Environmental Science

Ramesha Chandrappa
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Sustainable Air Pollution Management

Theory and Practice

Springer

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This book is dedicated to family and colleagues

Preface

As per World Health Organization, air pollution is now the major killer. But the message has not still gone into the minds of decision makers across the globe. Since the movement of pollutants does not respect political boundaries, they kill innocents across the borders. What is more painful is changing climate is posing challenge to predict the movement of pollutants. Decisions taken based on modeling studies and legislations are not delivering desired output. There is always gap between theory and practice. This book is written after reading more than 300 literature and more than 30 years of combined experience of authors to reduce the gap.

Intended Audience

The intended audience include students of both graduation and undergraduation who take over the challenge of cleaning the mess left by their previous generation and curbing emission from own generation. Apart from students, this book is written to guide policy makers and regulators who are changing the dimension of the world.

Goals and Motivation

The text is written to provide clear and concise understanding of challenges posed by air pollution and the solutions. Many works have been done in the field of air pollution by eminent scientist and technocrats. But the authors had unique experience working in a country which is witnessing rapid economic growth and associated impacts on environment. This book also discusses practical difficulties and practices.

Unique Features

Unique features of this book include deep discussion of many pollutants which are not monitored across the globe. The photographs of many air pollution source which contribute air pollutants have been included so that the people of next generation would get a chance to know the current situation the mankind has undergone.

About the Book

The past work of first author has been used as reference book in many universities due to uniqueness and simplicity. The experience is very helpful in bringing out this book so that students and practitioners can benefit from our exposure. Many new ideas have been discussed in this book which is not discussed elsewhere so that researchers and students can carry research on those topics.

Course Suggestion

This book can be used for both undergraduate and postgraduate students. References have been listed at the end of each chapter so that reader can refer original article if required.

Acknowledgment

We would like to thank our families, colleagues, and reviewers for making this project come to fruition.

We would have not achieved the goals set by us without the support of our professional contacts who have helped us in great extent. We are extremely thankful to Ms. Vijayalakshmi; Dr. Ammar, Tutor, Anatomy Section; Dr. Varsha Mokashi, Professor and Head of Department, Anatomy Department, Vydehi Institute of Medical Science for taking picture of lungs; and Dr. Dayanada S. Bilige, Professor, Pathology Department, Bangalore Medical College. We are thankful to Girish Bellur, Transoft International, who helped in obtaining permission to reproduce some of the outputs of the models.

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Chapter 1
Major Issues of Air Pollution

Abstract Environmental issues change from place to place and time to time. The issues include local as well as global issues. The understanding of issues is necessary to find solution. Air pollution issues have changed over a period of time. Issues like atmospheric brown cloud, climate change, hazardous air pollutants, black/muddy snow which are hardly discussed few decades back have now gaining importance. This chapter elaborates major issues due to air pollution.

'Pollution' is originated from Latin word '*Pollutus*' which means '*foul or unclear*'. Air pollution can be defined as 'Atmospheric condition in which substances is present at concentrations higher than their normal ambient levels to produce significant effects on humans, animals, vegetation or materials' (Seinfeld 1986).

Air composition

The air we breathe is most important natural resource which allows us to survive. The composition of air around us keeps changing continuously due to both natural as well as man made emissions into the atmosphere. Earth's atmosphere is a layer of gases retained by the gravity. On an average, as shown in Fig. 1.1 dry air consists of 78.09 % of nitrogen, 20.95 % of oxygen, 0.93 % of argon and 0.039 % of carbon dioxide by volume. Minor constituents such as methane (CH_4), Ozone (O_3), Sulphur Dioxide (SO_2), Nitrogen Dioxide (NO_2), Nitrous Oxide (N_2O), Carbon Monoxide (CO), Ammonia (NH_3) etc. are also present having very low mixing ratios. These constituents do vary place to place due to change in atmospheric conditions. The air constituents over the sea will not be same as at the shore; sea shore air may not have same concentrations of the constituents as desert air. Sea shore air will be dominated by water vapour where as desert air will have more suspended dust. Similarly, the thick Amazon forest will have more water vapour and volatile organic compounds whereas he air above solid waste dumping site is likely to have more methane and ammonia.

Low concentration of air pollutants does not mean that it can be neglected. Considering example of lead which is present in the atmosphere in traces, the total quantity in 1983 and in the mid-1990s, were estimated to be about 330,000 tonnes (Nriagu and Pacyna 1988) and 120,000 tonnes (Pacyna and Pacyna 2001), As per the study by Richardson et al. (2001), the whole emissions from natural sources were around 220,000–4,900,000 tonnes/year.

