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Ozone Hole
Past, Present, Future

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Dedicated to

Neelofer didi, Sofia aapa, Rubi behn
and the memory of Haidar bhai, daddy,
and ammi

—SAA

Neelu auntie, Sofi auntie, Rubi auntie
and the memory of Haider uncle, daadaji,
and daadi

—TA

Foreword

The ozone hole first emerged as a major global concern during the 1970s and threatened to cause irreparable damage to the earth and its inhabitants. For several years, the ozone hole was considered to be a figment of a few alarmists' imagination, but with increasing scientific evidence, urgent efforts had to be made to contain this. The Montreal Protocol, an international treaty designed to protect the ozone layer, entered into force in 1989 and has since undergone eight revisions. The rate of depletion of ozone in the stratosphere over the Antarctic—i.e. the ozone hole formation—thus began to be contained.

In the meantime, another two other serious global environmental concerns arose—that of global warming and ocean acidification. These concerns, and the apparent success in containing the ozone hole that was forming over the Antarctic in the spring every year, made the ozone hole a distant priority in public perception.

But this sense of comfort received a rude jolt in 2011 when it was discovered that large ozone holes—which were hitherto confined to the Antarctic—were now beginning to form over the Arctic as well. Equally disconcerting is the emerging evidence that ozone holes strongly influence climate, driving both terrestrial and ocean environments.

The above-mentioned contexts give this book enormous contemporary relevance. It is arguably the first book which includes a discussion on the ozone hole from the perspective of climate change. Written in a lucid storytelling style that has made the previous eight books and the teachings of these authors hugely popular, the book gives a fascinating narrative of the ozone hole story, from its past to the present and then future.

I commend Springer, especially its Acquisition Editor Ms. Melinda Paul, for conceiving this book project and piloting it to completion.

B. R. Babu, IAS
Secretary (Environment)
Government of Puducherry

Preface

All living beings pollute the earth with their excreta and/or dead bodies, but nature has an elaborate system of scavengers–ranging from microorganisms to large vertebrates–who clean up the pollution without disturbing the earth's ecological balance. Indeed, scavengers play as crucial a role as primary producers do in maintaining the earth's ecosystem.

The first cause of tilt in this delicate balance occurred when humankind discovered fire nearly 300,000 years ago. That discovery made *Homo sapiens* the first–and to date the only–species in the world to have the ability to harness sources of energy other than food energy. After the discovery of the wheel, humans were able to tap increasing amounts of energy from moving water and air. The wheel made inland transport easier, and humans used more and more biomass to fuel animal-driven transport across the world's landmass for several thousand years.

The more the energy humans learnt to use, the more material resources they consumed and the more pollution this generated. This trend steadily, though very slowly, increased from the point of discovery of fire 300,000 years ago to the mid-eighteenth century.

Then humans learnt to mine coal in large quantities. This fuelled the industrial revolution. As more and more machines made larger number of products, increasing material resources were consumed. On one hand, the generation of energy to run those machines caused pollution, and, on the other, producing goods from natural resources by those machines also caused pollution. When those goods completed their useful life and inevitably turned to waste, it caused even more pollution.

Then, in quick succession, humans learnt to mine petroleum and natural gas. These fossil fuels had much higher energy density and much greater availability than renewable energy sources (RES)–especially biomass, water power, and wind–on which humankind had depended till the mid-eighteenth century. Fossil fuels liberated humankind from the much less dense, much less wieldly, and much more expensive renewable energy sources–of which some like wind were intermittent to

boot. This and the then seemingly unlimited supply of fossil fuels took human technological 'advancement' on a very rapid and increasingly fast-forward mode during the nineteenth and twentieth centuries. The trend continues in the twenty-first century.

The exponential increase in technological 'advancement' went hand in hand with a proportionate increase in global human population and consumption, thereby causing a proportionate increase in pollution.

For long, environmental pollution was seen to cause harm at, or close to, the points where it was generated. But in the late 1960s and 1970s, the world was confronted with a problem which impacted areas hundreds or even thousands of kilometres away from the problem's point of origin–acid rain. The oxides of sulphur and nitrogen released as hot gases by thermal power plants and chemical industries were carried by wind to far-off places, where the oxides were dissolved into clouds making the rain highly acidic. This damaged pristine forests and lakes, corroded buildings, and rendered fertile soils underproductive or even barren.

Acid rain can be called humankind's first 'global environmental problem'. It signified that pollution generated far away can hurt us as severely as local pollution. But before the world could attain some measure of control over acid rain, it was hit by another global environmental problem–the ozone hole.

The ozone hole problem became common knowledge during the mid-1990s at a time when the world was sharply divided on whether it was getting warmer. As many scientists proclaimed that global warming was occurring as those who proclaimed that it wasn't. In subsequent years, thanks to the Montreal Protocol and associated measures described in this book, stratospheric ozone levels seemed to have stopped falling and even showed signs of recovery. But just as the threat of the ozone hole began to recede, that of global warming began to loom large. Soon it was joined by another rising spectre—that of ocean acidification.

