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RESEARCH WING OF

**ASSOCIATION OF PHYSICIANS OF INDIA**



# MONOGRAPH

# POLLUTION & HEALTH




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# POLLUTION & HEALTH

## MONOGRAPH

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## This book is dedicated to

My grand father



## Late Mahashya Kishori Ram

**(1895 - 1960)**

For setting all the moral, ethical, social & academic values for our family,



### Com. Ved Parkash Gupta

**(1.12.1932 - 8.5.2018)**



### Prof. Santosh Gupta

**(15.10.1934 - 20.6.2020)**

Both my parents spent their entire life crusading for those who couldn't defend their own rights and did everything in their power to fight injustice. My father Com. Ved Parkash Gupta, a true leftist, was one of the first Human Rights Activists of the region, member of PUCL and founder of Punjab Human Rights Committee who dedicated his life towards the upliftment of those who were wronged. My mother Prof. Santosh Gupta, a strong pillar of strength for our family, supported and encouraged my father to fight injustice, she spent her entire life helping and teaching students, especially those who couldn't afford education. Both our role models will forever be in our hearts and minds guiding us to follow the values they taught us.

# This book is dedicated to

**My parents**

**Com. Ved Parkash Gupta and Prof. Santosh Gupta**

who are my role models

**My wife, son and son-in-law**

**Dr. Sonia Arora, Dr. Varun Gupta and Dr. Manpreet Singh Brar**

who are my greatest support

**My friend, mentor and guide**

**Prof. Dr. Gurpreet S. Wander**

without whose continuous support I could not have achieved much academically

**My fellow advisors, reviewers and editors**

**Prof. Dr. Shashank Joshi, Prof. Dr. Milind Nadkar, Prof. Dr. Mangesh Tiwaskar and Prof. Dr. Jyotirmoy Pal**

this book would not have been possible without their whole hearted support

**My colleagues of API Malwa Branch**

**Dr. K. K. Nohria, Dr. M. R. Gupta, Dr. K. K. Goyal, Dr. Ashok Goyal and Dr. Sharad Gupta**

who always extend unconditional support for every academic and social activity

**My batchmates of GOMCO 1978 (Patiala)**

**Dr. Shardandu Sharma, Dr. Tajinder S. Goindi, Dr. Berinder S. Mangat, Dr. Gajinder Dewan and late Dr. Rakesh Gupta**

whose company influenced my personality to become a better person

**Most importantly my daughter**

**Dr. Meghna Gupta**

who is my strongest critic and influences every aspect of my life

**Last of all my teachers, patients and friends**

who taught me medicine and how to enjoy life

डॉ. जितेन्द्र सिंह
राज्य मंत्री (स्वतंत्र प्रभार),
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Department of Atomic Energy & Department of Space,
Government of India



## FOREWORD

It gives me immense pleasure and great honour to write the foreword for the Monograph titled "Pollution and Health" wherein adverse health effects of pollution on human beings have been highlighted.

The growing pollution levels have raised a public health concern both in India and globally. It has also generated interest amongst researchers to document significant health burden of pollution on human morbidity and mortality. In this direction, this monograph comprising of 34 chapters contributed by famous contributors from all over India and covering almost all aspects of adverse health effects of pollution on various systems of the body will definitely generate awareness and research interest amongst health care professionals and common people.

I appreciate the idea of publication of a monograph on 'Pollution and Health' and congratulate the entire editorial team of this monograph for providing a comprehensive book on the subject.

**Dr. Jitendra Singh**
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# FOREWORD



**Dr. B.N.Gangadhar**

Each one of us carry a duty to guard our own health, just as much as we expect the society, health department, to provide services of health care. Society too can help guide its members by ensuring that they are not contributing adversely to health. Pollution is a strong factor that adversely affects health and well-being. Containing pollution will promote good physical and mental health.

Pollution happens as a result of several 'developments' that are happening around us. It may appear that pollution is inevitable. However, it is necessary not to resign ourselves to this position.

We can do two things in this regard. 1). Ensure that pollution is reduced to the most minimal level in the process of these developments. 2). Each individual not only protects his/her self but also practices a lifestyle that reduces the effects of pollution on one's body and mind.

The first step in this regard is to become aware of the sources and the adverse effects of the pollution. Becoming aware is half victory achieved. Through this book -a Monograph on Pollution & Health- a reader (a doctor or another citizen) gets the required awareness. This awareness also needs to be widely spread. This should facilitate regulators and public to minimise or even avoid totally, the pollution-contributory activity by accepting alternatives that are nature-friendly.

The fight against pollution should become a movement in the society. The Monograph is a right step in this direction. I congratulate the contributors for taking this bold initiative. I hope each reader is enthused with this mission and takes part in the efforts of the society to mitigate the pollution, and promote sound physical and mental health, thereof.

**Dr. B.N.Gangadhar**
Chairman, National Medical Commission, New Delhi.
Professor Emeritus Integrative Medicine
NIMHANS, Bengaluru and National Distinguished Scientist Chair,
Dept of AYUSH, Govt of India

# FOREWORD



**Prof. Dr. G. S. Wander**

Pollution has become a major health concern world over. With increasing industrialization and prosperity, it is a major factor in India. Vehicular traffic, industrial sources, farm burning and domestic air pollution are major causes for us. Pollution affects health in multiple ways. We all know the effect it has on respiratory system however the cardiac and neurological effects have been realized more recently. The small PM particles are known to increase the risk of atherosclerosis all over the body. A lot of work is being done in our country by the environmentalists and the government. A lot more attention is required since we have one of the highest levels of pollution in the major cities.