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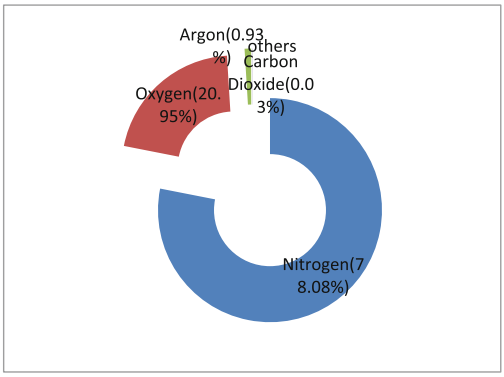

Neon	Ne	18.2 ppm
Helium	He	5.2 ppm
Methane	CH_4	2.0 ppm
Krypton	Kr	1.1 ppm
Sulfur dioxide	SO_2	1.0 ppm
Hydrogen	H_2	0.5 ppm
Nitrous Oxide	N_2O	0.5 ppm
Xenon	Xe	0.09 ppm
Ozone	O_3	0.07 ppm
Nitrogen dioxide	NO_2	0.02 ppm
Iodine	I_2	0.01 ppm
Ammonia	NH_3	traces
Carbon monoxide	CO	traces
Lead	Pb	traces
Mercury	Hg	traces
Persistent organic pollutants	POPs	traces

Fig. 1.1 Constuents of air

Atmosphere and its layers

When the solar system condensed out of "primordial solar nebula" which is nothing but interstellar cloud of gas and dust, the situation was not as complex as today and air pollution was not an issue. The early atmosphere of this planet was believed to be blend of carbon dioxide, nitrogen, water vapour and hydrogen. The early atmosphere of this planet was slightly reducing chemical mixture as compared to present atmosphere which is strongly oxidizing. With lapse of time, distinct layers of the atmosphere were formed with distinct characteristics. These are described below.

Troposphere: It is the lower most layer of atmosphere extending from the earth's surface to 10–15 km altitude depending on time and latitude (Fig. 1.2). This layer is characterised by declining temperature with height and rapid vertical mixing. Temperature at the ground is about 20 °C and it decreases gradually till the tropopause is reached. The tropopause is the boundary having constant temperature which separates the troposphere and stratosphere.

The decrease of atmospheric temperature (T) with height (z) is called as lapse rate (α) which is expressed as follows

$$\alpha = -\frac{dT}{dz}$$

The change in temperature of a mass of air as it moves upwards is called as adiabatic lapse rate. The dry adiabatic lapse rate (DALR) and the moist adiabatic lapse rate (MALR) are 9.8 and 4.9 °C/km respectively. Actual change of temperature with altitude for the stationary atmosphere or temperature gradient is known as Environmental Lapse Rate (ELR). Generally, decrease of 6.49 °C/km is considered as Environmental lapse rate. In the troposphere, atmospheric pressure also

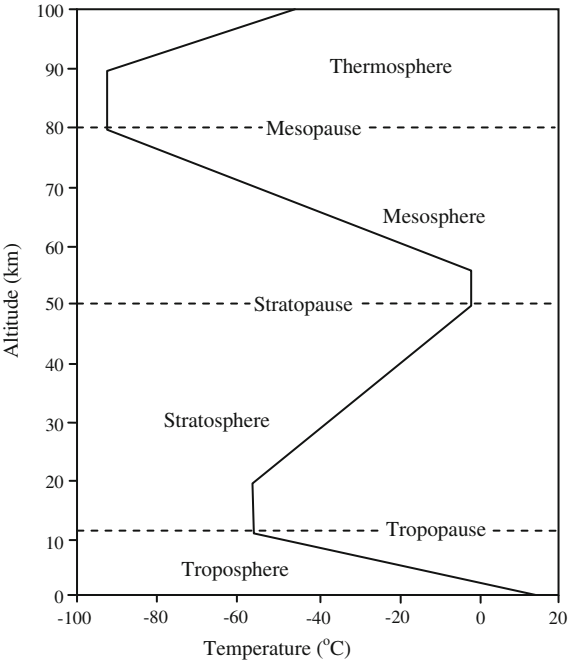

Fig. 1.2 Temperature profile with changing altitude across different layers of the atmosphere

decreases rapidly with the altitude. One can understand that climbing to an altitude of 5.5 km, would put you above 50 % of the atmosphere's molecules where atmospheric pressure is 500 mb only. Actually, the heating of the surface creates warm air at surface. The warm air rises, but air expands as it rises and cools as it expands (Adiabatic cooling). Typically, the troposphere is characterized by warm air at surface and cooler air above. If the cooler air exists at surface and the warmer air above, this is called as Buoyancy. If a rising air parcel becomes saturated condensation occurs. The condensation warms the air parcel due to the release of latent heat. So, a rising parcel cools less if it is saturated

The atmosphere near earth's surface is divided into different layers based on wind behaviour:

The laminar sublayer also called the viscous sublayer, is the region in which the flow is laminar. With respect atmosphere it is usually less a centimetre.
The surface layer extends from ≤30–50 m. The heat and vertical turbulent fluxes in this layer are constant.
The Ekman layer is the layer in a fluid where force balance between pressure gradient force, turbulent drag and coriolis force are balanced. It was named after scientist Vagn Walfrid Ekman who explained the phenomena for the first time. Ekman layer extends to height of 300–500 m. In this layer wind direction is affected by earth's rotation. Wind speed his layer generally increases with height.
Free atmosphere is the layer above Ekman layer in which the effect of the surface friction on the air motion is negligible.

