the international literature to extrapolate the expected number of events in different strata of the hypothetical population. This is true although epidemiological studies are needed to evaluate the health impact of specific pollutant compounds as well as their interactions in Latin American populations exposed to high levels of pollution.

Schwartz and Morris., (1995)\textsuperscript{106} examine the association between air pollution and cardiovascular hospital admissions for people aged 65 years and older in Detroit, Michigan, metropolitan area. The work concluded that after controlling seasonal and other long-term temporal trends, temperature, and dew point temperature, PM was associated with daily admissions for ischemic heart disease, while Sulfur Dioxide, Carbon Monoxide, and ozone had no independent contribution to ischemic heart disease admissions.

Pearce., (1996)\textsuperscript{85} carried out the studies of air-pollution epidemiology that have resulted in the use of transferable dose–response coefficients whereby the statistical relationship between air pollution and human health is applied outside
the countries of the original studies. The aim was to predict changes in premature mortality and morbidity. Some studies then apply economic valuations in order to see if health damage from air pollution should be treated as a priority concern in the countries to which the coefficients are applied. The preliminary work suggests that some forms of air pollution, notably inhalable PM and ambient lead, are serious matters for concern in the developing world.

Ryan., (1996)\textsuperscript{102} examined the applicability of market-based incentives for controlling emissions of PM from fixed sources in Santiago, Chile. A linear programming model has been developed to establish the costs of achieving different air-quality targets using marketable permits and command-and-control (CAC) policies. The main conclusion has been that an ambient permit system (APS) substantially reduces compliance costs of achieving a given air-quality target at each receptor location in the city. Consequently, the use of permits is warranted. However, spatial differentiation of permits is required, thus complicating the design and use of such an instrument.

Chestnut et al., (1997)\textsuperscript{18} carried out a study on air pollution, focusing on the benefits to human health through reductions in PM air pollution, a common pollutant in the urban environment. The authors summarize the results of a set of health effects and economic valuation studies conducted in Bangkok, Thailand. The authors concluded that Bangkok residents are willing to pay a higher share of their income to protect their health due to pollution.

Basly and Wald., (2000)\textsuperscript{12} have shown the potentialities of the earth observation data for the knowledge of the atmospheric pollutants concentration field over metropolitan areas. At present, deterministic modeling and decision support systems only use pollutant maps obtained with mathematical methods. But, given the few scattered stations measuring the pollutants concentrations, an accurate map of the spatial distribution is almost impossible with standard methods. The map derived from the earth observation data give errors close to those obtained by standards methods. The representation is nevertheless closer to the rural urban environment. It is concluded that earth observation in near future,
derived products could be treated in near real time in conjunction with pollutants measurements to provide accurate information to decision maker.

Linn et al., (2000) have evaluated associations between ambient Carbon Monoxide, Nitrogen Dioxide, Particulate Matter and hospital admissions for cardiopulmonary illnesses in metropolitan Los Angeles during 1992–1995. The authors have concluded that the association of pulmonary diseases with PM$_{10}$ and NO$_2$, and of cardiovascular diseases with Carbon Monoxide.

Galcano et al., (2001) outline the air-quality management and reports on a study to determine the spatial distribution of Total Suspended Particulate in Nairobi, Kenya’s capital city. A map showing the distribution has been produced, probably the first of its kind for the city, which shows that the levels of Total Suspended Particulate in most of Nairobi are much above the average recommended by the WHO.

Godson et al., (2002) carried out a study to measure the levels of selected atmospheric contaminants and assess their possible association with the prevalence of several self-reported respiratory and dermal symptoms among workers in the refinery and petrochemical complexes at Eleme. PM$_{10}$, lead and polycyclic aromatic hydrocarbons were determined in the atmosphere at Port Harcourt Refining Company and Eleme Petrochemical Complex Ltd., and the pollution levels were related with the health hazards to the workers. Questionnaires were administered to 400 randomly selected subjects from the industries. Five-year hospital data were obtained. The data were analyzed for logistic regression using Statistical Package for Social and Sciences (SPSS) software. The authors concluded that all the polycyclic aromatic hydrocarbons levels observed in these locations were higher than the WHO limit. Exposure to dust and smoke was found to be significantly associated with respiratory symptoms among 65.7% of Port Harcourt Refining Company and 57.1% of Eleme Petrochemical Complex Limited workers.

Slani et al. (2002) describe the development of an application to forecast the peak ozone levels with the aid of meteorological and air-quality variables, in the Greater Athens Area. A number of regression models were considered, while the
selection of the final model was based on extensive analysis and on literature. The model adapted includes variables that are available on a daily basis, so as daily operational maximum ozone concentration level forecast can be achieved.

Ahmad Farhan Mohd Sadullah et al., (2000)\textsuperscript{4} collected Carbon Monoxide and Sulfur Dioxides concentrations and traffic volume data were collected at several locations in Ipoh City in the state of Perak in Malaysia. Mathematical models based on pollutant concentration were developed using the least-squares method. The authors concluded that the results from these studies indicate that the maximum concentration of CO pollutant is higher in an enclosed surrounding for all the driving modes compared to an open-surrounding similar traffic volume. The relationships derived between traffics flows and pollutants concentrations indicate that the adopted approach to forecast pollutant levels from traffic counts is workable for Malaysian situation.

Yoshika Sekine et al., (2004)\textsuperscript{131} studied the air quality of eastern Asian region, especially inland China, because rapid change in social, economic and industrial activities has been causing a dramatic impact on the atmospheric environment in China. In this study, the authors described how the air-quality and related insecurity issues have changed in China and suggested the important roles of air-quality watching and common understanding on the environment.

Hung et al., (2005)\textsuperscript{45} carried out a study on air pollution and given results of spatial and temporal distribution of VOCs in ambient air surrounding the Hsinchu Science-Based Industrial Park, Taiwan. The authors concluded that spatial distribution shows a comparatively higher concentration of VOCs that was found at the sites, which are in the southwestern part of Science-Based Industrial Park, downwind of or close to factories. When the wind speed was low, the concentration of pollutant tended to increase and became uniformly distributed around the science park. The temporal distribution shows a decrease in ambient concentration of pollutants from February to June 2001, mainly due to the decline in the production volume of the Science-Based Industrial Park in this period. During the whole period of investigation, the concentration of most of the compounds was found to be lower than the factory-surrounding air-quality standard of Taiwan.
Punnakornchara et al., (2005)\textsuperscript{90} conducted a study and used the GIS technique to assess the air-quality monitoring. The authors revealed that the air pollution is a serious problem in thickly populated and industrialized areas in Thailand, especially in areas where pollution sources and the human population are concentrated. The authors concluded that the traditional air-quality monitoring system controlled by the pollution control department is extremely expensive. The analytical measuring equipment is costly and time consuming and can seldom be based on air-quality reporting in real-time air-quality levels through the internet in the form of maps. The air-quality report should be more in detail including information such as air-quality interpolated maps, relating to other information for better understanding the air-quality level.

