CHAPTER 1

INTRODUCTION

The earth's atmosphere is a relatively thin blanket of air surrounding the earth. Atmosphere is the life blanket of the earth, the essential ingredient of all living things. It shields the earth surface during the day from the direct heat and from harmful effects of solar and cosmic rays and at night it acts as a blanket preventing excessive loss of warmth to the outer space. Atmosphere comprises the air breathed by people, animals and plants. Air contains specific quantities of different gases and particulate matter. In Table 1 is given the typical gaseous constitution of the earth's lower atmosphere called homosphere which extends up to 90 km from the sea level (Strahler and Strahler, 1973).

The earth's atmosphere has evolved through ages and its present composition is the result of the processes that have been going on for very long. The unprecedented exploitation of the natural resources which has resulted from ever-increasing human population has affected the atmosphere adversely. One such effect has been the pollution of the atmosphere. Atmospheric pollution does occur naturally and due to human activity. However, the manmade or anthropogenic sources have become very important during the present century. Both solid and gaseous contaminants are being injected into the atmosphere at progressively increasing rates. The levels of concentration of these in the earth's atmosphere have become so high that ill-effects on all life forms are becoming apparent. This has resulted in a worldwide concern for the quality of the environment in general and the air in particular.

Earth's Atmosphere and Life on Earth

Life on the planet earth has been possible due to the presence of atmosphere on it. The atmosphere in the beginning was poisonous and consisted of gases like methane (CH_4), Water vapour (H_2O), nitrogen (N_2), amonia (NH_3), and hydrogen sulphide (H_2S) in order of their abundance (Emiliani, 1992). The famous Urey-Miller experiment has

Table 1

Gases of the Lower Atmosphere (Homosphere)

Name of Gas	Chemical Symbol	Per Cent by Volume
Nitrogen	N_2	78.084
Oxygen	O_2	20.946
Argon	A	00.934
Carbon dioxide	CO_2	00.033
Neon	Ne	00.00182
Helium	He	00.00053
Krypton	Kr	00.00012
Xenon	Xe	00.00009
Hydrogen	H_2	00.00005
Methane	CH_4	00.00002
Nitrous oxide	N_2O	00.00005

Data from: E. Gleuckauf, 1951, Compendium of Meteorology, Boston: American Meteorological Society (quoted by Strahler and Strahler, 1973).

amply demonstrated that amino acids, proteins and life in its basic form can be synthesised from the simplest molecules present in the initial atmosphere (quoted by Emiliani. 1992). Such incipient atmosphere was prepared for life by the interactions between the atmospheric gases and the incoming solar radiation. One important photochemical process of the early atmosphere has been 'photolysis,' which dissociates gas molecules in the presence of light (solar radiation). This resulted in the splitting of H_2O into H_2 and O. The oxygen atoms so released were used in oxidising CH_4 and formed CO_2. By this sequence of processes all CH_4 was soon turned into CO_2. Further evolution of the earth's atmosphere and that of life on earth have gone side by side, each life process leading to a corresponding change in the chemistry of the atmosphere.[1] This process has culminated in the present biosphere and atmosphere which can be considered stable for all practical purposes. This state of life and air has been present not since very long and both have been in a state of equilibrium with each other. The human beings have been the latest addition to the earth's biosphere (Sears, 1974) but by virtue of their intelligence and technological development they have been able to affect and modify the earth's atmosphere to such an extent that the equilibrium between life and air is being unduly disturbed. The use of fossil fuels by the humans has been the major culprit. Some gaseous by-products of the fuel use are injected into the atmosphere and lead to unnatural increase in their concentration. These unnatural concentrations sooner or later result in health problems in all life forms including humans. Such unnatural concentrations of gases are labeled as air pollution.

The 56,000 million Gt[2] of the earth's atmosphere is held to the earth by gravity. About 98% (by weight) of gases and particles lie within 30 km of the earth's surface, and more than half of it is in the lowest 5.5 km (Shiralkar, 1991). A large variety of complex and poorly understood chemical and physical processes occur in air among pollutants

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[1] For a detailed discussion on the origin and early evolution of life and the associated chemical processes, the reader is referred to C. Emiliani, 1992, *Planet Earth: Cosmology, Geology and the Evolution of Life and Environment*, Cambridge University Press, Part V, Chapters 19-24 (pp. 369-552).