Although it is a public health issue but we at API realize that it needs attention and awareness from all of us. As physicians we see the effects of air pollution in the causation of various non communicable diseases every day. This is an effort by Dr. Vitull Gupta who has always worked for issues of importance to all of us. He has been ably supported by all the office bearers of the Association of Physicians of India. We hope that this will inspire young doctors to conduct more research in this area so that we can look at the harmful effects of air and other pollutions on different organs of the body. We would like to thank all the authors for their contributions. Some of the top health administrators have given their opinions in this book, which will be a good reference for anyone interested in this topic. I feel this book will be useful for non-physicians and non-doctors as well since a good knowledge of the health effects of pollution is important for all the citizens.

I would like to acknowledge the great commitment Dr. Vitull Gupta has towards the health of the masses. We should all continue to contribute our bit in this direction so that we can make our environment healthy for living.

**Dr. Gurpreet S Wander**

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Principal & Professor of Cardiology,
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Past President, Hypertension Society of India.
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# FOREWORD



**Prof. Dr. Shashank Joshi**

As the world became industralised and transportation improved, it made air, water, food and soil contaminated by chemicals and matter which now is popularly termed as pollution. A leading physician, teacher and health activities committed to climate change Dr. Vitull K Gupta from Bathinda from the Malwa region of Punjab embarked on an ambitious journey of collating state of the art reviews on every area of pollution and how it affects health and disease from domain experts across our entire nation. I congratulate Dr. Vitull K Gupta for choosing this subject, which threatens our planet in this climate change crisis and creating this master piece monograph. This will serve as a reference book for physicians, clinicians, and students to gain knowledge as well encourage them to generate Indian evidence from their local geography from our nation.

This PRF - API monograph of 'Pollution and Health' covers every aspect of internal medicine from the classic heart disease, hypertension, diabetes, NCD spectrum to lung health, COPD to special impact on sexual health and mental health as well. The chapters on artificial intelligence as well spiritual health and their role in health and pollution is note worthy.

Beyond air pollution, it covers water and noise pollution and has some excellent chapters on ENT as well as gender bias and chapters related to women in obstetrics and gynecology space as well as. Cancer and neurogenerative disorders which have footprint links to pollution are also covered apart from strategies to mitigate pollution and I feel, I must complement Dr. Vitull K Gupta once again for ensuring that he has been able to get domain experts across India to compile this wonderful science based journey in the form of a book.

Sustainability initiatives are no longer associated with the Western world or China with India's emergence as a force in the global arena.

India’s energy consumption is the third highest in the world and an 8% rise in electricity consumption in 2024 is projected as per IEA (International Energy Agency) estimates. This surge in power demand will make it even more critical to balance the need for energy security, economic growth, and environmental sustainability.

There is an urgent need to build a greener world for the future generations and we have to congratulate the Government of India vision to make efforts in this direction and also ensuring

environmental ministries of center and state, through legislation and through education and empowerment to curb deleterious effect of pollution and climate change.

India's push to solar energy projects especially solar rooftops to solar pumps as well as wind energy shows its sustainability footprint and will to go green. Green hydrogen is another national commitment towards India going green movement and the National Green Hydrogen Mission. This is our quest to become the global leader in Green Hydrogen. India needs more solar parks, creation of green energy corridors and creation of more renewable energy projects but curbing pollution will be the key to health and development agenda. Human life expectancy as well as disease burden is threatened by both climate change and pollution and we need to commit to a greener India and greener world.

We need to plant trees every single day and mission tree will give lungs to mother earth so that we can live in a better and healthier world.

Jai Hind

Jai API, ICP, PRF

**Prof. Dr. Shashank Rameshchandra Joshi**
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Padmashri Awardee
Past President API
Past Dean ICP
Emeritus Editor JAPI
Editor API Textbook of Medicine

# FOREWORD



**Prof. Dr. Milind Y Nadkar**

To,

Prof. Dr. Vitull K. Gupta and Prof. Dr. G. S. Wander,

PRF-API Monograph "Pollution and Health"

As President, Association of Physicians of India, I feel sense of fulfilment to congratulate Prof. Dr. Vitull k. Gupta and Prof. Dr. G. S. Wander for publishing the monograph on 'Pollution and Health' under the aegis of Physicians Research Foundation of Association of Physicians of India. It gives me immense pleasure to write the foreword for one of its kind book including more than 40 chapters covering almost all aspects of adverse health effects of pollution on human beings.

This monograph gains much importance considering that increasing pollution levels has become a serious public health issue globally as well as in our rapidly growing nation. Increasing pollution and its adverse health effects has generated a lot of interest among researchers and has document adverse effects of pollution to human health. I think this monograph comprising of more than 40 chapters by renowned national faculty of researchers and contributors discussing almost every adverse health effects of pollution on human health will provide a comprehensive reference book to the world. I must congratulate the editorial team of monograph 'Pollution and Health' comprising of Chief Editor, Prof. Dr Vitull K Gupta, advisors, editors and reviewers, Prof. Dr. G. S. Wander, Prof. Dr. Shashank Joshi, Prof. Dr. Mangesh Tiwaskar, Prof. Dr. Jyotirmoy Pal, executive editor, Dr. Meghna Gupta and assistant editor, Dr. Manpreet Singh Brar for providing a comprehensive book which will surely act as a reference book on pollution and health.

I feel honoured to be part of editorial team and congratulate API (Malwa Branch) and PRF of API for this great academic initiative. I am sure we that together we will definitely be able overcome the growing menace of pollution and publication of monograph is one step forward in this direction.

Jai Hind, Long Live Bharat.

**Prof. Dr. Milind Y Nadkar**
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# FOREWORD



**Dr. V. Mohan**

It gives me great pleasure to write this foreword for the monograph on Pollution and Health edited by Prof. Dr. Vitull Gupta. I have always admired Dr. Vitull Gupta for his originality and for his proactive nature in taking up relevant causes for the benefit of humanity. His book 'Pollution and Health' is also a step in this direction. Dr Vitull Gupta has assembled some of the top scientists and doyens in the medical profession to contribute chapters related to various aspects of the effect of pollution on health. It has been my privilege to contribute a chapter to this book.