Jerrrett et al., (2005)\textsuperscript{56} studied the health effects of chronic air-pollution exposure within industrial cities, using a geo-statistical technique in combination with small-area data. The authors have concluded that the results suggest that chronic air-pollution exposure significantly increased the risk of premature cardio-respiratory and cancer mortalities. Subsequent studies have also found significant associations between ozone and Nitrogen Dioxide on higher mortality rates.

Ari Karppinen et al., (2005)\textsuperscript{10} developed a model for the human exposure to ambient-air pollution in an urban area. The main objective was to evaluate the exposure of population with a reasonable accuracy, instead of the personal exposures of specific individuals. The authors were utilized a previously developed modeling system for predicting the traffic flows, emissions originated from stationary and vehicular sources, and atmospheric dispersion of pollution in an urban area. A model was developed for combining the predicted concentrations, the location of the population and the time spent at home, workplace and other places of activity. The model developed has been designed to be utilized by the municipal authorities in urban planning, for example, for evaluating the impacts of future traffic planning and land-use scenarios.

Zvi Boger., (2005)\textsuperscript{134} carried out a work on air pollution that nitric acid production plants emit small amounts of Nitrogen Oxides (NO\textsubscript{x}) to the environment. Several Artificial Neural Networks (ANN) models were trained to predict the NO\textsubscript{x}
concentration in the tail gas, and their total amount emitted into the environment. The ANN models gave small errors, 0.6% relative error on the NO$_x$ concentration prediction and 0.006 kg/h on daily emission in the 20-45 kg NO$_x$/h range. Knowledge extraction from the trained ANN models revealed the underlying relationships between the plant operating variables and the NO$_x$ emission rate, especially the beneficial effect of cooling the absorbed gas and reticulating liquids in the absorption towers.

Somayeh Saraf Poor and Fatemeh Maleki., (2006)$^{114}$ conducted a study on human health due to the impact of air pollution in Tehran city, Iran. The objective of this study was to determine the relation between air pollution and newborn birth weight and low birth weight. One thousand newborn infants with an age of 28–42 weeks were selected randomly. This study revealed that mothers who lived in areas in which the level of particular matter <10 $\mu$m (PM$_{10}$) and Carbon Monoxide (CO) had been within the range of permitted level, in their trimester of pregnancy, delivered babies with a weight higher than those inhabited in areas polluted with two mentioned pollutants, with higher density. The authors concluded that the increase of pollutants such as CO, SO$_2$ and NO$_2$ low birth weight could be anticipated to reduce, since mothers who work in pollutant areas are subject to this disorder.

Maruf Hassain et al., (2006)$^{65}$ carried out a study on some air-quality parameters of Chittagong Metropolitan city in Bangladesh. Selecting five specific stations of Chittagong metropolitan. The authors concluded that the Kalurg industrial area is showing a higher impact of air pollution. Other air pollutants in residential and traffic area were relatively acceptable limits.

Jana Klanova et al., (2006)$^{53}$ studied the potential of passive air sampling devices (polyurethane foam disks) to assess the influence of local sources on the quality of the surrounding environment. Valasske Mezirici, a coal tar and mixed tar oils processing plant, and Spolana Neratovice, a chemical factory with the history of high production of organ chlorinated pesticides, were selected as the point sources of polycyclic aromatic hydrocarbons, and organ chlorinated pesticides, respectively. The authors concluded that useful data about the air concentrations
of POPs in the investigated regions, more importantly, it provided information on the transport and fate of POPs in the vicinity of local sources of contamination useful for the estimation of their influence.

Peter C. Chu et al., (2008) conducted a study on air pollution in Lanzhou which is one of the most polluted cities in China. The authors stated that Sulfur Dioxide (SO₂) concentrations have shown evident seasonal variability. Pollution was generally within the second-level criterion in spring, summer, and fall but was much higher than the second-level criterion and sometimes reaches mid-level pollution in water. The authors concluded that meteorological conditions were found to be important for SO₂ pollution. Observational and modeling studies conducted in this study showed a close connection between static stability and SO₂ pollution in Lanzhou, China during winter.

Shujun Song., (2008) carried out a study on spatial analysis that includes the processing of a wide range of air, water and soil pollution data and possibly noise assessment and waste management data. Other spatial inputs consist of data from remote sensing and GPS field measurements. Integration and spatial data management were carried out within the framework of a GIS. From modeling point of view, GIS was used mainly for the pre- and post-processing of data to be displayed in digital map layers and visualized in 3D scenes. Moreover, for pre- and post-processing, deterministic and geo-statistical methods were used for spatial interpolation. The authors concluded that the methods used can also be applied for the environmental analysis of other urban areas. It can be used as screening methods to more closely target key areas and to develop more detailed measuring and modeling strategies. Integration of all the data within a GIS framework therefore represents a useful approach for performing more complex environmental analyses that can support the decision-making processes of urban planning.

Yajie Ma et al., (2008) conducted a study on air pollution in urban area. In this paper, they presented a distributed infrastructure based on wireless sensors network and Grid computing technology for air-pollution monitoring and mining, which aims to develop low-cost and ubiquitous sensor networks to collect real-time,
large-scale and comprehensive environmental data from road traffic emissions for air-pollution monitoring in urban environment. The authors present a two-layer network or framework, P2P e-Science Grid architecture, and the distributed data mining algorithm as the solutions to address the challenges. The authors simulated the system in Tinyos to examine the operation of each sensor as well as the networking performance and also examined the effectiveness of the algorithm.

El-Harbawi et al., (2008)\textsuperscript{27} carried out an overview of the existing literature about air-pollution assessment and evaluation for earlier and current methods. These methods include mathematical models, simulation modeling, and simulation software. The authors concluded that the best way is by simulating the mathematical models through computer techniques. Furthermore, the integration of GISs and simulation models, combined with suitable databases and expert systems within a common and interactive Graphical User Interface (GUI) should make for more powerful and easy to use – and understand – risk information systems.

