1. Introduction

Nature's countryside, favoured by an equable climate and blessed with clean air and
ample pure water, is indeed a wondrous and most precious resource for mankind. In contrast,
many of man's cities are dreary, even ugly in parts, and impose on their suffering inhabitant's
air poisoned by pollution and other unpleasant or injurious effects. With the rapid rate of
urbanization, mankind's bricks, concrete and asphalt are continuing to expand at the expense
of nature's green spaces and forests.

The disagreeable effects of rampant urbanization are often at their worst in hot climates
of some developing countries, which unfortunately is just where sprawling cities are growing
most swiftly, often in a haphazard way and without proper regard for crucial climatological
considerations.

Urban climates are mostly inferior to their rural counterparts except insofar as the less
cold winters of high-latitude cities may be considered an improvement. However, much can
be done to minimize the adverse effects of urbanization provided that specialized
climatological expertise is introduced and intelligently used in the urban planning process. It
may be argued that little can be done to improve the environment of existing cities except when
major redevelopment is undertaken. Nevertheless, many cities are still expanding, with
alarming rate in some developing countries, and this fact provides a golden opportunity to
inject some climatological sense into further urban growth.

Complex interactions between the atmosphere and the terrain over which it passes
influence the climate. Consequently, when the terrain is changed, so also is the climate.

The rapid rate at which the urbanization is taking place, especially in hot climates, raises
many difficult questions ranging far wider than merely how best to scatter some green spaces
amongst the concrete.

*Would large built up areas modify the climate on a regional scale? If so, how?*

*What is the best way to distribute the industrial, commercial, and residential areas whilst at
the same time preserving valuable arable land? Is a group of self-contained satellite towns*
better than the single huge conurbation?

Should all the industry be concentrated in one area to facilitate pollution control? If so, should the working people, living perhaps in "dormitory" suburbs, be discouraged from commuting by car through the availability of super-efficient, clean public transport? How can adverse effects on human health best be alleviated?...

The questions are endless, but, as yet, the answers few! But one thing is sure: if wise, effective solutions are to be found, specialized climatologists will have to play their part in close collaboration with the various professional planners involved.

1.2 Air Pollution

Air pollutants are airborne particles and gases that occur in concentrations that endanger the health and well-being of organisms or disrupt the orderly functioning of the environment. Air pollution comes from many different sources, "stationary sources" such as factories, power plants, and smelters — "mobile sources" including cars, buses, planes, trucks and trains — and "natural sources" such as wildfire, windblown dust, and volcanic eruptions — all contribute to air pollution. Pollutants may be grouped into two categories: primary and secondary. Primary pollutants are emitted directly from identifiable sources. They pollute the air immediately upon being emitted. Secondary pollutants, on the other hand, are produced in the atmosphere when certain chemical reactions take place among primary pollutants.

1.2.1 Why we are worried about the problem of air pollution?

Air pollution is a continuous threat to health and welfare. An average adult male requires about 13.5 kg of air each day compared with about 1.2 kg of food and 2 kg of water. The cleanness of air, therefore, should certainly be as important to us as the cleanness of our food and water (Lutgens and Tarbuck, 1992).

Indian cities are being exposed to high levels of air pollution and people living in these cities are paying a price for the deterioration in air quality. The World Bank has estimated that Indians are spending Rs 4,550 crores every year on treatment of diseases caused by ambient air pollution (Brandon and Homman, 1992). This number exceeds the annual average number of fatalities of all the remaining weather-related hazards combined.
1.2.2 Type, Sources and Adverse effect of air pollution

Air is never perfectly clean, even nature pollutes the atmosphere. Many natural sources of air pollution have always existed. Ash from volcanic eruptions, salt particles from breaking waves, pollen and spores released by plants, smoke from forest and brush fires, and windblown dust are all examples of "natural air pollution".

Surprisingly perhaps, agricultural operations also throw up much solid matter. In certain parts of the world there is a danger that extensive farming may increase the production of dust.