[2] 1 Gt = one Gigatonne = a billion metric tons.

discharged, between pollutants and substances found naturally in the atmosphere, and between pollutants and incoming solar radiation. Air contains a mixture of certain gases in definite proportions. If this proportion is altered even slightly, life on earth would become impossible. Few years back air pollution was considered as a problem only the of metropolitan and industrial complexes, but now it is recognised as a regional problem having ecological implications for the entire area around the source. As the inhabited area of the world is expanding and as the deterioration of air quality spreads far and wide, the air pollution is becoming more of a global problem. Environmental scientists as well as the common people are becoming more and more aware of this problem. As a result large number of publications are coming out on the focal theme of air pollution.

Air Pollution

Pollution is a relative concept. Almost no substance exists in a pure state in nature. Only when the impurities rise above a certain equilibrium level, a substance becomes harmful and dangerous and is labeled as polluted. Environmental pollution may be defined as the unfavourable alteration of our surroundings, wholly or largely as a by-product of human action, through direct and indirect effects of changes in energy patterns, radiation level, chemical and physical constitution and abundance of organisms (Karpagam, 1990). The pollution of water and air are ones causing most concern today. Everyone immediately becomes aware of air pollution because of its effects on smell organs and on the atmospheric visibility.

Air contains specific quantities of different gases (Table 1) and particulate matter. The components of air are in a very delicate balance with each other. As long as this balance is maintained the air remains healthy. When this balance is disturbed, air becomes polluted and unhealthy for the life forms on the earth. Increased human activity has been disturbing this balance and the environmental quality of the atmosphere is being degraded. Some quantities of polluting gases and solids are already present in the air but when their concentration exceeds a threshold value they become irritant. The term air pollution is, therefore, applied when there is an excessive concentration of these gases and solids in the

atmosphere which is harmful to the humans and their environment. Air pollution is a growing menace to health throughout the world.

Dust storms, fires, volcanoes and ocean storms polluted the air with vast quantities of particles and impurities of various sorts even before the humans came on stage. There are many natural sources of air pollution (Table 2). Natural sources of air pollutants include forest fires, pollen, soil erosion, volcanic eruptions, and evaporation of volatile organic compounds from leaves. It has been found that fungi, bacteria, viruses, algae and insects pollute air by releasing certain gases. Air pollution from human activity also goes back to the day when humans invented fire. Our ancestors had it in their smoke-filled caves and later in their cities. Over 2000 years ago Seneca complained of bad air in Rome. In 1273 AD King Edward I of England passed the first known air quality laws which forbade the use of a particular type of coal. In 1300 AD King Richard III put a heavy tax on coal to discourage its use (Miller, Jr., 1982).

The problem of air pollution was first brought to a sharp focus when air pollution episodes took place in Los Angeles in 1940, Donora in 1948, and London in 1952. These episodes resulted in large number of deaths and aroused public interest and stimulated the health authorities to take steps to ensure clean air. For quite some time these happenings were considered as accidental chance events but "the emergence in recent years of global environmental issues like ozone depletion, climate change, and the loss of biodiversity, has brought the environment considerable prominence on the international political agenda" (Rajan, 1997). Importance of the global environment has been recognised by the United Nations which organised the United Nations Conference on Environment and Development (UNCED) at Rio de Janeiro in 1992. In this conference the largest gathering of world leaders put their heads together to think about environment and related issues. The 1987 report of the World Commission on Environment and Development (WCED) also recognised the importance of the global environmental issues. The 1992 edition of the *World Development Report* focused on development and environment. This

Table 2

Sources of Primary Atmospheric Pollutants

Natural Sources of Pollutants	Sources of Man-made Pollutants
Volcanic dust	Fuel combustion (CO_2, SO_2, lead)
Sea salts from breaking waves	Chemical processes
Pollens terpenes from plants	Nuclear fusion and fission
Aggravated by Man's activities:	Smelting and refining of ores
Smoke of forest and grass fires	Mining, quarrying
Blowing dust	Farming
Bacteria, viruses	

Source: Association of American Geographers, 1968, *Air Pollution*, Commission on College Geography, Resource Paper No. 2, Fig. 3, p. 9 (quoted by Strahler and Strahler, 1973).