Syle Tahirysyajet et al., (2008)\textsuperscript{115} carried out a study in the city of Mitrouces. More concretely, the monitoring covers the area in the northeast part of Mitrovica, where the scope of monitoring points is nine, which covers the urban area with a higher density of population. From the use of lead and zinc mine in Stronterg and activities carried out by chemical industries, a series of problems were caused with the created dust depositions dumps from the remains of chemical–technological processes of the mine in Zvecan and other industrial activities. The authors concluded that from two years monitoring of air quality by the dust operation pollution, from the obtained values at Mitrovica city and its south-east part in particular has a high level of pollution, which exceeds the WHO recommended values for 20 times.

El-Harbawi et al., (2008)\textsuperscript{28} developed a software package for accident simulation and damage potential estimation. The software is coded in visual basic and is compatible with Windows working environments. With a comprehensive software package integrated with the geographical information system to predict and display the consequence of chemical hazards. The software is a user-friendly
and effective tool for evaluating the consequences of major chemical accidents, process decision-making for land-use planning, namely locating suitable hazardous installations, hazardous waste disposal areas and emergency response plan.

Jollios et al., (2009)\textsuperscript{33} illustrated three modern statistical methods through a case study, which arises from a scientific collaboration between Air Normand on the application side and University of Paris and the Institute National des Sciences Appliqués in Rouen on the academic side. The study was to analyze PM\textsubscript{10} pollution in Rouen area using six different monitoring sites and to quantify the effects of variables of different types, mainly meteorological factors and other pollutant measurements. Three methodologies – random forests, mixtures of linear models, and nonlinear additive models – are used in the analysis. In addition to the statistical interest of the study, authors gave detailed software oriented results and complete code using three freely available R packages.

Ebru Akpınar et al., (2009)\textsuperscript{26} carried out study on air pollution. In the present study, relationship between monitored air pollutant concentrations such as SO\textsubscript{2} and the total Suspended Particles (TSP) data and meteorological factors such as wind speed, temperature, relative humidity and atmospheric pressure was investigated from October to March for a period of three years (2003, 2004 and 2005) for Elazığ city. According to the results, linear and non-linear regression analysis, it was found that there is a moderate and weak level of co-relation between the air pollutant concentrations and the meteorological factors in Elazığ city.

Cannistraro and Ponterio., (2009)\textsuperscript{15} reported an analysis about the outdoor air pollution of the urban center of the city of Messina. The variations of the most critical pollutants concentrations and their trends with to climatic parameters and vehicular traffic have been studied. Linear regressions have been effectuated for representing the relations among the pollutants; the differences between pollutants concentrations on weekend or weekday were also analyzed. In order to evaluate air pollution and its effects on human health, a method for calculating a pollution index was implemented and applied in the urban center of the city.
Currie and Neidell, (2005) explored the impact of air pollutants on infant health, measured by birth weight, gestation and mortality, in New Jersey. Present work combines information about mother’s residential location from birth certificates with information on air-quality monitors. Authors suggest negative effects of exposure to Carbon Monoxide on children health, both during and after birth, even in areas at low levels of pollution. Few of the pollution measures are statistically significant, and when they are likely to suggest the positive effects on birth weight and gestation. The authors also report some evidence of significant effects of PM and ozone on health at birth.

Janke et al., (2009) studied the relationship between common sources of airborne pollution and population mortality for England. Using data at Local Authority level over the period of 1998–2005, authors examine whether current levels of airborne pollution are associated with excess deaths. After controlling for unobserved heterogeneity, the authors find that higher levels of PM and ozone are associated with higher mortality rates, arguing that the effect sizes are considerably larger than previously estimated.

Jeremy E. Diem and Andrew C. Comrie (2009) discussed the problem and its solution, which involves the use of linear regression. Large ranges of temporal variability’s are used to compensate for sparse spatial observations that are a few ozone monitors. Gridded estimates of emissions of ozone precursor chemicals, which are developed, stored, and manipulated within a GIS, are the core predictor variables in multiple linear regression models. Cross-validation of the pooled models reveals an overall $R^2$ of 0.90 and approximately 7% error. Composite ozone maps predict that the highest ozone concentrations occur in a monitor-less area on the eastern edge of Tucson. The maps also reveal the need for ozone monitors in industrialized areas and in rural, forested areas.

Mihaella Cretu et al., (2010) carried out a study at two pollution sources located near to an airport. Measurements at source and in the atmosphere were performed. The dispersion estimation was realized on specialized software using the input measured data for emission and meteorological data. The authors concluded that the atmospheric dispersion modeling predicted the downwind
concentration of air pollutants emitted from stationary sources such as industrial plants, and forecast air-pollution events that might pose a health hazard for the general public, as well as sensitive groups.

Cornelius O. Akanni., (2010)\textsuperscript{20} conducted a study on air pollution. Leaf samples of Terminalia Catappa L. (Almond) trees dominant in Lagos metropolis, Nigeria was collected from 34 sampling points located within dominant land-uses, along traffic corridors and six stations located 250-m away during the short-wet and short-dry seasons for two years. The author concluded that step-wise regression analyses further showed that traffic density, air temperature and land-use contributed significantly to air pollution. The microclimate of Lagos metropolis is characterized by relatively high air temperature, low wind speed and air pollution that varied according to traffic density and land-use. Concentrations of pollutants were higher than the WHO air-quality standards and were also higher along traffic corridor.

Pias Utang et al., (2010)\textsuperscript{88} collected data on wind speed and direction for different parts of the region as well as surface vector winds at 925-hpa level over the region were obtained for some stations and from NCEP/NCAR/NOAA analysis project data sets. The analysis suggests spatial variation in concentration and dispersion of pollutant at different temporal scales, attributed mainly to differential wind direction and speed, while the coastal meteorology, such as surface inversions, could be additional contributor to pollutant concentration and variation at the short term. The authors concluded that, on the basis of the wind climatology in the region, the pollution concentration is generally high, while the dispersion is low. Residential areas are allocated faraway from industrial areas, oil or gas installations, and high traffic road networks, separated by wide areas of green belts, the valuable options in spatial planning is essential.

Manjola Banja et al., (2010)\textsuperscript{67} carried out a study on air pollution, and mapping of air pollution within a GIS environment for 6 selected points at the urban area of Tirana during 2009. Surveys for air pollutants such as NO\textsubscript{x}, NO\textsubscript{2}, O\textsubscript{3} and SO\textsubscript{2} were conducted using a passive sampler, Analysis based on European Directive that indicates the passive sampling as an indicative method for
preliminary evaluation of air quality. GIS was used to compare the two planar views representing the periods of passive sampling in order to investigate the influence of meteorological conditions. The visualized result has the potential to provide the valuable information for pollution impact analysis, by including also the dimension of the influenced area and population. The spatial assessment of air pollution within the Tirana urban area can be exploited by environmental and medical authorities in order to plan their future strategies.