Stratosphere: It is positioned just above the troposphere extending from 11–50 km. In the stratosphere, temperature increases with altitude, from −60 °C at base to 0 °C at the top of the stratosphere. The increase in temperature is basically due to the absorption of solar energy by the ozone layer. Ozone (O_3) is effective absorbing species for solar UV radiation (200–310 nm with a maximal absorption at about 250 nm) in the stratosphere. Generally, UV-C (280–100 nm) which is highly harmful is entirely screened out by dioxygen (<200 nm) and ozone (>about 200 nm) before 35 km height. UV-B (315–280 nm) radiation is mostly screened by ozone layer. UV-A (400–315 nm) reaches earth surface having small damage e.g. premature ageing of skin etc.

Mesosphere: Just above the stratosphere, the mesosphere exists extending from 50–80 km altitude, The space shuttles orbit in this layer of the atmosphere. Due to decrease in solar heating, temperature decreases with altitude in the mesosphere, 0 °C at base, −95 °C at the top of the mesosphere. The top of the mesosphere is the coldest region of atmosphere. Polar mesospheric clouds of water ice are seen in this layer which are known as Noctilucent clouds. These are highest clouds in earth atmosphere and are seen mostly during summer months between 50 and 70 degree N and S. The D layer of ionosphere also exists in mesosphere which is seen during the day time. Meteors burn up in the mesosphere while entering the earth atmosphere.

Thermosphere: Thermosphere is the last layer of the atmosphere which exists at 80 km and above up to exosphere. In the thermosphere, the temperature increases with altitude as atoms of this layer are accelerated by solar radiation. Temperature at the base of the thermosphere is −95 °C but it is 100 °C at 120 km and 1500 °C at upper part. Though the temperature of this layer is very high but the heat content negligible. Auroras exist in thermosphere. The **Auroras are seen due** to the effect of energetic particles (electrons and photons) coming in the solar wind. Charged particle entering the atmosphere ionize atmospheric constituents. The **aurora** can be seen best in the dark sky or 'magnetic midnight' time. In northern latitudes, the effect is known as the **Aurora** borealis (or the northern lights), named after the Roman goddess of dawn, **Aurora**, and the Greek name for the north wind, Boreas, by Galileo in 1619. International Space Station orbits in upper part of thermosphere (320–380 km). In the thermosphere, ionization occurs due to UV rays. E and F regions of ionosphere exist in this layer. At the Exosphere (beginning 500–1000 km), the atmosphere turns into space.

Ionosphere: In fact, the Ionosphere extends from 50–1000 km covering partly mesosphere and thermosphere. It has diurnal and seasonal variation as the ionization depends upon Sun and its activity. As mentioned earlier, the D region of the ionosphere exists in the mesosphere while E and F regions of the ionosphere exist in the thermosphere. Ionosphere is a shell of electrons and electrically charged atoms and molecules. E and F regions are present at nights. D region is formed during day time when the E and F regions become much stronger. Often during the day, the F region is further differentiated into F1 and F2 regions. In the D region, UV rays ionize NO and X-rays ionize O_2 and N_2. In the E region, X-rays and far

UV ionize O_2^-. E region can reflect radio waves lower than 10 MHz. Extreme UV rays ionize O_2 in the F- region during nights. F layer is responsible for short wave (HF) radio communication for long distances.

History of air pollution

Ever since the discovery of fire, air pollution has been a problem. "heavy air of Rome" in 61 A.D., has been recorded by Roman philosopher Seneca. In 1273, King Edward I prohibited burning of coal in London (William and Lou 2003). By the 1280s, people were using coal as fuel in processes like limekilns and metalworking leading to air pollution which had black smoke as well as oxides of sulphur. Late 18th and early 19th centuries saw dramatic changes in manufacturing, agriculture, mining, production as well as transportation. Invention of electric power in the nineteenth century resulted in coal fired electric generation in 1880s. Very famous example of air pollution is the smog formation around Los Angeles during the 1940s which led to the passing of first state environmental legislation in USA. In 1955, the Air Pollution Control Act was enacted in USA which was the first federal environmental legislation in the country. Later on in 1960s, oil overtook coal as the source of primary energy. Extensive use of oil led to the emissions wherever vehicles moved.