gives credence to the idea that environment is recognised as a significant aspect of modern development process and that it is a global concern. Air pollution has been recognised as one major environmental problem which leads to "many acute and chronic health impacts: [such as] excessive urban particulate matter levels are responsible for 300,000-700,000 premature deaths annually and for half of childhood chronic coughing; 400 million-700 million people, mainly women and children in poor rural areas, [are] affected by smoky indoor air." (*World Development Report, 1992*) It has been suggested in the same report that air pollution also adversely affects productivity of the economies by "restrictions on vehicle and industrial activity during critical episodes; [and by the] effect of acid rain on forests and water bodies. The realisation that human activity is leading to global warming and climate change has created conditions for the major industrial nations of the world to sit together at Kyoto (Japan) in 1997 to chalk out strategies for the alleviation of our environment (United Nation,1997; Meyerson,1998). During the 1960s and 1970s people began to listen seriously to predictions that the human existance would be threatened unless the humans adjusted their activities to their environment so as to minimise the impact on the environment. Scientists said that the earth was becoming polluted and that the soil, minerals and fuel resources were being used faster than they were being replaced (Turk, 1985).

Air pollution is defined by the World Health Organisation (WHO) as "the presence in the air of substances put there by acts of man in concentrations sufficient to interfere with the comfort, safety, or health of man or with full use or enjoyment of his property." The presence of contaminants in the atmosphere is considered to be in sufficient quantities and duration to cause them to be injurious to human health, animal and plant life and reduce welfare in general.

More than hundred air pollutants have been identified. The important ones are carbon dioxide (CO_2), carbon monoxide (CO), sulfur dioxide (SO_2), sulfur trioxide (SO_3), hydrogen sulfide (H_2S), organic sulfide, fluorine compounds, oxides of nitrogen (NO_x) and ammonia, aldehydes, beryllium, carcinogenic agents (e.g. radioactive substances),

hydrocarbons, photochemical oxidants like ozone (O_3), peroxyacylnitrates (PAN) and various aldehydes and particulate matter. In the present study only suspended particulate matter (SPM), sulfur dioxide (SO_2), and oxides of nitrogen (NO_x) are dealt with because the data on these have been regularly recorded and published by the Central Pollution Control Board of India for a relatively large number of stations throughout the country.

Health effects of air pollution are easily observed under conditions of high pollutant concentration. It was in the tragedy of Donora, Pennsylvania, in October 1948 that the attention was first drawn to the fact that air pollution can kill. This tragedy was caused mainly by the high concentration of particulates and SO_2 among other air pollutants. Donora is an industrial town and is located in a deep valley on the Monongahela river. During the incident sulfur dioxide and its oxidation products accumulated in the valley causing respiratory problems to 6000 persons of which 1500 became seriously ill and 14 died.

Excessive concentrations of air pollutants can develop on any geographical scale, thus creating a local , regional or even a global problem. A number of local air pollution events have been devastating. One of these occurred between the 4th and 10th December 1952 in London, England. A high-pressure atmospheric cell began to centre on the city, shrouding it in several layers of noxious clouds. The unburnt remains of coal and residue gases from factories floated into the air. Weak winds could not carry these pollutants away. Smoke and moisture accumulated in the lower layers of the atmosphere. Visibility was only a few metres. The humidity was 100 per cent and the air completely calm. On the 9th December the high-pressure air cell finally began to move as a cold front passed over the area. Four thousand Londoners died during this episode.

In July of 1976 a stable air mass developed over Milan, Italy. A chemical plant at nearby Seveso released toxic tetrachlorodibenzo-p-dioxin into the atmosphere. The pollutant remained in the air for about three weeks, forcing the evacuation of 700 people (Miller, 1985).

On a number of occasions excessive pollution concentrations have covered nearly half of the area of the United States. One such phenomenon known as Episode 104 occurred near the southern tip of Lake Michigan between August 22 and September 1, 1969. An inversion of temperature was reported near the earth surface. Temperature increased rather than decreasing with height up to 400 metres of elevation. The cooler, pollutant-laden air was held near the ground by the warm air above it. Absence of winds during this time resulted in no upward or horizontal movement of the pollutants. The high-pressure cell that caused Episode 104 began to spread rapidly from the source area at the southern tip of Lake Michigan. The level of sulfur dioxide was trebled in just one day. All cities of the region experienced problems of air pollution. The sky finally became clear by September 1, and the pollutants moved out over the Atlantic Ocean.