Mihairella Cretu et al., (2010)\textsuperscript{71} carried out a case study at two pollution sources located near to an airport. Measurements at source and in the atmosphere were performed. The dispersion estimation was realized on specialized software using measured data for emission and meteorological data. The work performed in this article aims to quantify the contribution of various pollution sources to the local air pollution from an airport area. In order to evaluate when the functioning of the sources dangerous for populations, authors elaborate the worst scenario regarding CO, NO\textsubscript{x}, and SO\textsubscript{2}, which can be applied by the authorities from both pollution sources.

Pengfei et al., (2011)\textsuperscript{87} carried out a study in Shanghai city with the aim of understanding the fog chemistry in a Chinese megacity; twenty-six fog water samples were collected in urban Shanghai to estimate pH, electrical conductivity, ten inorganic major ions and four major organic acids. The total ionic concentration and the electrical conductivity of fog samples were one or two orders of magnitude higher than those often found in Europe, North America and other Asian countries. Pollutants were expected to be mainly from local sources, including factories, motor vehicle emissions and civil construction. Non-local sources such as moderate- and long-range transport of sea salt also contributed to pollution levels in fog events as indicated by back trajectory analysis. The authors concluded that a high ratio of NO\textsubscript{3}/SO\textsubscript{2} and a low ratio of HCOO/CH\textsubscript{3}COO were consistent with large attributions from vehicular emissions that produce severe air pollution in megacities.

Richa Rai et al., (2011)\textsuperscript{98} carried out the present and future trends of major gaseous pollutants emissions and their impact on crop performance. The collated
information based on field experiments concludes that air pollutants not only affect the vegetation near the point sources and also urban centers. Air pollutants cause deleterious effects on physiology and metabolism of plants due to their oxidizing potential. Responses of plants vary between different species and their cultivars. The authors concluded that there is a need to screen out sensitive and tolerant cultivars in India and establish the exposure indices of all the important crops to reduce the crop loss.

Ulku Alver Şahin et al., (2011)\(^{122}\) predicted the daily air pollutant concentrations of PM\(_{10}\) and SO\(_2\) from the Yenibosna and Umranıye air-pollution measurement stations in Istanbul for times at which pollution data were not recorded. The authors predicted these pollutant concentrations using the Cellular Neural Network (CNN) model with meteorological parameters, estimating the missing daily pollutant concentrations for two data sets from 2002 to 2003 of 50% and 20% respectively. The authors concluded that the results of the CNN model predictions are compared with the results of a multivariate linear regression (LR). The results show that the correlation between predicted and observed data was higher for all the pollutants using the CNN model (0.54–0.87). The CNN model predicted SO\(_2\) concentrations better than PM\(_{10}\) concentrations. Another interesting result is that winter concentrations of all the pollutants were predicted well than summer concentrations.

Ahmad Zia Ul-Saufie et al., (2012)\(^{3}\) carried out a study to determine the best robust regression models for future prediction of PM\(_{10}\) concentration in Pulau Pinang, Malaysia. Robust method is less sensitive than ordinary least-squares (OLS) to large changes in small part of the data. Robust regression works by assigning a weight to each data point. The weighting functions used in this study are Huber, Andrews, Bisquare, Cauchy, Fair, Logistic, Talwar, Welsch and OLS. The model comparison statistics using Prediction Accuracy (PA), Coefficient of Determination (R\(^2\)), Index of Agreement (IA), Normalized Absolute Error (NAE) and Root Mean Square Error (RMSE) show that Fair is the best weighting function for next day and next 2-day prediction while Cauchy is the best for next 3-day.
Performance indicators showed that the developed robust regression models can be used for long-term prediction of PM$_{10}$.

Raffaele Lagravinese et al., (2013)\textsuperscript{96} examined the relationship between air pollution and hospital admissions for chronic obstructive pulmonary disease (COPD) in Italy, at province level, over the period of 2004–2009. Authors used information on annual mean concentrations of Carbon Monoxide, Nitrogen Dioxide, PM, and ozone measured at monitoring station level to build province-level indicators. In their model for hospital admissions, they allow pollution measures to be the subject to measure error and possibly correlated with the error term. By adopting an instrumental variable's approach, the authors find that higher levels of PM and Carbon Monoxide are associated with higher hospitalization of children, while ozone has an influence on hospital admissions of the elderly.

Federico Monsalve, et al., (2013)\textsuperscript{32} carried out study on hospital admission. The study considers the relationship between the risk of hospital admission due to respiratory diseases, the daily weather, and the air pollution conditions between 2000 and 2006. A synoptic climatologically approach was used to investigate the links between weather types and all hospital admissions due to respiratory diseases in Castilla-La Mancha (CLM), Spain. The main circulation weather types (CWTs) were determined for winter and spring, the seasons with the highest percentage of hospital admissions, and the frequency distribution of these types was also analyzed. The study includes a summary of the main characteristics of the hospital admission series and their distribution over the study period of seven years, as well as the frequency distributions of the admissions classified by gender and age, for each season, month and day of the week. In addition, an admission index was used to compare CWTs and hospital admissions due to respiratory diseases. The results show distinctly different responses of daily respiratory disease admission rates (RD) to the eight CWTs identified in winter and in spring. In winter, three CWTs (southwesterly (SW), anti cyclonic (A) and hybrid anti cyclonic southwesterly (HASW)) present values 1.5 times above the average admission rates. In contrast, there are no significant differences in spring season. Finally, the results of Principal Component Analysis applied to the daily series of
meteorological parameters, atmospheric pollutants and morbidity data revealed that in winter the decrease in RD is related to increases in temperature and pressure. These results represent an important step in identifying reliable connections between weather-air pollutants and human health.

Yousefi Kebria D. et al., (2013)\textsuperscript{132} carried out a study on air pollution, and modeling of PM10, O\textsubscript{3} and CO pollutants concentrations in Tehran. Parameters affecting the concentration of pollutants was specified according to weather and traffic statistics and the relation between various variables such as transportation, precipitation, maximum and minimum temperature and also relation between humidity and air pollution was investigated. A model was presented according to regression method to estimate the concentration of PM10, O\textsubscript{3} and CO pollutants in city streets with appropriate accuracy for future years. One of applications of this model is assessment and predictions of production factors of these pollutants for manage and control tools.