Unfortunately, pollution is increasing day by day especially in the major cities and towns. Earlier, pollution was believed to affect only the respiratory system, today we know that it affects all organs and is linked even to non-communicable diseases like diabetes. In fact, our own work has shown that air pollution is directly associated with new onset type 2 diabetes.

This monograph brought out by Dr. Vitull Gupta will form a valuable addition to any library and it's a must read for all doctors, post graduate students and scientists. I congratulate Dr Vitull Gupta, the associate editors and the authors who have contributed to magnificent monograph and wish Dr. Vitull Gupta all the very best.

**Dr. V. Mohan**
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Chairman, Dr. Mohan's Diabetes Specialities Centre.
President, Madras Diabetes Research Foundation, Chennai.
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# FOREWORD



**Dr. Anoop Misra**

To,

Prof. (Dr.) G S Wander and Prof. (Dr.) Vitull k. Gupta,

PRF-API Monograph "Pollution and Health"

I am pleased to introduce the Foreword for the PRF-API monograph, "Pollution and Health." Under the leadership of Chief Editor Prof. Dr. Vitull K Gupta, and with contributions from a dedicated team of advisors, editors, and reviewers, this work addresses the significant issue of pollution in India.

As India continues to develop, pollution-stemming from industrialization, urbanization and increased vehicle emissions-presents a serious challenge. This monograph explores the health impacts of air, water, and soil pollution, and also discusses climate change.

The book, with 34 chapters, features the expertise of respected scholars and practitioners. An 'Open Forum' section includes practical insights from medical professionals, enhancing the academic discussion.

The editorial team, led by Prof. Dr. Gupta, has effectively communicated complex scientific ideas in an accessible way. This monograph is a valuable resource for healthcare professionals, policymakers, and the public, both in India and globally. It aims to raise awareness of pollution's impact on health and inspire actions to reduce its effects.

This work is more than a collection of research; it is a cal! to action for a healthier, more sustainable future.

With Best wishes

**Prof. (Dr.) Anoop Misra**
M.B.B.S, M.D, M.A.M.S, F.I.M.S.A
Executive Chairman, Fortis C-DOC Centre of Excellence for Diabetes.
Chairman, Fortis C-DOC Centre of Excellence for Diabetes, Metabolic Diseases & Endocrinology.
Chairman, National Diabetes, obesity and cholesterol Foundation (N-Doc), Director, Diabetes and Metabolic Diseases, Diabetes Foundation (India) (DFI), Padma Shree Awarded by President of India, 2007, New Delhi, Dr. BC Roy Awarded hy President of India, 2006, New Delhi, Former Faculty, Dept. of Human Nutrition, Medicine & Endocrinology, South-western Medical Centre at Dallas, Texas, USA, Former Professor, Dept. of Medicine, All India Institute of Medical Sciences, New Delhi, Honorary Professor, Institute of Life Sciences, Hyderabad, Fortis C-DOC Hospital for Diabetes & Allied Sciences.
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# FOREWORD



**Dr. Mangesh Tiwaskar**

In the intricate dance of life, the health of humanity and the health of our planet are inextricably intertwined. Today, more than ever, we are witnessing the profound consequences of this interconnectedness as the spectre of pollution that looms large over our world. From the air we breathe to the water we drink and the soil that nourishes us, pollution's insidious reach threatens the very foundation of our well-being. It is with a sense of both urgency and hope that we present this monograph, "Pollution & Health," a collaborative effort of the Physicians Research Foundation and the Association of Physicians of India. Under the meticulous editorship of Prof. Dr. Vitull Gupta and Prof. Dr. Gurpreet Singh Wander, this compendium gathers the collective wisdom of India's leading physicians and specialists, offering a comprehensive exploration of the multifaceted relationship between pollution and human health. Within these pages, a stark reality of pollution related menace unfolds. We witness the devastating toll of air pollution, which claims millions of lives each year through respiratory diseases, cardiovascular complications, chronic metabolic diseases, and even cancers. We confront the alarming consequences of water pollution, which jeopardizes access to clean drinking water and exposes populations to a host of waterborne diseases. We grapple with the insidious effects of soil pollution, which contaminates our food supply and disrupts the delicate balance of ecosystems. This monograph does not shy away from the harsh truths. It lays bare the disproportionate impact of pollution on vulnerable populations, particularly women, children, and the elderly. It highlights the burden of disease borne by those living in marginalized settings, where environmental injustice compounds the health risks.

But amidst these sobering revelations, a glimmer of hope shines through. This monograph is not merely a chronicle of despair; it is a call to action, a testament to the resilience of the human spirit, and a roadmap towards a healthier and more sustainable future.

Leading experts from our country delve into the intricate mechanisms through which pollution wreaks havoc on human health. We gain a deeper understanding of the complex interplay between environmental toxins and our physiological systems, exploring the emerging field of environmental epigenetics, which sheds light on how pollution can alter gene expression and contribute to the development of chronic diseases across generations. This monograph doesn't stop at diagnosis; it empowers us with solutions. It offers a comprehensive overview of strategies to combat pollution at its source, from cleaner industrial processes and sustainable energy solutions to improved waste

management and urban planning. It underscores the importance of individual and collective action, empowering individuals to make informed choices that protect their health and the environment. In a unique and insightful addition, this work ventures into the spiritual dimensions of pollution. Recognizing that our relationship with the environment is not merely a matter of physical health, it delves into the interconnectedness of our well-being with the natural world. It reminds us of the ancient wisdom that calls upon us to live in harmony with nature, fostering a sense of stewardship and reverence for the delicate balance of our planet.