Many other episodes also occurred in different parts of the world. All these episodes are of great concern because they provide significant evidence by which we can evaluate the effects of air pollution on health.

Anthropogenic Air Pollution Sources

Anthropogenic sources of air pollution which have become very significant during the present century add tremendous amount of pollutants to the air. These pollutants are added to the atmosphere as gases or particulates. In Table 3 are given estimates of the global particulate production from natural and man-made sources (after Bach, 1976 (quoted by Lockwood, 1979)). It is seen that although natural particle production is very large, yet the human contribution is also not insignificant by any means. In Table 4 are given the estimated global emissions of various gases along with those from the United States and the tropical areas from man-made and natural sources (after Bach, 1976(quoted by Lockwood, 1979)). These data reiterate the significance of anthropogenic pollution sources. The man-made pollution sources may be classified into four broad categories:

1. Industrial Processes: In recent years many types of industries have sprung up. These are, for example, chemical industries, metallurgical industries, oil refineries, fertiliser factories etc. All these have contributed to air pollution significantly.

Table 3

Estimates of Global Particle Production from Natural and Man-made Sources (10^6 tons/year)

Source	After Peterson and Junge (1971)		After Hidy and Brock (1971)	After SMIC Report 1971 (particle size <20 μm)
	All sizes	< 5 μm		
		Man-made		
Direct Particle Production				
Transportation	2.2	1.8		
Stationary fuel sources	43.4	9.6		
Industrial processes	56.4	12.4		
Solid waste disposal	2.4	0.4		
Miscellaneous	28.8	5.4		
Subtotal	133.2	29.6	36.8-110	10-90
Particles formed from gases				
Converted sulphates	220	200	109.5	130-200
Converted nitrates	40	35	23	30-35
Converted hydrocarbons	15	15	27	15-90
Subtotal	275	250	159.5	175-325
Total	408	280	269	185-415
		Natural		
Direct Particle Production				
Sea salt	1000	500	1095	300
Wind blown dust	500	250	7-365	100-500
Volcanic emissions		25	4	25-150
Meteoric debris	10	0	0.02-0.2	
Forest fires	35	5	146	3-150
Subtotal	1545	780	1610	428-1100
Particles formed from gases				
Converted sulphates	420	335	36.8-365	130-200
Converted nitrates	75	60	600-620	140-700
Converted nitrates	75	75	182-1095	75-200
Subtotal	570	470	2080	345-1100
Total	2115	1250	3690	773-2200
Grand Total	**2523**	**1530**	**3959**	**958-2615**

Source: W. Bach, 1976 (quoted by Lockwood, 1979).

2. Combustion: Industrial and domestic combustion of coal, oil, and other fuels is a prominent source of smoke, dust and SO_2.
3. Motor Vehicles: Motor vehicles constitute one of the principal sources of air pollution. Automobiles used in developed countries are more technologically advanced and are mostly equipped with pollution control devices. Air crafts and other forms of transport contribute to air pollution by emitting hydrocarbons, SO_2, NO_x, CO, CO_2, and SPM (Ali, 1979).
4. Miscellaneous: Agricultural activities, crop spraying, pest control, burning of refuse, nuclear energy programmes, building activities like road and building construction also contribute to air pollution mostly in the form of SPM.

Geographically, the sources of air pollution are of three types: point sources, line sources, and regional sources. A point source of air pollution is a single point origin of emission into the atmosphere. Pollution may occur as a steady emission over an extended period as from a factory chimney or as a single sudden emission in a short period of time such as a nuclear or chemical explosion. The distribution of the pollutant will depend on wind speed and direction at the time of emission and immediately after it. If the air is calm the pollutant will be concentrated in a small area whereas wind movement will distribute it over a large area extending in an elongated manner downwind from the point source. The continuous point sources of emission are the most familiar, most conspicuous, and most studied.

Line sources of air pollution are less common than the point sources. A line source might be a heavily traveled highway, or it could be a line of chemical or heavy industrial plants. Dispersal of the pollutants along a highway can become a major problem if the wind flows parallel to the highway. In this situation pollutants may be concentrated at a place downwind along the road.