2.9 Air-Pollution Studies in India

Sing et al., (1990)\textsuperscript{110} conducted a study on three air pollutants, SO\textsubscript{2}, SPM and NO\textsubscript{x}, which were identified as major pollutants in urban cities. A comparative study was conducted between predicted and observed concentrations of these pollutants at different receptor points over Delhi. A receptor-oriented Gaussian plume model (HTLT) and the climatologically dispersion model (CDM) were used to estimate the long-term concentration of non-respective pollutants due to emissions from area and point sources. Modified stability parameters were used for low wind speed and calm intervals. The authors concluded that an error analysis of 54 pairs of observed and predicted concentrations showed that the performance of both the models was highly satisfactory, giving an RMSE of 1.61 for the HTLT model and 1.50 for CDM.

Chery., (1992)\textsuperscript{16} conducted studies to estimate the concentration levels of CO, HC, NO\textsubscript{x}, SO\textsubscript{2} and Pb across five dense roads of Delhi. The concentration level of pollutants was estimated using a line source dispersion model. The predicted levels were compared with the ambient standards to assess the status of air quality near study areas.
Cropper and Maureen., (1997)\textsuperscript{21} reported the results of a study relating levels of PM to daily deaths in Delhi, India. The authors conclude: (a) the impact of PM on total non-trauma deaths in Delhi is smaller than effects found in the United States. (b) The impacts of air pollution on deaths by age-group may be very different in developing countries than in the United States, where peak effects occur among people aged sixty-five and older. In Delhi, peak effects occur between the ages of fifteen and forty-four, implicating that a death associated with air pollution causes more life-years to be lost.

Meenakshi and Saseetharan., (2003)\textsuperscript{68} developed a program in C language to use generating frequency table for air pollutant; pollution rose diagrams are the two-way joint frequency distribution between wind direction and pollution concentration. The data of pollutant concentration and the frequency of occurrence of a specific range in a particular wind direction are the basic requirement for air-quality management programs. The authors revealed that, a computer program developed in C language and is used to generate the frequency table by getting the pollutant concentration and the prevailing wind direction on the monitoring day as input.

Mohanraj and Azeez., (2004)\textsuperscript{70} carried out a study on air pollution is a serious worldwide concern since it is linked with adverse health effects and revealed the association of SPM in air with acute and chronic respiratory disorders, lung cancer, morbidity and mortality. Odds ratio estimated by several studies of the dose–response relationship for Particulate Matter-associated respiratory sickness and premature mortality, increased with rise in Particulate Matter levels. Associations have been found with cardiovascular deaths, with myocardial infarctions and ventricular fibrillation. In India, haphazard urbanization, unprecedented vehicular emissions and inadequate infrastructure development are the supplementary factors for the fall in air quality. Challenge for the future generation in India lies in grappling the menace of air-pollution-induced diseases. The authors reviewed of atmospheric PM, its inhalation, deposition and toxicity, with experiences from the western countries and the current Indian scenario.
Reddy and Reddy., (2005)\textsuperscript{97} carried out a study on air pollution in Industrial Development Area (IDA) located at 20 km away from Hyderabad, that has mainly basic chemical and drugs and pharmaceutical units, by carrying a comprehensive study to know the status of air-pollution problems and to formulate stringent emission standards for identified source of pollutants, so as to improve air quality in and around the IDA. In IDA, ammonia, chlorine (g) and hydrochloric acid usage is very common in process control, while solvents such as acetone, benzene, toluene and methanol are used as process media, causes release of respective pollutants to the atmosphere through unconfined sources. The authors concluded that common pollutants such as SPM, SO\textsubscript{2} and NO\textsubscript{2} observed that the emission values are exceeding the National Standards.

Tripathy., (2006)\textsuperscript{121} conducted a study on air-quality monitoring in coal mining area near Tharia. The study revealed that the mean values of SPM, SO\textsubscript{2}, NO\textsubscript{2}, CO, dust fall rate and sulfate rate for the study period July–October 1996. The authors concluded that the air quality showed the higher values of the above parameters in five areas.

Akabar Ziauddin and Siddiqui., (2007)\textsuperscript{6} developed AQI for air-quality monitoring data in industrial area, residential area and commercial area. In this study, monitoring was carried out for 15 stations with respect to SPM, RSPM, SO\textsubscript{2} and NO\textsubscript{x} for a period of 24 h, and then they developed AQI to compare the quality of air. The authors concluded that five stations showed the critical conditions of air quality with AQI values above 100. The seven stations showed AQI values between 76 and 100, representing heavy air pollution. The two sites showed moderate air pollution and one site showed light air pollution.

Singal., (2008)\textsuperscript{111} reported the scenario of air-pollution activities in India. The air-pollution parameters of SO\textsubscript{x}, NO\textsubscript{2} and SPM in urban areas were initiated in 1984 with a network of 28 stations in 7 cities, but at present monitoring is being carried out at 324 stations, covering nearly the whole country. The parameters monitored are SO\textsubscript{2}, NO\textsubscript{2}, SPM and RSPM. Based on the analysis of the acquired data and the need to cover specific pollutants, the standards required and
extended in monitoring cover rural areas and specific monitoring areas, and the required compliance program.

Nagappa and Sharathchandra., (2008)\textsuperscript{74} indicated the ambient-air quality in seven major cities of Karnataka state under National Air Quality Program (NAMP). The data of ambient-air quality collected during the period of 2002–2008 in Bangalore city, and 2006–2008 for other cities like Mysore, Hubli, Dharwad, Mangalore, Hassan, Gulbarga and Belgam have been studied. The selected sampling sites belong to three different types of anthropogenic activities that is sensitive, residential, and commercial and industrial areas in the city. The authors concluded that the observed ambient-air concentration of SPM and RSPM was well above the prescribed standards at almost all the sites except Mysore and Mangalore. While the average ambient-air concentrations of SO\textsubscript{2} and NO\textsubscript{x} were below the permissible limits at all the centers but are having an increasing trend over the years and in this work, the exceedence factors of these cities is all in the areas, that is, sensitive, residential and commercial, are moderately to severely polluted.

Neha Dubey and Shamsh Pervez., (2008)\textsuperscript{75} carried out an investigation of variation in ambient PM in urban–industrial areas. The work presented here focus on the effect of meteorological parameters on ambient PM levels and the relationship of those levels at industrial complexes with their components at receptor ambient sites. Seven monitoring stations were identified in the study area for the measurement of PM\textsubscript{10} levels during 2005–2006. Of the seven sampling stations, three were located in three major industrial complexes in the study area, and the remaining four were taken as receptor zones of PM. The authors concluded that all the receptor PM\textsubscript{10} values showed a moderate correlation with specific industrial complexes; most of the receptors showed a PM\textsubscript{10} level exceeding Indian NAAQS for industrial areas.