But it is in these cities and industrial complexes that mankind offend most by discharging into the atmosphere over millions of tones per year of solid matter worldwide, along with various gases including carbon monoxide, carbon dioxide and oxides of sulphur and nitrogen. This contamination, mostly arising from the burning of fossil fuels, causes great damage and in heavily polluted city areas has serious harmful effects on health. A brief description of major air pollutants is presented below:

1.2.2.1 Particulate matters are the solid and liquid aerosols suspended in the atmosphere. These are emitted into the atmosphere by sources such as factories, power plants, motor vehicles, construction activity, fires and natural windblown dusts.

Atmospheric particles can scatter and absorb sunlight, thus reducing visibility by attenuating the light from objects and illuminating the air, reducing the contrast between the objects and their background. The visual range is approximately inversely proportional to the concentration of particulate matter. Reduced visibility is aesthetically undesirable and it is also dangerous for aircraft and motor vehicles. High relative humidity can sufficiently increase the effect of pollution on visibility. Of particular interest is PM$_{10}$, which is the Respiratory Particulate Matter having size less than or equal to 10μm in diameter. Most particulate matter is removed from the atmosphere by gravitational settling.

The effect of particulate matter on materials include corrosion of metals when the air is humid; erosion and soiling of buildings, sculptures, and painted surfaces. PM$_{10}$ causes respiratory problems in human beings.

1.2.2.2 Sulphur oxides The most important oxides of sulphur emitted by sources of pollutants is sulphur dioxide (SO$_2$). It is a chemically active trace species, because atmospheric SO$_2$ reacts photochemically (homogenous conversion) and on airborne particles (heterogeneous
conversion) to produce sulphates. Atmospheric sulphate particles are active cloud condensation nuclei. An increase in the number of cloud condensation nuclei on a global scale may increase cloud amount and hence albedo. An enhancement in atmospheric sulphate particles in the stratosphere may increase short-wave reflection to space.

The residence time of SO$_2$ in the atmosphere is only a few days at most and this is the reason why the SO$_2$ mass in the atmosphere is so small compared to annual anthropogenic emissions. Actually only about one-third of the sulphur oxide in the atmosphere is believed to be produced by anthropogenic activities. Natural sulphur sources are biologically produced hydrogen sulphide (H$_2$S) (from decay of organic matter) that is eventually oxidized to sulphur oxides and sulphates from sea spray. It plays a significant role in producing acid deposition. It forms sulphate particles. These particles return to Earth’s surface via dry or wet deposition. Both processes transfer excess acidity to their deposition sites. This acidity may damage sensitive ecosystems.

Sulphur oxides can damage materials, mainly through their conversion into the highly reactive sulphuric acid. SO$_2$ has been found to affect vegetation adversely even at concentrations below 0.03 ppm. Major human health concern associated with their exposure include effects on breathing and respiratory system, damage to lung tissue, cancer, and premature death.

1.2.2.3 Carbon monoxide (CO) originates from the incomplete combustion of carbonaceous material and is emitted into the air in largest quantities. Surprisingly, little is known accurately about the sources and sinks of CO in the atmosphere; CO can be oxidized to carbon dioxide (CO$_2$), but the rate at which this occurs seems to be very slow and mixtures of CO and O$_2$ exposed to sunlight for several years have remained almost unchanged. Since the residence time of CO in the atmosphere is at most only a few months, some removal process must exist. Perhaps CO is absorbed and oxidized on surfaces; perhaps it is removed and utilized by plants or animals; or perhaps photochemical or catalytic processes are involved in its removal. Recent research indicates that soils are capable of removing large amount of CO from the atmosphere, probably due to the activity of soil microorganisms (Inman, et al, 1971).

The toxic effect of CO on human beings arises from it’s reversible combination with haemoglobin in the blood; haemoglobin has a greater affinity for CO than it does for O$_2$. The combination of haemoglobin with CO lessens the oxygen-carrying capacity of the blood so that
less O$_2$ is available to the body cell.