The open forum section, a testament to the collaborative spirit of this endeavour, provides a platform for diverse voices and perspectives. It invites readers to engage in a dialogue that transcends disciplinary boundaries, fostering a holistic understanding of the complex challenges we face.

This monograph, a culmination of tireless dedication and expertise, stands as an invaluable resource for healthcare professionals, policymakers, educators, and individuals alike. It is a testament to the unwavering commitment of India's medical community to protect and promote the health of our nation. As we navigate the complexities of the 21st century, let us heed the clarion call of this monograph. Let us work together to create a world where clean air, water, and soil are not luxuries but fundamental rights. Let us build a future where the health and well-being of all people are protected from the ravages of pollution. Let us embrace the wisdom that reminds us that we are not separate from nature but an integral part of its intricate melody of life. In the words of the great Indian poet Rabindranath Tagore, "The butterfly counts not months but moments, and has time enough." Let us seize the moments we have, and work tirelessly to ensure that future generations have time enough to experience the beauty and bounty of a healthy planet.

**Dr. Mangesh Tiwaskar**

MD, MRCP Examiner. Editor-in-Chief, JAPI, Former General Secretary API, ICP, PRF. Guest Editor of "Insulight" Journal. Consultant Physician & Diabetologist, Shilpa Medical Research Centre, Rainbow Apts., Avdhoot Nagar, Dahisar (E) Mumbai.

# FOREWORD



**Dr. H.K. Chopra**

It is a great pleasure and honour for me, to be writing the Foreword for the need based state of art PRF- API (Physicians Research Foundation) monograph on “Pollution and Health” published by Association of Physicians of India (Malwa Branch) on behalf of Physicians Research Foundation, Research Wing of Association of Physicians of India, first of its kind, from India to the world with brainstorming, mind-boggling, scintillating and thought provoking content on every possible aspect. The main theme of this monograph is to highlight the robust relationship between various types of pollutions and systemic illnesses including gender bias, social economic perspective, artificial intelligence, mitigating strategies, and spiritual dimensions. This monograph highlights on the wisdom of the doctor and everyone around him including God’s grace. The monograph navigation is contributed by 83 authors in 43 chapters focusing on pollution and health, including chapters on climate change and global warming under the dynamic chief editorship of Dr. Vitull K. Gupta, advisors, editors and reviewers, Prof. Dr. G. S. Wander, Prof. Dr. Shashank Joshi, Prof. Dr. Milind Nadkar, Prof. Dr. Mangesh Tiwaskar, Prof. Dr. Jyotirmoy Pal, executive editor, Dr. Meghna Gupta and assistant editor, Dr. Manpreet Singh Brar.

The chapters are well outlined, organized and well written with authenticity. The writing style of every chapter is vivid, concise, practical, eloquent, and guideline directed. The clinical examples are exhilarating and thought provoking with meaningful messages. All the editors, advisors, reviewers and contributors are epitome of devotion, dedication, dynamism, philosophy and humanity all in one. They are also an apostle of elegance and generosity in every aspect of expressions in this monograph. They are an embodiment of compassion, selfless service, sacrifice, healing, humility, humanity, hope and are crusaders of victory and vision. This monograph nurtures positivity during crisis and emergency care of every aspect of pollution including mental pollution with mitigating solutions such as artificial intelligence and spiritual dimensions.

I congratulate Prof. Dr. Vitull K. Gupta and all the editors, advisors, reviewers and contributors for accomplishing this extraordinary brilliant monograph as an achievement of amalgamation of great clinical relevance in the realm of “Pollution and Science” integrating physical orchestra, emotional and psychological orchestra, neurohormonal, biochemical orchestra, genetic and epigenetic orchestra and quantum orchestra in human beings.

I appeal to each and everyone to read, understand and practice all that is mentioned in this unique monograph for enhancing our wisdom connecting pollution and health.

I wish this monograph "Pollution and Heath" published by API Malwa Branch on behalf of Physicians Research Foundation Research Wing of Association of Physicians of India a great success to impact locally, focally and globally.

*"The good physician treats the disease; the great physician treats the patient who has the disease and a super great physician prevent the disease by enhancing awareness on Pollution and Health".*

**Dr. H.K. Chopra**

Chief Cardiologist, Medanta-Moolchand Heart Institute. Chairman CME, Moolchand-Medcity, Delhi. President, World Wellness Foundation, WHA. Country Head, AHA. Chairman, KDC Instant Healthcare India LLP. Editor in Chief, Top 13 Focused Textbooks of Cardiology. Editor in Chief, 40 Handbooks in Cardiology and Medicine. National Awardee, DST, Govt. of India A National Stamp released GOI, for focused Textboook of Cardiology. National Past President, CSI & IAE. Former Editor in Chief, IHJ & JIAE. Published 1554 articles in various national and international Journals and textbooks. Worked at Ceders Sinai, Medical Centre, UCLA, USA, University of Alabama, UAB, USA.

# FOREWORD



**Dr. Banshi Saboo**

In recent years, the rising epidemic of diabetes has awakened the global health community, though a chronic health condition still the epidemic is alarming. Lifestyle as unhealthy diet and physical inactivity are well-known researched factors, but a very often overlooked culprit is environmental pollution. The emerging research has proved a significant link between pollution and diabetes; thereby, an urgent necessity for comprehensive strategies to curtail pollution is needed to halt the epidemic.

**The Science Behind the Link:** The fine particulate matter ($PM_{2.5}$) of air pollutants has been proven to be a factor in exacerbating diabetes and its progression. These microscopic particles, which originate from vehicle emissions, industrial processes, and other sources, can penetrate the lungs and enter the bloodstream deep. Within the body and bloodstream, they can trigger oxidative stress and systemic inflammation, which can impair insulin sensitivity and beta-cell function, thereby onset of diabetes and its progression.