Regional sources cover a two-dimensional area of the earth surface of varying size. Atmospheric pollution may be limited to a few square kilometers over an industrial area,

or it may cover a very large area several hundred or thousands or more square kilometers. Regional sources are made up of many point and line sources that combine to pollute a large area. These sources may emit all types of atmospheric pollutants. The development of regional pollution depends on stable air conditions that prevent the vertical dispersal of pollutants and topography and horizontal atmospheric pressure distribution which prevents and controls horizontal dispersal of the pollutants.

Air Pollutants

There have been identified several hundreds of air pollutants. Some important air pollutants are discussed briefly in the following paragraphs.

Carbon Oxides

Mainly two oxides of carbon (CO and CO_2) are present in the atmosphere. Their concentration in the earth's atmosphere has been increasing ever since the industrial revolution. Carbon monoxide (CO) is a colourless and odourless poisonous gas and is produced by incomplete combustion. In addition to the natural sources such as animal respiration, fermentation processes and slow oxidation of carbonaceous material, the human activities inject large quantities of CO and CO_2 into the atmosphere (Table 4). Earth scientists are debating over the possible effects of rising concentration of CO in the atmosphere. It is generally accepted that from about 290 ppm (0.029 %) at the turn of the century, the level of CO_2 in the atmosphere has risen to 330 ppm (0.033 %) in the last quarter of the present century (Strahler and Strahler, 1973). It is further projected that the level of the atmospheric CO_2 might reach 380 ppm (0.038 %) by the year 2000 AD (Keller, 1985).

The major anthropogenic sources of carbon dioxide (CO_2) are combustion of fossil fuels for power, heat, and transportation. The chemical nature of these emissions depends on the conditions of combustion and on the chemical composition of the fossil fuels, specially their impurities. The combustion of a ton of standard quality coal produces

Table 4

Global, Tropical and United States Emission Estimates

Constituents	Total emission estimates (10^6 tons per year)				
	U.S. 1972	Tropical Agricultural Burning	Global Man-made	Global Natural	Global Total
CO	97	290	190-640	68-5000	258-5640
CO_2		7222	11793-16329	127005-907180	138798-923509
HC	25	72	80-90	90-435	170-525
CH_4			14-210	330-2086	344-2296
SO_2	30		62-133	40	62-173
H_2S			3	100	103
NO				390	390
NO_2			48	453-696	453-744
NO_x	22	7	45	453	498
NH_3			4	1052-5352	1052-5356
N_2O				144-589	144-589
Particulates	18	62	185-415	773-3690	958-4105

Source: W. Bach, 1976 (quoted by Lockwood, 1979).

about 3.7 tons of carbon dioxide (Horne, 1978). It is estimated that roughly half of CO_2 injected nto the atmosphere is washed down by rain or used by vegetation but 40 to 50 % of the CO_2 produced has remained in the atmosphere leading to progressive build up of CO_2 concentration. Carbon dioxide is an absorber and emitter of short wave and long wave radiation and its presence in large proportions leads to increased absorption of both the incoming solar (short wave) radiation and the outgoing terrestrial (long wave) radiation. Carbon dioxide has been recognised as one of the four greenhouse gases (GHGs), others being methane (CH_4), chlorofluorocarbons (CFCs), and nitrous oxide (N_2O) (Parikh and Gokarn, 1993). For obvious reasons CO_2 has received the maximum attention from the environmental activists and scientists alike. Greater concentration of CO_2 changes the energy balance so as to raise the temperature of the atmosphere. This is the so-called 'greenhouse effect.'

Carbon monoxide (CO), on the other hand, is a toxic gas which combines very strongly with hemoglobin (Hb) as shown below:-

$$Hb \cdot H_2O + CO \Rightarrow Hb \cdot CO + H_2O$$

This interferes with the essential oxygen-bearing function of the respiratory pigments and reduces the oxygen-carrying capacity of blood (Figure 1)[3]. This, in turn, impairs judgement, aggravates heart and respiratory diseases, and leads to headaches, fatigue and even death. An exposure to 1500 ppm of CO for an hour can endanger a man's life. Acute CO poisoning claims more than 1000 lives each year in the United States. The average amount of CO in the troposphere is estimated to be about 530,000,000 tons. The average residence time of CO in the earth's atmosphere is only between 0.1 and 0.3 years (McConnell et al., 1971; Weinstock, 1972).