1.2.2.4 *Hydrocarbons* are chemical compounds containing only carbon and hydrogen. The gaseous and volatile liquid hydrocarbons are of particular interest as air pollutants. Natural sources of hydrocarbons are largely biological.

Hydrocarbons are of particular concern because of their involvement in the production of photochemical oxidants, which cause eye irritation and other effects.

1.2.2.5 *Nitrogen oxides* form a large family of trace gases that are ubiquitous in the Earth's troposphere. Their origin is from both natural and anthropogenic processes; transport from the stratosphere is also thought to be a source. Oxides of nitrogen play a crucial role in determining the atmospheric ozone concentration. They can also contribute to acid precipitation. Although many different oxides of nitrogen are known, only nitric oxide (NO) and nitrogen dioxide (NO$_2$) are emitted to the atmosphere by human activities in significant quantities. They are formed by the reaction of nitrogen and oxygen in the atmosphere when combustion takes place at high temperatures (typically exceeding 1100°C) and cooling occurs fast enough to prevent decomposition:

$$N_2 + xO_2 \leftrightarrow 2NO_x$$

Usually less than 0.5% of the NO$_x$ is initially emitted as NO$_2$ (EPA, 1971) and these pollutants have a residence time in the atmosphere of only 3 or 4 days. Anthropogenic NO$_x$ pollution is significant in urban areas since peak NO concentrations are often above 1 ppm and NO$_2$ levels occasionally exceed 0.5 ppm. Both these oxides play an important role in the production of photochemical smog.

Nitrogen oxides are known to produce corrosion of metals due to production of particulate nitrates (EPA, 1971). NO is not an irritant and it is not believed to have any adverse health effect on human beings at concentrations that occur in the atmosphere, even in highly polluted areas. These concentrations are dangerous, however, because of the possibility of oxidation to NO$_2$. Haemoglobin has an extraordinary affinity for NO (about 1500 times its affinity for CO) but fortunately atmospheric NO appears to be unable to enter the bloodstream to react with the haemoglobin. NO$_2$ is reddish gas, it's importance in photochemical reactions is due to its strong absorption of ultraviolet radiation. Long-term exposures to 0.06 ppm has been related to an increase in acute respiratory disease in human beings (EPA, 1971).
1.3 Air pollution and meteorology

Air pollution and meteorology are linked in two ways. One concerns the influence that weather conditions have on the dilution of pollutants. The second connection is the reverse and deals with the effect that air pollution has on weather and climate.

1.3.1 Meteorological effect on air pollution

Of particular importance to air pollution is the troposphere. The lapse rate of the troposphere is about $-6.5 \, ^{\circ}\text{C/km}$. If the actual lapse rate is greater in magnitude than the adiabatic lapse rate, a rising parcel of air will become warmer and less dense than the surrounding air so it will continue to rise. This would be desirable if the parcel contains pollutants. A temperature inversion is said to exist when the normal lapse rate in the lower atmosphere is inverted and the temperature actually increases with height. Exhaust gases and pollutants will rise only a certain height under these conditions and persistent inversions that exist several days can be very dangerous.

There is essentially nothing that can be done to prevent a temperature inversion. The energy that would be required to stir the polluted air artificially to prevent dispersion of the pollution is too great. The construction of tall stacks may enable pollutants to rise enough to go above the inversion ceiling.

Once the pollutants are released into the air their fate is solely controlled by the atmospheric conditions. The turbulent mixing, photochemical reactions by solar radiation, removal by rainout, washout, agglomeration and fallout are some of the significant meteorological processes in air pollution depletion.

Two of the most important atmospheric conditions affecting the dispersion of pollutants are (1) the strength of the wind and (2) the stability of the atmosphere. These factors are critical because they determine how rapidly pollutants are diluted by mixing with the surrounding air after leaving the source.