Prasanthi Sam and Rajeshwari., (2008)\textsuperscript{89} conducted a questionnaire survey on health due to air pollution in Karnool town. In this study, the authors revealed that the public of Karnool town are directly exposed to pollution for nearly 10 h/day particularly the autoriksha drivers. The main symptoms observed were cough90\%,
eye irritation 80%, throat irritation 80%, breathlessness 20%, headache and dizziness 40%. The authors conducted the pulmonary function test, with this some of them exhibited normal pulmonary function, but the autoriksha drivers were suffering with respiratory disorders due to exposure of vehicular and industrial pollution in urban areas.

Vasanthy and Jeganathan., (2008)\textsuperscript{124} conducted ambient-air quality monitoring for different parameters around nine cement factories in and around Ariyalur town. In this study, the highest value of NO\textsubscript{x} recorded at Vellore Street during the daytime was 111\(\mu\)g/m\textsuperscript{3} and during night time 103\(\mu\)g/m\textsuperscript{3}. The authors concluded that the parameter of NO\textsubscript{x} shows a higher value at Vellore Street during the daytime which is higher than the standards.

Vijay Bhaskar B, and Vikram M. Mehta., (2010)\textsuperscript{125} Carried out a study on air pollution, In the present study, airborne particulate pollutants data were collected for a period of 4 years (2005–2008) at 13 locations in Ahmedabad, a mega city in Gujarat State in western India. The seasonal- and annual-average concentrations of the two pollutants were mostly above Indian air quality standards and were generally comparable with those observed in most other Indian urban areas. During this study period, there was a continuous decrease of particulate pollutants concentrations within Ahmedabad however, the concentrations were just above the permissible limits set by the Central Pollution Control Board (CPCB). These particulate pollutants concentrations were compared with meteorological variables such as rainfall, humidity, temperature, and wind speed. Both SPM and PM10 showed significant negative correlations with rainfall. Air Quality Index (AQI) was calculated for all stations for all months. Which varied from 25 to 193.3. AQI was high in summer season and low in monsoon season. AQI values varied from Good (0–50) to Hazardous (300–500). On the basis of the AQI scale, it is found that the atmospheric environment of Ahmedabad is moderately polluted.

Pavan et al., (2011)\textsuperscript{83} conducted a study on pollutant dispersion in the atmosphere and the analysis based on Computational Fluid Dynamics (CFD) codes offered an opportunity of model development based on first principles of physics and hence such models have an edge over the existing models. The
present work aimed (Kaiga Atomic Power Plant) at bringing out some of the distinct merits and demerits of the CFD based models. The choice of codes and the features to be employed from within the code for a specific problem needs expertise in thermal hydraulics and numerical techniques. The authors concluded that the use of CFD code for pollutant dispersion studies, which clearly brings out the success and advantage of CFD, based approach for modeling complex terrain.

Getarani Panda et al., (2011)\textsuperscript{36} conducted ambient-air quality studies at Balasore town in Orissa state. In this study, the ambient-air quality with respect to SPM, SO\textsubscript{2} and NO\textsubscript{2} have been monitored in different sensitive areas and residential areas during 2009 in three different seasons for obtained data mean and standard deviations. The authors revealed that all the concentrations of SPM, SO\textsubscript{2} and NO\textsubscript{2} in the winter season shown high results than standards for both residential and sensitive area, in post-monsoon and summer season the values were lower than winter season but not much less than the ambient-air quality standards, the authors concluded that Balsore town is polluted due to various activities.

Rahas Bihari Panda et al., (2011)\textsuperscript{35} developed AQI of Balasore town, Orissa. In this study, the concentration of various pollutants collected in Balsore town during June 2005 to May 2006, and AQI has developed for proper future planning of the town. Author’s revealed that the acute air-pollution potential in the studied area and surrounding locations. Air-quality indices indicate overall air-pollution status on the basis of these results an appropriate action plan can be adopted to minimize air-pollution indices value within the acceptable limits. The authors concluded that the study clearly demonstrates that it will be more appropriate to consider AQI rather than individual air pollutant level while controlling the air pollution in industrial areas and the data will be useful in developing an effective air-pollution control strategy for industrial areas.

Harish., (2012)\textsuperscript{42} attempted to study on urban air pollution in Bangalore city by emission of gases by vehicles which emit from them. The present day environment crisis demands a change in attitude, which initiatives can be taken to rescue environment from destruction in the city of Bangalore. But the urban areas
have a big share in the present day environmental problems from the automobiles throughout the world. This will finally focus on the attempt on the effects due to increase in the vehicle ratio in the city. Based on the facts and data obtained, the scenarios regarding future vehicle growth and their impact for travel are discussed to overcome emissions problems. The main objective is based on the emission of vehicles and their problems. In future vehicle-based emissions testing should be conducted for at least once in three months in Bangalore to gain a more accurate picture of the emissions that occur from the specific vehicles in this city. The results posed by important issues on transport and facts of existing situation will be used for the recommendations.

Ajith Benedict Rayan, (Bangalore) indicated from those emissions from two-wheel vehicles, when inhaled, lead to immediate cough and allergies. Around 17% of the air is polluted with PM and 67% with nitrous oxide which is emitted from two-wheelers vehicles. Study area reported that since car engines are Euro models, can take care of the pollution levels, but this is absent in case of two-wheel vehicles.

Bosky Khanna.,(2013) Bangalore, indicated that the number of cases of new patients with respiratory problems is more in winters, those who are already suffering from asthma or wheezing suffer from allergies during monsoons too.

H. Paramesh, (Times of India 2013) reported that the dust coming from petrol and diesel products (<2.5μm) and can cause lung inflammation, asthma and bronchitis. Besides, among senior citizens with lesser immunity, these can pass through respiratory tracts and could cause cardiac arrest.

2.10 Model for Air Pollution

2.10.1 General

Monitoring is more reliable as it gives an accurate measurement of a pollutant for a receptor site. However, this involves huge cost, time and manpower. Models on the other hand are both time and resource saving but may have inherent inaccuracies in predictions. However, they have own importance in environmental management program as they can be used for the predictions of space–time pollutants concentration due to different industrial emissions.
Mathematical models can be used to predict air quality in cases where the field observation of airborne effluents has been studied for a long time and has not undergone considerable revision. (Benarie M M 1987)\textsuperscript{13}

2.10.2 Types of Air-Quality Models

Air-quality models can be classified by mathematical formulation or by objective. One formulation can meet more than one objective, just as one objective can be addressed with more than one formulation. This section discusses mathematical formulations and modeling objectives.

- **Mathematical Formulation**

  Each mathematical formulation has inherent assumptions, advantages, limitations, and requirements for its implementation. This section presents information to select the formulation most appropriately to the requirements of modeling study based on data collection.