A study published in The Lancet Planetary Health estimated that air pollution contributed to 3.2 million new diabetes cases globally in 2016, accounting for about 14% of all new cases that year. This alarming statistic highlights the impact of pollution on public health and the need for stringent air quality regulations.

**Impact on Vulnerable Populations:** The disproportionate burden of diabetes due to pollution amongst vulnerable populations mainly those in low- and middle-income countries is yet enough to call for global research, but disproportionate can't be a reason for not discussing the issue "Pollution and Diabetes". In India rapid urbanization led to severe air quality degradation, along with limited access to healthcare exacerbates the poor prognosis of the diabetes epidemic.

**Policy Implications:** Addressing the link between pollution and diabetes requires a multifaceted approach. Policymakers must prioritize the reduction of air pollution through stricter emissions standards, investment in clean energy, and the promotion of sustainable transportation. Additionally, public health initiatives should focus on raising awareness about the health risks of pollution and advocating for lifestyle changes that can mitigate its impact.

Healthcare providers also have a critical role to play. By incorporating environmental health into patient education and advocating for policies that reduce pollution, they can help protect their patients from the harmful effects of air pollution. For instance, promoting the use of reusable insulin pens over disposable ones can reduce medical waste and its associated environmental impact.

**The Way Forward:** The fight against diabetes cannot be won without addressing the environmental factors that contribute to its prevalence. As we continue to grapple with the challenges of urbanization and industrialization, we must recognize the interconnectedness of environmental and public health. By taking bold action to reduce pollution, we can not only improve air quality but also make significant strides in the global battle against diabetes.

In conclusion, the link between pollution and diabetes is a clarion call for integrated health and environmental policies. It is time for governments, healthcare providers, and communities to come together to tackle this pressing issue. Only through collective action can we hope to create a healthier, more sustainable future for all.

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# FOREWORD



**Mr. Devinder Sharma**

We live in difficult times. When I say difficult I mean at a time when it is becoming increasingly difficult to fathom the right from the wrong. While the cyber world is loaded with information, in fact over-loaded, it is quite a challenge to decipher the right kind of information, especially in an area that is not only dear to us all but also crucial – health. In a recent expose, the Daily Mail has come out with an investigative analysis. It says more than half of UK Government Advisors on nutrition are paid by food companies. Clearly, the stakes are very high. We also know that large corporations owning our food supply chains are into intensification. But an interesting metaanalysis shows that 89 per cent of the packed food that adorns the supermarket shelves is not of the requisite quality. This study was done for over 32,000 food products that are manufactured in seven countries, including India. And these include processed foods from some of the big food giants. While there is a talk of achieving zero-emissions by mid-century, media reports warn the rise in the sales of SUV cars pose a serious health and environment risk. In 2023, there were more than 360 million SUVs on the roads worldwide. The carbon emission touched 1 billion tonnes, at least 1 million more than the previous year. Some media reports say if SUVs were a country, it would rank among the world's 10 highest carbon-polluters. Simply put, these cars have a large climate footprint. In India, of the 42-lakh cars sold in 2023, as many as 51 per cent were SUVs. If these cars are so polluting, as I said earlier, I am sure these have serious health and environmental impacts. The two examples I listed above clearly show how the right kind of information and analysis is missing from public discourse. Whether it has been manipulated to hide the shocking details or the harmful implications conveniently ignored, the tragedy is that we, the people remain ignorant about the health implications or live under an illusion that all is well. The health implications are generally considered to be inevitable fallout of the development process; something we have to live with or die for. Pollution can be from stubble burning and it can also be from automobile exhausts. It can from toxic wastes that are released into a river, and it can also be from contamination of groundwater. While there is an urgent need for putting a stop to the harmful elements that damage air, water and land right at the place from where it begin; but it is also important for people to know how and what pollutants do to your body. The painstaking efforts by Dr Vitull K Gupta to bring together a galaxy of distinguished experts and practitioners from the medical fraternity to publish a unique monograph on "Pollution and Health" is a step towards making the right kind of information available to the general public. Divided in 35 chapters, it looks at various dimensions through which human health can be viewed. As I said at the very beginning, this publication will go a long away in not only taking the right kind of message to the people but also enable them to decipher the right from the wrong.