Whereas wind speed governs the rate with which pollutants are initially mixed, atmospheric stability determines the extent to which vertical motions will mix the pollutants with cleaner air above. The vertical distance between the earth's surface and the height to which convectional currents extend is termed as mixing depth. Generally, greater the mixing depth, the better the air quality. When air is stable, convectional motions are suppressed and mixing depths are small. Conversely, an unstable atmosphere promotes vertical air movements.
and greater mixing depths. Because heating of the earth’s surface by the sun enhances convectional movements, mixing depths are usually greater during the afternoon hours. For the same reason, mixing depths during the summer months are typically greater than during the winter months.

Pollution is often worse in light winds, with the highest concentrations occurring when cold (heavy) air stagnates beneath warm (lighter) air and hugs the ground, trapping pollution. Such conditions have many causes and are found in every climate.

Although for some years considerable efforts have been made to the alleviation of air pollution, one still relies heavily on the atmospheric processes which does a good job in reducing the concentration of pollutants through dilution by turbulent winds and cleaning by rain. Consequently meteorologists are crucially involved and must be brought to bear on combative measures. However, there are limits to the scavenging efficiency of atmospheric processes as evidenced by the pall which hangs over many cities much of the time, making evident the self-inflicted plague of pollution.

The implementation of meteorologically appropriate projects may frequently be essential for improving air pollution problems. Choice of sites with local climate in mind, avoiding inversion and poor ventilation areas, design of chimney stacks are examples supporting the advice.

1.3.2 Effect of Pollution on climate

The air pollution has got both local as well as global effects on the climate. They are:

1.3.2.1 Local effects of pollution on climate Pollution in the atmosphere is capable of very important effects on the climate in localized areas, especially urban areas (Landsberg, 1970). The effects in urban areas include the following:

(i) High temperatures Minimum daily temperatures in urban areas are often 5 to 10 °C higher than those in the surrounding rural areas and annual mean temperatures are typically 0.5 to 1.3 °C higher (Peterson, 1969).

(ii) Attenuation of solar radiation Particulate matter in the atmosphere, whose urban concentrations are typically 10 times those of the rural areas, is capable of reducing the amount of solar radiation falling on the city by 15 to 20%. These concentrations are accompanied by a reduction in visibility.
(iii) **Lowering of wind speeds** The presence of urban construction leads to increased turbulence because of the increase in surface roughness and wind speeds near the surface of the earth are reduced (Landsberg, 1970).

(iv) **Increased cloudiness** This is probably due to the updrafts produced by the urban heat island and partly to the large number of small particles produced by man's activities, which are capable of serving as condensation nuclei for water vapour in the atmosphere (Landsberg, 1970).

### 1.3.2.2 Global effects of pollution on climate

The global effects of pollution on climate are less marked than the local effects but they may be of great importance in the long run (Singer, 1970).

As the millennium draws to a close, global warming has emerged as one of the most important environmental issues ever to confront humanity. This concern arises from the fact that our everyday activities may be leading to changes in the Earth's atmosphere that have the potential to significantly alter the planet's heat and radiation balance, and thereby lead to a warmer climate in the next century. The major pollutants affecting the climate on the global scale are discussed briefly in the following lines.

(i) **Carbon dioxide** The release of vast, and atmospherically significant quantities of carbon dioxide by the combustion of fossil fuels has led to fears of significant climate influences should the CO$_2$ in the atmosphere actually increase with time. The absorption bands of CO$_2$ in the infrared region would become more important with an increase of CO$_2$ concentration and the present radiation balance of the earth would be changed in such a manner as to increase the average surface temperature. The first calculation of this increase was by the famous chemist Svante Arrenhius in 1896; he estimated that a doubling of the atmospheric CO$_2$ concentration would increase the surface temperature by 5 to 6 °C, with different warming at different latitudes. Arrhenius felt that CO$_2$ variations due to volcanic activity might be of climatic importance. In 1938, Callendar (Callendar, 1938) showed that there was evidence of a gradual increase in atmospheric CO$_2$ and that man's activities might be responsible. In the mid-1950's, detailed studies of the CO$_2$ absorption by Plass (Plass, 1956) led him to predict a 3.6 °C rise in the surface temperature from a doubling of the atmospheric CO$_2$ concentration. More recent calculations (Manabe and Wetherald, 1967; Rasool and Schneider, 1971) incorporating the
effects of convection, humidity and cloudiness have predicted rises of 0.8 to 2.9 °C in surface temperature from doubling of CO\textsubscript{2} concentration.