Hydrocarbons

These are organic compounds containing carbon and hydrogen. Included in this category are methane (CH_4), butane (C_4H_{10}), and benzene (C_6H_6). The main

[3] The maps and diagrams referred to in this thesis are included as a separate section at the end of the text.

anthropogenic sources of hydrocarbons are incomplete fossil fuel combustion in automobiles and furnaces, evaporation of industrial solvents, oil spills, tobacco smoke, forest fires and plant decay. Chlorinated hydrocarbons affect fat tissue and liver (Figure 1). Other hydrocarbons injure the respiratory organs, some cause cancer, irritate eyes, and take part in the formation of photochemical smog.

Photochemical Oxidants

Photochemical oxidants are produced in the atmosphere by the action of sunlight on hydrocarbons and nitrogen oxides. Thus, they are considered as secondary pollutants. They aggravate respiratory and heart ailments, irritate eyes, throat and respiratory tract (Figures 1 and 2), cause injury to leaves and inhibit plant growth. They also decrease atmospheric visibility and deteriorate rubber, textiles, and plants.

Inorganic Compounds

Under this category are included asbestos, hydrogen fluoride (HF), hydrogen sulfide (H_2S), ammonia (NH_3), sulfuric acid (H_2SO_4) and nitric acid (HNO_3) released from various sources. Hydrogen fluoride comes from petroleum refining, glass etching, aluminum and fertiliser industries; hydrogen sulfide is released from chemical industry and petroleum refining; ammonia is released from chemical and fertiliser industry; sulfuric acid is produced in the atmosphere by the reaction of sulfur trioxide and water vapour and also comes from chemical industry; and nitric acid is released by chemical industry and is also a secondary pollutant produced by the reactions of nitrogen dioxide and water vapour in the atmosphere.

Health effects of inorganic compounds include skin burns, irritation in the mucous membranes, irritation in the eyes and throat, irritation in the upper respiratory passages, and increase in mortality. They also cause bronchitis and heart, liver, lung and kidney damage (Figure 1). They also form particulates in the atmosphere which corrode metals and rock monuments and are toxic at high concentrations.

Organic Compounds

These are carbon-containing compounds which are released in the atmosphere as pesticides, herbicides. alcohols. acids and other chemicals. These are related with the modern agricultural processes. forestry and pest control. They enter the food chain in agro-forestry produce and travel up the food chain becoming more and more concentrated at higher levels. They are harmful to some fish. shellfish. predatory birds and mammals and concentrate in human fats and may cause birth and genetic defects and cancer.

Radioactive Substances

Radioactive substances are released into the atmosphere by natural as well as human sources. Natural sources include radioactive rocks. soils and cosmic rays. Anthropogenic sources are uranium mining, nuclear processes. power generation, nuclear weapons testing and coal burning. Health effects of the radioactive substances include genetic defects, cancer, injuries to leaves and reduction in plant growth.

Sulfur Oxides

Included in this category are sulfur dioxide (SO_2) and sulfur trioxide (SO_3). Sulfur is an essential component of organisms and therefore when different kinds of organic fuels are burnt a mixture of oxides mainly SO_2 and SO_3 are produced (Turk. 1985). Atmospheric sulfur exists in the form of several gaseous compounds as well as in a variety of chemical species in condensed phase of aerosols and cloud droplets. Its sources are natural as well as anthropogenic (Table 3 and 4). The H_2S injected into the atmosphere is rapidly oxidised to SO_2 and H_2SO_4 by a number of reactions (Singh, 1989).

Sulfur dioxide is released into the atmosphere largely by the industrial combustion of coal and oil. power plants. smelting of sulfur-containing ores and volcanic eruptions. It aggravates respiratory diseases. impairs breathing, irritates eyes and respiratory tract. damages plants and reduces growth. When mixed with water it causes acid rain and corrodes metals. deteriorates building stone. paper, nylon and leather.

Oxides of Nitrogen

This category includes nitrous oxide (N_2O), nitric oxide (NO) and nitrogen dioxide (NO_2). Nitrogen is found in living tissue and therefore is present in all fossil fuels. This nitrogen together with small amount of atmospheric nitrogen oxidises to form nitrogen oxide (NO) and nitrogen dioxide (NO_2). These two together are referred to as NO_x (Singh, 1987).