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# PREFACE



**Prof. Dr. Vitull K. Gupta**

This monograph "Pollution and Health" is one of its kind, exploring the relationship between pollution and health so that it will benefit health care professionals globally. Pollution has become a grave public health issue affecting every aspect of life and adversely influencing climate change. I feel short of words while thanking Prof. Dr. Gurpreet S. Wander, Director, PRF-API for guiding and authorizing me for the publication of this prestigious monograph. I greatly appreciate the suggestions and advice by our Hon'ble advisors, reviewers and editors Prof. Dr. Shashank Joshi, Prof. Dr. Milind Nadkar, Prof. Dr. Mangesh Tiwaskar and Prof. Dr. Jyotirmoy Pal in developing the scientific agenda for this monograph and selecting extremely distinguished national faculty for contributing various chapters. I am immensely indebted to the editorial skills of Dr. Meghna Gupta, Executive Editor and Dr. Manpreet Singh Brar, Assistant Editor for editing the monograph to perfection. I have no words to express my sincere thanks for the efforts of our talented and eminent contributors, who have written excellent and informative chapters detailing all aspects of 'Pollution and Health' in Indian context. Each chapter comprises of latest information expressed in simple text, which will enable readers to have detailed insight of the subject easily. I am very proud to have extremely talented, intelligent, ethical and academic seniors like Dr. Gurpreet Singh Wander, Dr. Paramjeet Singh Aulakh, Dr. Hem Raj Goyal, Dr. Sanjeev Uppal, Dr. Sudhir Verma, Dr. Ashwani Maheshwari, Dr. Vinay Jindal, Dr. Bimal Garg, Dr. Karamveer Goyal, Dr. Rajiv Vadhera, Dr Rajiv Dosajh and Dr. U. P. Singh, who polished my academic skills and still continue to guide me. I wish to express my gratitude to all members of the Association of Physicians of India (Malwa Branch) including Dr. K. K. Nohria, Dr. M. R. Gupta, Dr. K. K. Goyal, Dr. Ashok Goyal and Dr. Sharad Gupta for their unconditional moral support for the publication of this monograph. I will be failing in my duty, if I do not mention my childhood friends Mr. Surinder Katia, Mr. Anil Garg, Mr. Sat Dev Dharni, Mr. Ashwani Malhotra and batchmates Dr. Shardandu Sharma, Dr. Tajinder Singh Goindi, Dr. Berinder Singh Mangat, Dr. Gajinder Dewan and late Dr. Rakesh Gupta and for their unconditional support and on whom I can rely, through the thick and thin of my life. I feel blessed to have come in contact with Prof. Dr. D. K. Singh, Director, AIIMS, Bathinda, a great inspiring, motivating and learned personality. Contribution of my family, my wife Dr. Sonia Arora, son Dr. Varun Gupta and daughter Dr. Meghna Gupta is extremely valuable in promoting and sustaining my academic as well as social activities. It gives me immense pleasure to dedicate this unique monograph to all my doctor colleagues of India. I am sure that this monograph will be very useful to the global community of health care professionals as well as common people in understanding the adverse effects of pollution on health.

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# EDITORIAL



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Earth's health and health of earth's inhabitants are inextricably linked to each other. Pollution and climate change are interlinked and are increasingly being recognised as the gravest threat to both earth and every living being on earth. Pollution is not just an environmental issue but has been recognised as a serious public health crisis that demands immediate attention which requires information about pollution and its adverse effects on mankind. In the pursuit of creating awareness, Physicians Research Foundation of Association of Physicians of India is publishing one of its kind monograph 'Pollution and Health' in an effort to provide insights into the adverse effects of pollution on human health.

The monograph contains chapters contributed by famous academicians from all over India that will apprise the readers about the relationship of pollution to various human organ systems. This monograph is an effort to help the global community realise the realities of this silent crisis, as pollution exacerbates existing health inequalities and undermines the wellbeing of our future generations. Adverse effects of air, soil, water, noise, radioactive, biochemical/biological and chemical pollution are discussed in various chapters of the monograph. A study published in The Lancet in 2017 drew attention towards the staggering economic cost of pollution to the global economy and estimated that pollution costs more than $4.6 trillion every year in healthcare cost and lost productivity to the global economy. This financial burden disproportionately affects low income countries as well as deprived and marginalized section of society both in developed as well as developing countries. Challenge of mitigating adverse effects of pollution are immense and the benefits equally profound. We must act before it is too late. Our collective future depends on it and publication of this monograph 'Pollution and Health' is a small contribution in an effort to save our planet and its inhabitants.

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Chapter - 1

# Pollution: An Overview

*Meghna Gupta, Keshav Garg, Manpreet Singh Brar*

**Introduction:**

The United Nations Environment Programme (UNEP) defines pollution as "the indirect or direct alteration of the biological, thermal, physical or radioactive properties of any medium in such a way as to create a hazard or potential hazard to human health or to the health, safety or welfare of any living species." [1] Pollution poses significant threats to human health, ecosystems and economies worldwide. It contributes to the burden of disease, degrades the environment and imposes economic costs through healthcare expenses, loss of productivity, and environmental remediation efforts.[2] Using data from the Global Burden of Diseases, Injuries and Risk Factors Study 2019, a study on pollution and health published by the Lancet Commission found that pollution causes over 90 lakh premature deaths worldwide.[3]

**Pollution can be categorised into several types:** Air, water, soil, noise, radioactive, biochemical/biological and chemical pollution. This chapter provides an overview of the sources, causes, permissible limits and present status of each type of pollution, with a particular focus on the Indian context.

**Air Pollution:**

The World Health Organisation (WHO) defines air pollution as "the contamination of the indoor or outdoor environment by any chemical, physical or biological agent that modifies the natural characteristics of the atmosphere." [4] These pollutants can be in the form of gases, particulates or biological molecules. The combustion of fossil fuels, industrial discharges and vehicular emissions are common sources.

**Types and Causes of Air Pollution:** There are two types of air pollution: ambient (outside) air and indoor air pollution. Particulate matter ($PM_{2.5}$ and $PM_{10}$), nitrogen oxides (NOx), sulphur dioxide ($SO_2$), carbon monoxide (CO), ozone ($O_3$) and volatile organic compounds (VOCs) are examples of outdoor air pollution. Burning solid fuels for cooking and heating, such as wood, coal and crop residues, is the primary cause of indoor air pollution.

**Major Sources Include:**

1. **Industrial Emissions:** Factories and power plants release pollutants $SO_2$, NOx, PM and VOCs.
2. **Transportation:** Vehicle emissions are a major source of nitrogen oxides, carbon monoxide (CO), hydrocarbons and PM.

3. **Agriculture:** Agricultural activities, including the use of fertilizers and pesticides, contribute to the release of ammonia and other pollutants.
4. **Household Activities:** The use of solid fuels for cooking and heating contributes to indoor air pollution.
5. **Burning of Fossil Fuels:** Coal, oil and natural gas combustion produces $CO_2$, $SO_2$ and NOx.

**Permissible Limits of Pollutants:** The permissible limits for key air pollutants are set on daily mean and annual mean by regulatory bodies such as the WHO[5] and the Central Pollution Control Board, India (CPCB).[6] These limits are designed to protect human health and the environment.