(ii) **Particulate matter** The particulate matter in the atmosphere is believed to have the effect of cooling the earth. Small particulate are effective scatters of electro-magnetic radiation, with the intensity of the scattered radiation being inversely proportional to the fourth power of the wavelength of the incident radiation as well as directly proportional to the intensity of the incident radiation. An increase in the particulate matter in the atmosphere would thus scatter the solar short wave radiation more than the terrestrial long wave radiation increasing the albedo of the earth and cooling it somewhere. It has long been recognized that the dust injected into the atmosphere by great volcanic eruptions can cool the earth for the following years, mainly because much of the dust will be thrown into the stratosphere and only descend back to earth (Lamb, 1970). But man’s activities may be contributing to a gradual increase in these concentrations. Although volcanic dust in the stratosphere leads to cooling of the earth’s surface, it is not certain that increasing atmospheric aerosol concentrations would have the same effect since particulate matter is capable of absorbing radiation as well as scattering it (Landsberg, 1970; Rasool, 1971). Dust on snow and ice reduces reflection and increases absorption and can promote melting.

### 1.4 State of Environment Today

Industrialization and consequent urbanization injects foreign particles and gases into the urban atmosphere, which, inadvertently, modify climate and deteriorate the air quality. Urban agglomerations increase air temperature, steepen low level lapse rates, slow horizontal winds and induce updrafts. Urbanization also increases turbulence and cloud formation, fog and reduces near surface humidities. Pollutants are increased by one to several orders of magnitude. They reduce solar radiation intensity, visibility and shorten the sun-shine duration. Their effects on cloud formation and rainfall over and in the vicinity of cities is still uncertain, but evidence points to occasional cases of stimulation of precipitation and perhaps some cases of inhibition.

The urban heat islands have a direct role in pollution distribution. The size, shape and intensity of the heat island depends upon topography, climate, building density, material of construction, wind speed, wind direction and time of the day and year. Heat islands are prominent on calm clear winter nights, and intense in mid–winter. In the air pollution dynamics, the density of pollutants from the moment of leaving the source till they reach the
receptor is solely governed by the meteorological factors. This, known as the diffusion and transport phase, controls the pollution from industrial plants, in the selection of location, in it's design of equipment and in its day-today operation.

With this backdrop, the study envisages delineation of guidelines for evaluation and decision making related to overall regional development in industry, human settlements, agriculture, energy, water, transportation, communication and other public amenities, with appropriate environmental safeguards.

India is one of the fast developing countries where rapid industrialization and urbanization is taking place. Air pollution is one of the negative impacts on the environment. In those regions where the topographic and meteorological conditions are conducive for the accumulation and concentration of pollutants, these may adversely affect public health, material and vegetation in the area. It is therefore essential to take necessary steps to control emissions and manage air quality.

1.5 Usefulness of air quality simulation models in air quality management

Air quality is not just a function of the quality and the types of pollutants emitted into the air, but it is closely linked to the atmosphere's ability to disperse and transport these noxious substances. Dispersal in turn is related to the stability of the atmosphere.

Air quality measurements using chemical methods and instrumentation (air quality monitoring) is the direct way of managing air pollution. However it has got several limitations. These are:

a. Direct monitoring is expensive and needs lot of man power.

b. Due to limitations in the spatial and temporal coverage of air quality measurements, monitoring data normally are not sufficient as the sole basis for demonstrating the adequacy of emission limits for existing sources.

c. Also, the impacts of new sources that do not yet exist can only be determined through modelling.