- **Empirical or Statistical Model**

  An empirical model is an application of mathematics to a series of related data values for the purpose of establishing a relationship among dependent and independent variables. Various types of relationships (e.g., linear, exponential, logarithmic) can be tested to fit the data. Statistics are applied to determine the values of parameters required for the specific formulation, as well as to estimate how well the resulting equation fits the data (i.e., goodness-of-fit). Empirical models should be used with caution. That may be valid only within the range of the data from which they were derived. That is, interpolation between data values is acceptable, but extrapolation to a set of conditions outside the range of data may yield invalid results.

  \[ Y = b_1 + b_2 X_2 + \ldots + b_k X_k + e \]

where \( Y \) is dependent variable, \( X_2, X_3, \ldots, X_k \) are independent variables, \( b_1, b_2, \ldots, b_k \) are linear regression parameters and \( e \) is an estimated error term, which is obtained from independent random sampling from the normal distribution with mean zero and constant variance.

- **Gaussian Model**
The Gaussian plume model is a (relatively) simple mathematical model that is typically applied to point source emitters, such as coal-burning electricity-producing plants. Occasionally, this model will be applied to non-point source emitters, such as exhaust from automobiles in an urban area. One of the key assumptions of this model is that over short periods of time (such as a few hours) steady-state conditions exist with regard to air pollutant emissions and meteorological changes. Air pollution is represented by an idealized plume coming from the top of a stack of some height and diameter. One of the primary calculations is the effective stack height. As the gases are heated in the plant (from the burning of coal or other materials), the hot plume will be thrust upwards some distance above the top of the stack the effective stack height. It is required to calculate this vertical displacement, which depends on the stack gas exit velocity and temperature, and the temperature of the surrounding air (Sing et al., 1990)\textsuperscript{110}. Concentration of pollution at a point \((x,y,z)\) generated by a source at height \(H\) can be estimated using the expression.

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

\(X = \text{Pollutant concentration, } \mu g/m^3\)
\((x,y,z) = \text{Co-ordinates of the receptor point}\)
\(H = \text{Height of emission, matters}\)
\(U = \text{Wind Speed, m/s}\)
\(Q = \text{Emission rate, g/m}^2/\text{s}\)
\(\sigma_y \quad \sigma_x = \text{Standard deviation of plume concentration distribution across horizontal and vertical dimensions of plume at downwind distance, } x\)

\(\Rightarrow \text{Lagrangian Model}\)

Lagrangian models do not utilize the steady-state assumption. Instead, they are built on probability distributions for wind speed and direction. Therefore, they can support constant, time-varying, and intermittent emission sources. Lagrangian models require more computational resources (that is computer memory, CPU speed, and disk storage) than Gaussian models.
\[
\frac{du_i}{dt} = a_i(x_i, u_i)dt + b_i(x_i, u_i)\xi_i(t),
\]

where \( u_i \) is the turbulent velocity, \( a_i(x_i, u_i)dt \) is the deterministic term, \( b_i(x_i, u_i)\xi_i(t) \) is the stochastic term and \( \xi_i \) is a normally distributed (average 0 and variance \( dt \)) random increment.

- **Eulerian Model**

Eulerian models are typically used for urban-to-global scale air-quality modeling studies and employ five-dimensional data sets. The modeling domain is divided into three-dimensional grid cells, each of which is homogeneous (e.g., a well-mixed reactor). Pollutants are adverted between the grid cells in the \( x \)- and \( y \)-direction (horizontal) and the \( z \)-direction (vertical), which are the first three dimensions. The fourth dimension is time, and the fifth dimension is chemical species. All the relevant chemical species are included in the model in the form of a chemical mechanism. Therefore, Eulerian models are well-suited for full atmospheric chemistry. Eulerian models also require a vast amount of data, which spawns the need for numerous related models and pre- and post-processor. Eulerian models are, however, customarily used to investigate air-quality issues related to tropospheric ozone, \( \text{PM}_{2.5} \) formation, secondary organic aerosols, and visibility.

\[
U_i \frac{\partial C}{\partial x_i} = \frac{\partial}{\partial x_i} \left( K_i \frac{\partial C}{\partial x_i} \right),
\]

where \( i = 1, 2, 3; C \) denotes the average concentration; \( x_i \) is the position; \( U_i \) is the mean wind velocity and \( K_i \) is the eddy diffusivity. The cross-wind integration of Eq., in which the longitudinal axis coincides with the direction of the average wind and the longitudinal diffusion is neglected.

- **Hybrid Model**

A hybrid approach combines two or more of the other mathematical types of models. Two examples are the Lagrangian–Gaussian and the plume-in-grid approaches. In both the examples, the reason for combining approaches is to reduce the overall computing cost while attaining improved results over using just one approach. The Lagrangian–Gaussian hybrid starts as a Lagrangian model. This gives a more detailed solution close to the source than a steady-state
Gaussian plume model. However, the computational cost increases with the number of particles that need to be tracked throughout the modeling domain. Therefore, when the particles are very old and far from the source, they are tested to determine if they can be approximated by a Gaussian distribution. If so, then a Gaussian construct is substituted, and the number of particles being tracked is reduced.

- **Box Model**

  The simplest form of a dispersion model is the Box Model, which is often used to estimate the air pollution due to area sources. The Box represents a three-dimensional volume within which air pollutants are assumed to be thoroughly mixed. Box models can be used to obtain the order of magnitude estimates of ambient pollution levels. However, the simplifying assumptions of the model lead to results that do not simulate true atmospheric conditions accurately. Special application of the box model is an elevated inversion above a point source in a valley (Nirjar et al., 2002)

  \[
  QA = \frac{u \times Y \times H \times C \times \cos \theta}{X \times Y} \]

  where

  QA = Emission flux in micrograms per second per meter squared (µg·s\(^{-1}\)·m\(^{-2}\)),
  
  u = Measured wind speed meters per second (m/s),
  
  Y = Width of field meters (m),
  
  H = Plume height (m),
  
  C = Net measured (downwind – upwind) concentration in micrograms per cubic meter (µg/m\(^3\)),
  
  \(\theta\) = Difference of the wind direction from ideal (0-45) (used as 0 for all tests), and
  
  X = Upwind length of field (m).