**Table 1: Permissible Limits for Key Air Pollutants.** [5, 6]

| Pollutants | Average Time | WHO Standards | Indian Standards |
|---|---|---|---|
| **Particulate Matter** ($PM_{2.5}$) µg/m³ | Annual Mean | 5 µg/m³ | 40 µg/m³ |
| | 24 Hours Mean | 15 µg/m³ | 60 µg/m³ |
| **Particulate Matter** ($PM_{10}$) µg/m³ | Annual Mean | 15 µg/m³ | 60 µg/m³ |
| | 24 Hours Mean | 45 µg/m³ | 100 µg/m³ |
| **Nitrogen Dioxide** ($NO_2$) µg/m³ | Annual Mean | 40 µg/m³ | 40 µg/m³ |
| | 24 Hours Mean | 25 µg/m³ | 80 µg/m³ |
| **Sulfur Dioxide** ($SO_2$) µg/m³ | Annual Mean | 20 µg/m³ | 50 µg/m³ |
| | 24 Hours Mean | 40 µg/m³ | 80 µg/m³ |

**Present Status in India:** The UNEP estimates that air pollution causes 7 million premature deaths globally.[7] In India, air pollution is a significant public health issue and it has been reported that, along with China, India has the highest number of premature deaths due to air pollution.[8] According to the Global Burden of Disease Study, air pollution was responsible for 1.24 million deaths in India in 2017, accounting for 12.5% of the total deaths in the country.[9] It is estimated that air pollution costs India approximately $36.8 billion annually, which is about 1.36% of its GDP.[10]

Air pollution levels in India often exceed permissible limits, particularly in urban areas. According to the CPCB, major cities like Delhi, Mumbai and Kolkata frequently report $PM_{2.5}$ and $PM_{10}$ levels that are several times higher than the prescribed limits. Efforts to control air pollution include the implementation of stricter emission standards, promotion of cleaner fuels and increased monitoring of air quality.

**Water Pollution:**

Water pollution is defined as the phenomenon of contamination of water sources by different undesirable and unwanted substances termed as pollutants, rendering the water unfit for consumption.[11] This may be the consequence of inappropriate garbage disposal, runoff from farms and industrial discharges.

**Types and Causes:** Water pollution can be categorised into surface water pollution and groundwater pollution. Surface water pollution involves rivers, lakes and oceans, while groundwater pollution affects aquifers and other underground water sources. According to CPCB, the most common source of water pollution in India is untreated sewage.[12] Major pollutants include heavy metals, nitrates, phosphates and pathogens.

- **Industrial Discharge:** Factories release chemicals, heavy metals and toxins into rivers and lakes.
- **Agricultural Runoff:** Pesticides, fertilizers and animal waste enter water bodies through runoff.
- **Domestic Sewage:** Untreated or inadequately treated sewage contributes pathogens and organic matter.
- **Oil Spills:** Accidental or intentional release of oil contaminates water bodies.

**Permissible Limits of Pollutants:** Permissible limits for key water pollutants are established by agencies such as the WHO and CPCB[13] to ensure safe water quality.

**Table 2: Permissible Limits for Key Water Pollutants.**

| Pollutants | WHO Standards | Indian Standards |
|---|---|---|
| **Lead** | 0.01 mg/L | 0.01 mg/L |
| **Arsenic** | 0.01 mg/L | 0.01 mg/L |
| **Nitrates** | 50 mg/L | 45 mg/L |
| **Total Coliforms** | 0 per 100 mL | 50 per 100 mL |
| **pH** | – | 6.5 - 8.5 |

**Present Status in India:** In India, water pollution is a critical issue affecting both urban and rural populations. According to the CPCB, in 2015 about 70% of India's surface water resources and a number of its groundwater reserves were contaminated by biological, toxic, organic and inorganic pollutants. The number of polluted surface water resources in India has now reduced to around 46% of the total as per CPCB's 2022 report.[14] A study by Lancet estimated that around 5,00,000 premature deaths occurred in India in 2019 due to water pollution.[15] Similarly, a study by National Institution for Transforming India (NITI) Aayog Composite Water Management Index (CWMI) report 2018 states that every year, 2 lakh people die in India due to inadequate access to clean water.[16] It is estimated that water pollution costs the country around $6.7–8.7 billion annually.[17] The CPCB has identified several stretches of rivers as critically polluted and initiatives like the National Mission for Clean Ganga (NMCG) aim to address this issue through improved waste management and pollution control measures.

**Soil Pollution:**

Any chemical or material that is out of place, present in soil at a higher quantity than usual and has a negative impact on any organism that is not the intended target is referred to as soil pollution.[18]

Sources include industrial waste, agricultural chemicals and improper disposal of waste.

**Types and Causes:** Soil pollution is caused by the deposition of pollutants from industrial activities, agricultural runoff and improper disposal of hazardous waste. Soil pollution results from the deposition of hazardous substances through industrial activities, agricultural practices and improper waste disposal. Major pollutants include pesticides, persistent organic pollutants and heavy metals including lead, arsenic, and mercury are examples of common contaminants.[19]

- **Industrial Waste:** Dumping of hazardous waste contaminates soil with heavy metals and chemicals.
- **Agricultural Chemicals:** Excessive use of pesticides and fertilizers leads to soil contamination.
- **Waste Disposal:** Improper disposal of household and industrial waste contributes to soil pollution.

**Permissible Limits of Pollutants:** Permissible limits for soil pollutants are established to protect soil quality and prevent harm to human health and the environment.