With the industrial revolution in the post eighteenth century economy changed to machine-based manufacturing in many of the present developed countries. Mechanization of the textile industries and iron-making techniques increased demand for fuel and their by air pollution in those areas of such activities. The developments in 19th century led to second industrial revolution.

The construction activity also saw shift in construction material as well as technology. The invention of cement replaced mud walls (Fig. 1.3) and increase in cement demand lead to emissions from this sector.

Fig. 1.3 Remnants of historic building with mud masonry in an Asian City

Fig. 1.4 Traffic from a developing Asian country

As the European and American markets were saturated, Asian markets opened up for vehicles which are currently unbalanced where in poor people ride on bus top or trucks while rich people ride in individual cars (Fig. 1.4). While the economic crisis in Greece resulted in reduction of air pollution (Vrekoussis et al. 2013) China witnessed dramatic air quality detonation last decade. Analysis of data from monitoring network created by WHO and UNEP in 50 cities in 35 developed as well as developing countries shows that over the past 15–20 year indicate that the lessons of earlier experiences in the now developed countries have yet to be learned. Air pollution in 20 of the 24 megacities shows that ambient air pollution at levels where serious health effects (David et al. 1996). The rise of population in the developing countries in future with a lack for air pollution control will worsen in many more cities.

In the beginning of 1970s when the rapid growth in Europe lead to environmental pollution and air pollution of London which resulted in death of more than 5000 people was fresh in memory the United National Conference of the Human environment in Stockholm in 1972 lead to foundation of international cooperation in this regard. This is followed by series of development that aimed to bring down air pollution. Convention on Long-range Transboundary Air Pollution in 1979 was signed UNECE countries. Governments of UNECE member states signed the convention on Long-range Transboundary Air Pollution on 13 November 1979. The 1985 lphur Protocol or 30 % protocol aimed to bring down 30 % SO_2 at national level by countries of UNECE region.

All business decisions affect the air and atmosphere. Hence, like water which is purified, packaged and priced, soon pure air will also be priced. There are oxygen bars opened up in many parts of the world to supply oxygen to customers. However, inspite of urgent need of stringent air pollution policies and regulations in several parts of the world, air pollution control is still not a political priority as compared to the business and economy in many parts of the world. As a result the pollution is continued in one form of other, many forms are not even monitored and controlled. Over the years only few conventional air pollutants such SO_2, NO_2,

particulate matter, O_3 etc. are monitored by the researchers and the pollution control authorities. Pollutants such as Persistent Organic Pollutants (POPs) were neglected in the past but have been considered recently for continuous monitoring due to their severe health effects. Both organic as well as inorganic air pollutants cause deadly deceases and hence, their monitoring is very important for humans and environment.

While many developing countries took the matter seriously others were only keen to satisfy international community. Even though environmental legislations were enacted all over the world, the capacity of enforcing agencies was limited mainly due to insufficient knowledge and research capacity with enforcing agency. Many organisations had very few staff to start with limited budget to monitor and travel. The absence of expertise had either lead to improper monitoring by selecting improper sampling site/methodology and poor analysis. Many organisations till date are dogged with insufficient manpower to the extent of one to ten technical/scientific staff for a million of citizens.

What makes air pollution most challenging compared to other pollution is its complexity. As mentioned above, unlike water which can be contained in a container for easy study it is difficult to simulate the atmospheric setup in a laboratory. Further, aerodynamics at earth's surface cannot be easily explained by mathematics as it occurs in nature. A variety of factors like radiation, friction, flow pattern, chemical reaction, influence by biological setup, changing climate, changing weather, changing living style, new inventions, social changes, law of the land, attitude of the people, physiology of people, economic changes of the region together is responsible for the scenario at a given time at a given reason.

Due to complexity of problem, air pollution has not been thoroughly understood by many developing countries and is not a priority. Issues like the poor governance, low research capability, illiteracy, corruption, national/international conflicts and political instability has often cause of low attention to air pollution in spite that millions die due to air pollution all over the world. In spite of magnitude of the problem, the loss of life and wealth due to air pollution is invisible to many government servants. This could be attributed to low emotional intelligence of people responsible to serve the people who act as trustees of the country to protect interest of people and property of the country. Illiteracy among the citizens was also cause for not complaining about the pollution. The use of staff for other duties like election/census/sports has also one of the many reason for poor implementation of environmental laws. Many of the enforcing agency are worried about financial expenditure rather pollution control as misappropriation of financial resource could end up officer responsible for appreciation in jail. On the other hand, the unaccounted pollution is not at all fault as serious as financial misappropriation. The environmental laws can also be misused to raise funds or cause inconvenience to rivals by people in power.

As shown in Fig. 1.5, issues, causes, influencing factors and impacts of air pollution can be attributed to many aspects which are not quantifiable. The corruption among governance, low ethics among industries, non availability of technology, incapability to adopt new technology and low research capability plague