To make matters worse has come the news of the largest ever ozone hole being recorded over the Arctic in 2011. In the subsequent years also, the Arctic has recorded more stratospheric ozone losses than it did in the past. Till these developments, the attention vis-à-vis stratospheric ozone depletion was largely focused on the Antarctic because the temperature and other conditions over the Antarctic are much more conducive to the formation of ozone holes than they are at the Arctic.

The other sobering realization is that more and more complex and strong interrelationships are being discovered between ozone depletion and the other two global jeopardies: climate change and ocean acidification. Quite often, what is good for preventing one becomes a cause of promoting the other two just as, equally often, the same agent can jeopardize all three. These happenings have brought the issue of ozone holes once again to the centre stage, along with rising concerns for climate change and ocean acidification.

This book aims to underscore the re-emergence of the ozone hole problem and deals with it in its current context. It traces the history of the ozone hole from the stage of formation of the stratospheric ozone 'layer', millions of years ago, to the time in the late twentieth century when the anthropogenic destruction of that ozone

was discovered and brings the reader right up to the present day. Factors that influence stratospheric ozone—favourably or unfavourably—are discussed, and the ways to halt ozone depletion are catalogued. All along, there is special emphasis on the interaction of the ozone hole and climate.

We hope that this book proves a timely and useful addition to the repertoire of global environmental issues.

We acknowledge with gratitude the support of the University Grants Commission, New Delhi, for emeritus professorship and associated grants (to S.A.A.) that enabled the writing of this book. The willing help of Ms. Tabassum Abbasi in searching and collating material for the book was a source of relief and happiness, as was the effort of Ms. K. Ananda Jothi in word processing, correcting the innumerable spelling errors and rewriting that this book has gone through.

Puducherry, India S.A. Abbasi
Puducherry, India Tasneem Abbasi

About the Authors

Tasneem Abbasi has obtained her B.Tech. and M.Tech. degrees in chemical engineering and environmental engineering, respectively, both in first class with distinction from Pondicherry University. She has also studied for a master's degree in water and environmental engineering on a Trilateral Chevening Scholarship at the University of Survey, UK, topping her class of 26 students. She subsequently received her Ph.D. from Anna University of Technology.

In a professional career spanning 15 years, Dr. Tasneem has published over 80 papers in indexed journals, with over 1500 citations and a Hirsch Index of 22. She has authored ten books and seven patent claims. She is holding a concurrent position of Visiting Associate Professor at Worcester Polytechnic Institute, USA, and has been a recipient of the *Young Engineer Award* and the *Suman Sharma Award for Outstanding Women Engineer*. She has also received the *Best Presentation* award at World Recourse Forum, Dawos, and the *Best Teacher Award* at Pondicherry University. This is her second book with *Springer* after the critical and commercial success of *Biogas Technology*.

S. A. Abbasi has been a full university professor since 1987 after being Head-in-charge of the Water Quality & Environment Division at the Centre for Water Resources, Kozhikode, during 1979–1987. He was a Visiting-cum-adjunct Professor at California State University during 1984–1987.

With 41 books, over 350 papers in indexed journals, 8 patents, over 4500 citations and a Hirsch Index currently at 37, Prof. Abbasi is among the world's foremost environmental experts. Among numerous coveted

honours and awards received by him are the *National Design Award in Environmental Engineering*, the *National Hydrology Award*, the International Desalination Association's $20,000 prize, and fellowships of the National Academy of Sciences and the Indian Institute of Chemical Engineers.

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Chapter 1
Ozone in the Atmosphere

This chapter sets the backdrop for discussing ozone hole and its ramifications. It recapitulates what atmosphere consists of, how ozone forms in the atmosphere, and why is the presence of ozone so vital to our well-being.

1 Introduction

1.1 Environmental Pollution and Its Globalization

Environmental pollution has been occurring with increasing intensity and geographic spread ever since the humankind discovered fire about 300,000 years ago [3]. But environmental pollution began to attract popular attention on a global scale only since the lower half of the previous century [2–4]. This has happened as growing population and industrialization have made environmental pollution increasingly prevalent and bothersome [5].

In a 1962 book *Silent Spring*, Rachel Carson [6] called to attention the perils of indiscriminate pesticide use. This widely noticed book was followed by another iconic publication—*Limits to Growth* [7]—which predicated that world oil resources would peak by about 2010 (which they indeed have) and that the present paradigm of growth being inherently unsustainable would bring the earth's ecosystem to collapse in the twenty-first century. Several major environmental disasters also began to surface, typified by the London smog (1952), the Minamata disaster (1956), the Thanksgiving Day tragedy (1966), the Seveso disaster (1976), the Amoco Cadiz oil spill (1978), the Love Canal episode (1978), and others [3].

For long it was assumed that environmental pollution would harm only the place where it was caused, at most nearby areas. But then the world was confronted with a problem which impacted areas hundreds or even thousands of kilometers away from the problem's point of origin—the acid rain [1]. The oxides of sulphur and nitrogen released as hot gases by thermal power plants and chemical industries went high up in the sky and were carried by winds to far-off places. There the oxides were

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