  Note that equation can be simplified in that field width is both in the denominator
2.11 Software Available for Air-Pollution Modeling

2.11.1 GIS Software

GIS has created a new era of environmental modeling. More powerful computers have made running air-quality models at global and local spatial scales possible. In order to understand the function of more complex models, the modeling system should consist of other subsystems (point and area sources of pollution, spatial description of terrain elevations, meteorological data and air-quality monitoring networks). Obviously, the use of GIS has become essential in providing boundary conditions to the air-quality models (Kumar 2006)\textsuperscript{59}. In case of large-scale air-quality modeling, more detailed spatial data are needed to include the impact of buildings and other manmade barriers on the distribution of air pollutants. Apart from this approach, the statistical theory is also used to indicate spatio-temporal interactions. Due to spatial properties of the GIS, space coordinates can be derived from a spatial query in the frame of GIS functionality. The associations between the data repository and spatial objects in the Arc GIS geo data base are specified by relationships, which are stored into the relationship classes (Matejicek, 2005)\textsuperscript{63}. In this study, this method has been considered and shown in Chapter 4.

- **Industrial Source Complex Short Term (ISCST3) Model**

ISCST3 is designed to support the EPA's regulatory modeling programs. And it is a steady-state Gaussian dispersion model with a number of options available to the user. These options include the use of stack-tip downwash, buoyancy-induced dispersion, final plume rise (except for sources with building downwash), a routine for processing averages when calm winds occur, and default values for wind profile exponents and for the vertical potential temperature gradients. The short-term model also incorporates COMPLEX1 screening model dispersion algorithms for receptors in complex terrain. The model calculates the concentration value for each source and receptor combination for each hour of meteorological input and calculates user-selected short-term averages. The user also has the option of selecting averages for the entire period of meteorological input data.
- **Industrial Source Complex Plume Rise Model Enhancement (ISC-PRIME) Model**

  The ISC-PRIME model (Dated 99020) is based on a version of IS CST3 (dated 96113) that incorporates the PRIME (Plume Rise Model Enhancement) algorithms for improved treatment of building downwash. The PRIME sub-model handles the stack/building geometry better than the IS CST3 algorithm since it internally accounts for the plume rise and trajectory around building obstacles. The building dimensions preprocessor program, BPIP, has been modified to provide additional values for ISC-PRIME. The modified program, called BPIP-PRM, readily accepts a BPIP input file and outputs additional values needed as input to ISC-PRIME.

- **AERMIC Dispersion Model (AERMOD)**

  The AERMOD model (Dated 99351) has been developed by AERMIC (American Meteorological Society/Environmental Protection Agency Regulatory Model Improvement Committee). It is based on an older version of the IS CST2 model (version 93109). Special features of AERMOD include its ability to treat the vertical in homogeneity of the planetary boundary layer, special treatment of surface releases, irregularly shaped area sources, a three-plume model for the convective boundary layer, limitation of vertical mixing in the stable boundary layer, and fixing the reflecting surface at the stack base.

  The AERMOD model is actually a modeling system with three separate components: AERMOD (AERMIC Dispersion Model), AERMAP (AERMOD Terrain Preprocessor), and AERMET (AERMOD Meteorological Preprocessor). AERMET is the meteorological preprocessor for the AERMOD. Input data can come from hourly cloud cover observations, surface meteorological observations and twice-a-day upper air soundings. Output includes surface meteorological observations and parameters and vertical profiles of several atmospheric parameters. The AERMAP preprocessor is a terrain preprocessor designed to simplify and standardize the input of terrain data for AERMOD.

- **California PUFF (CALPUFF) Model**
CALPUFF is an advanced, integrated Gaussian puff modeling system for the simulation of atmospheric pollution dispersion distributed by the Atmospheric Studies Group at Travelers Research Corporation (TRC) Solutions. It is maintained by the model developers and distributed by TRC. The model has been adopted by the USEPA in its Guideline on Air Quality Models as a preferred model for assessing the long-range transport of pollutants near-field applications involving complex meteorological conditions and their impacts on Federal Class I areas and on a case-by-case basis for certain. The integrated modeling system consists of three main components and a set of pre- and post-processing programs. The main components of the modeling system are CALMET (a diagnostic 3-dimensional meteorological model), CALPUFF (an air-quality dispersion model), and CALPOST (a post-processing package). Each of these programs has a Graphical User Interface (GUI). The CALPUFF model is designed to simulate the dispersion of buoyant, puff or continuous point and area pollution sources as well as the dispersion of buoyant, continuous line sources.

- **Complex Terrain Dispersion Model-Plus (CTDMPLUS) Model**

CTDMPLUS is a refined Gaussian plume dispersion model designed to estimate hourly concentrations of plume material from elevated point sources at receptors on or near isolated terrain features. This model can assess stable and neutral atmospheric conditions as well as daytime, unstable conditions. Its use of meteorological data and terrain information is different from other regulatory models in that considerable detail for both types of input data is required and is supplied by preprocessors specifically designed for CTDMPLUS. Hourly profiles of wind and temperature measurements are used by CTDMPLUS to compute plume rise, plume penetration, convective scaling parameters.

- **SELMAGIS**

It is based on the Geographical Information System Arc GIS 9.1–9.3, 10 and is used as an extension in Arc Map.

- **ADMS 4 software**

ADMS 4 is used to model the impact of existing and proposed industrial installations. Current and future air-quality can be assessed with respect to the air-
quality standards such as the EU Air Quality Directive, UK Air Quality Strategy, US NAAQS.

- **IMMI Software**

  IMMI is software especially designed for noise- and air-pollution mapping. All National European and International calculation methods of importance are implemented in a convenient user-friendly and practical working environment.

- **CALINE Models**

  California Department of Transportation (CALTRANS) has been the leader in the development of dispersion models for highways. The first line source dispersion model, CALINE, was published in 1972 for predicting the CO concentration. In 1975, a revised version of the original model, CALINE2, was developed. This model could compute concentration for depressed sections and for winds parallel to the roadway. Subsequent studies indicated that CALINE2 seriously over predicted concentration for stable, parallel wind conditions.

  In 1979, third version, CALINE3 was developed. CALINE3 retained the basic Gaussian dispersion methodology but used new horizontal and vertical dispersion curves modified for the effects of surface roughness, average time and vehicle-induced turbulence. In 1980, EPA authorized CALINE3 for use in estimating the concentration of non-reactive pollutants near highways. CALINE4 is the latest version, and the concentration of CO, NO₂ and aerosols can be predicted using this model. (Niraj et al, 2002)⁷⁶

- **SPSS Software**

  Statistical Package for the Social Sciences (SPSS) is a Windows based program that can be used to perform data entry and analysis and to create tables and graphs. SPSS is capable of handling large amounts of data and can perform all of the analyses covered in the text and much more. SPSS is commonly used in the Social Sciences and in the business world as it is user friendly and advanced tool for developing simple linear and multiple regression equations. (Godson et al., 2002)³⁸