Oxides of nitrogen are released into the atmosphere by the combustion of fuel in motor vehicles, industrial activities and by lightening. It aggravates respiratory disease, increases susceptibility to chronic respiratory infections, can cause acute bronchitis, and heart, lung, liver and kidney damage. It also reduces the ability of lungs of clearing themselves of particulates. It also causes acid rain and fades paints and dyes and forms photochemical smog.

Particulates

Suspended particulate matter (SPM) comprises very fine solid and liquid matter suspended in air. These particulates include carbon, metallic dust, tars, resins, aerosols, solid oxides, nitrates and sulfates, carbon particles, heavy dust etc. (Swarup et al., 1992).

Particulate material are released into the air from a great variety of sources (Table 3). They include forest fires, wind erosion, volcanic eruptions, and photochemical and chemical reactions in the atmosphere among the natural sources, and coal burning, farming, mining, construction, road building, dust stirred up by automobile movement, auto exhaust, and fuel burning in industrial and power plants among anthropogenic sources.

Particulates can cause cancer, aggravate respiratory and heart diseases and are toxic at high concentrations. They cause cough, irritate throat and lead to chest discomfort. They interfere with photosynthesis and reduce atmospheric visibility. They

also deteriorate plant and building surfaces by settling on them. Particulate matter may affect weather and climate by affecting local and global heat budget.

Statement of the Problem

Air pollution has definitely become a necessary and rather unavoidable by-product of the modern, mostly industry-based, way of living. India, which has mostly been an agricultural country, is fast becoming more and more industrialised. Agriculture also is becoming more mechanised and 'modern.' Urbanisation in India is progressing at a fast rate and along with it there is being experienced an automobile revolution. Number of motor vehicles both in urban and rural areas is increasing at an alarming rate. All these operations pollute air. Large quantities of polluting gases and particulate matter are injected by these processes into the atmosphere. The health-related and other manifestations of air pollution are becoming apparent and call for research into the cause and effect of these and the remedial measures that could be taken.

Indian cities as well as the countryside are experiencing progressively greater and greater onslaught of modern living and technological advancement. Air pollution is becoming a great problem to be reckoned with. Most of the sources of pollution - automobiles, factories, power plants, construction activity etc. - are greatly concentrated in the urban areas. As a result the cities are becoming relatively much more polluted than the countryside. It has been due to this that the Central Pollution Control Board of India has been established for the purpose of monitoring of pollution in urban and industrial locations spread all over the country. Each state has a State Pollution Control Board which works under the direction and supervision of the Central Pollution Control Board. A network of ambient air quality recording stations has been created in important urban and industrial areas. These recording stations have been operational for various lengths of time. Levels of concentration of SO_2, NO_x, and SPM as micrograms per cubic metre ($\mu g/m^3$) are measured at regular intervals of time and average monthly values are published by the state and central Pollution Control Boards. Such data for some Indian cities selected on the basis of regularity and completeness of data for the period between

1988 and 1994 have been used in the present dissertation for the purpose of a countrywide spatial and temporal analysis.

Hypotheses

The problem of air pollution is closely associated with anthropogenic activity like industries, power generation, fuel (fossil and other) utilisation, construction, road building, urbanisation and modern way of living (Meyerson,1998; De Sa,1998). The Indian urban areas are getting affected by air pollution to a considerable extent. Even in the absence of heavy industrial activity, the transport vehicles and domestic fuel combustion have contributed significantly to air pollution. It has been postulated that increase in industrial, construction, and transport activities has a direct effect on the level of air pollution. The level of air pollution is also related to the pattern of domestic fuel combustion, the traditional methods being more polluting than modern, technologically more advanced, methods. In view of these considerations the following hypotheses are postulated:

1. The overall pollution levels have been increasing over the years;
2. Pollution is much more in the industrial towns than in the non-industrial towns;
3. The SPM concentrations are more than those of SO_2 and NO_x concentrations; and
4. Of SO_2 and NO_x concentrations in the industrial towns, the concentration of NO_x is more.

These hypotheses will be tested for 72 ambient air quality recording stations located in 28 industrial and non-industrial Indian cities. An attempt will be made to visualise both the spatial and temporal trends in air quality measures in these select Indian cities