Thus, models, while uniquely filling one program need, have become primarily analytical tools in most air quality assessments. Air quality measurements though can be used as complementary to dispersion models, with due regard for the strengths and weaknesses of both analysis techniques, measurements are particularly useful in assessing the accuracy of the model estimates.
However, knowledge of the role of atmospheric motions and diffusion processes, which can determine the dispersal of pollutants, may be obtained on the basis of fundamental governing equations. Thus it is imperative to establish the transport and dispersion patterns for given areas, based on the mathematical models of the local atmosphere. Air pollution simulation models are indeed capable of providing the most probable concentration of pollutants likely to occur at any given location within the areas of concern in relation to a source of known characteristics, when adequate meteorological data is available.

Air quality models are capable of predicting the temporal and spatial distribution of pollutant concentrations for a given domain of interest. The multifaceted usefulness of air pollution modelling can be stated as follows:

a. routine or continuous assessment of air quality in a region,
b. prevention of significant deterioration of air quality possibly by limiting or eliminating the sources of air pollution,
c. screening an area prior to ambient air monitoring,
d. land use planning,
e. economic planning of control strategies,
f. designing stack parameters (stack height, diameter, emission temperature, etc.) for minimum ground level concentrations,
g. assessing the severity of episodal emissions, and
h. Pollution forecast during worst meteorological conditions to prevent build-up of air pollutants.

1.6 Suitability of Models

The extent to which a specific air quality model is suitable for the evaluation of source impact depends upon: (i) the meteorological and topographic complexities of the area; (ii) the level of details and accuracy needed for the analysis; (iii) the technical competence of those undertaking such simulation modelling; (iv) the resources available; and (v) the details and accuracy of the data base, i.e., emissions inventory, meteorological data, and air quality data (EPA, 1997).

1.7 Classes of models

The air quality models can be categorized into four generic classes: (i) Gaussian, (ii)
numerical, (iii) statistical or empirical, and (iv) physical. Gaussian models are most widely used for assessing the impact of non-reactive pollutants. Numerical models may be appropriate than Gaussian models for area source urban applications that involve reactive pollutants and are often better suited for research than for operational use, on having a realistic set of equations to describe the physical phenomena, depend reasonably on a good data base to drive and to test the model, and sufficient computer capability and time and therefore are not widely applied. However, Statistical or empirical techniques are frequently employed in situations where incomplete scientific understanding of the physical and chemical processes or lack of the required data bases make the use of a Gaussian or numerical model impractical. The fourth generic type, the physical modelling involves the use of wind tunnel or other fluid modelling facilities. This class of modelling is a complex process requiring high level of technical expertise, as well as access to the necessary facilities (EPA, 1997).

The Gaussian plume models have been widely used in air pollution studies, especially for regulatory purposes. However, the straight line Gaussian plume model may not be suitable for the inhomogeneous conditions in complex terrain because the model is restricted by key assumptions: (i) spatial homogeneity, (ii) stationary conditions, and (iii) flat terrain. To overcome some of the limitations, a Gaussian puff approach has been utilized (e.g. Ludwig et al., 1977; Sheih, 1978; Zannetti, 1981, 1986).

The Gaussian puff model can accommodate meteorological and emission conditions, and can treat temporal and spatial variations in the meteorological parameters typical of complex topographic region. The model approximates continuous emission from stacks with a series of discrete ‘instantaneous’ puffs, one puff is generated at each time step, and contains all the mass emitted during that time interval. The puffs are advected according to the prevailing winds, and grow at a rate appropriate to the atmospheric stability conditions in the vicinity of the puffs. Each puff can be considered as a horizontal cloud of pollutants where the concentration of the material has a Gaussian distribution (Slade, 1968). Under steady-state conditions, the puff model reduces to Gaussian plume model.

In the second chapter, an elaborate description about the study area along with the objectives of the research work are presented. Also literature survey on the Urban Heat Island, Planetary Boundary Layer depth and their determination, spatial and temporal variations are discussed.