- Lead: 85 mg/kg (CPCB)
- Cadmium: 3 mg/kg (CPCB)
- Chromium: 75 mg/kg (CPCB)
- DDT: 0.1 mg/kg (CPCB)

Malwa region in Punjab has high levels of uranium in its groundwater, as acknowledged by the Indian government in 2012.[20]

**Present Status in India:** In India, soil pollution is widespread, particularly in areas with intensive agriculture and industrial activities. A report by the National Bureau of Soil Survey and Land Use Planning highlighted that about 30% of the total geographic area of India is affected by soil degradation.[21] Studies by the CPCB have shown elevated levels of heavy metals and pesticides in the soil of various regions, necessitating stricter regulation and monitoring.

**Noise Pollution:**

The existence of high or damaging noise levels in the surroundings is known as noise pollution. Major sources include traffic, industrial activities, urban development, loudspeakers and household instruments.[22]

**Types and Causes:** Noise pollution can be classified into occupational and environmental noise pollution. Occupational noise pollution affects workers in industries such as manufacturing and construction, while environmental noise pollution impacts the general public and is primarily caused by traffic, industrial activities and construction. Major sources include traffic, construction, industrial machinery and entertainment venues.

- **Traffic:** Vehicles, trains, and aircraft generate significant noise levels.
- **Construction:** Building activities produce high noise levels from machinery and tools.
- **Industrial Activities:** Factories and plants emit continuous noise from equipment and processes.
- **Urban Activities:** Loudspeakers, music concerts and public events contribute to noise

pollution.

**Permissible Limits of Noise:** Permissible noise levels are defined to protect public health and well-being. The CPCB and WHO set noise limits for different areas and times of the day.

- Outdoor living areas: 50-55 dB (decibels)
- School classrooms: 35 dB
- Hospital: 30 dB
- Industrial/Commercial areas: 70 dB
- Ceremonies: 100 dB

**Present Status in India:** In India, noise pollution is a major problem.[23] A study published in the Indian Journal of Community Medicine found that noise pollution in Indian cities is above the permissible limits, posing a significant risk to public health.[24] According to UNEP's Frontier 2022 study, Moradabad, Uttar Pradesh, is the second most noisy city in the world.[25] According to this report, Asansol and Kolkata (both in West Bengal), follow Moradabad when it comes to the top three noise polluted cities of India. The CPCB monitors noise levels and implements regulations to reduce exposure to harmful noise levels.

**Radioactive Pollution:**

Radioactive materials being present in the environment are referred to as radioactive contamination. Sources include nuclear power plants, improper disposal of nuclear waste, nuclear weapons and natural sources like cosmic radiation.[26]

**Types and Causes:** Radioactive pollution can result from accidents at nuclear power plants, improper disposal of radioactive waste and natural sources such as radon gas. Radioactive isotopes like uranium, thorium and radon are common pollutants. Major sources include nuclear accidents, improper disposal of radioactive waste and the use of radioactive materials in medicine and industry.

- **Nuclear Power plants:** Accidents and leaks release radioactive materials.
- **Medical Facilities:** Use of radioactive isotopes in diagnosis and treatment.
- **Natural Sources:** Radon gas and cosmic radiation.

**Permissible Limits of Radiation:** Permissible radiation exposure levels are set to minimise health risks and measured in millisieverts (mSv). The International Commission on Radiological Protection (ICRP) and national agencies like the Atomic Energy Regulatory Board (AERB)[27] in India provide guidelines.

- **Public Exposure:** 1 mSv/year (ICRP); 1 mSv/year (AERB)
- **Occupational Exposure:** 20 mSv/year (ICRP); 20 mSv/year (AERB)

**Present Status in India:** In India, radioactive pollution is a concern in areas near nuclear power plants and uranium mining sites. The Bhabha Atomic Research Centre (BARC) monitors radiation levels in these areas to ensure public safety.[28] Radiation pollution in India is generally controlled through strict regulations and monitoring by the Atomic Energy Regulatory Board (AERB). However, incidents of improper disposal of radioactive materials and natural radiation sources like radon gas still pose challenges.

### Biochemical/Biological Pollution:

When harmful biological agents are released into the environment, it is referred to as biological pollution. Sources include untreated sewage, agricultural runoff and invasive species.[29]

**Types and Causes:** Biological pollution is caused by the discharge of untreated sewage, agricultural runoff containing pathogens and the introduction of invasive species. Common pollutants include bacteria, viruses, parasites and invasive aquatic plants.

**Environmental Impact:** Fish and other aquatic life can die due to oxygen deprivation in water bodies brought on by biological contamination. It can also change the makeup of aquatic habitats and interfere with aquatic animals' reproductive cycles. Further, detrimental algal blooms can be driven by biological pollution, which can have much more detrimental effects on aquatic life and water quality.

**Present Status in India:** In India, biological pollution is a major concern, particularly in rural areas where access to sanitation facilities is limited. The introduction of corona virus in India can also be considered a biological pollution which had a devastating effect on the Indian population.

### Chemical Pollution:

The existence or escalation of chemical pollutants, which are either absent from nature or present in quantities greater than their background natural values in our surroundings is referred to as chemical pollution.[30] Major sources include industrial discharges, agricultural runoff and improper disposal of hazardous waste.

**Types and Causes:** Chemical pollution is caused by the release of industrial effluents, agricultural runoff containing pesticides and fertilisers and improper disposal of hazardous waste. Common pollutants include heavy metals such as lead, pesticides, pharmaceuticals and persistent organic pollutants.

**Present Status in India:** In India, chemical pollution is a significant issue, particularly in industrial areas. The Central Pollution Control Board (CPCB) monitors chemical pollution levels and enforces regulations to mitigate its impact.[31] A study by Lancet, has shown that exposure to lead is responsible for causing 9 lakh deaths per year globally.[3] This study has also shown that there is an upward trend in mortality due to chemical pollution in India.

### Conclusion:

Pollution is a multifaceted issue that poses significant threats to human health, ecosystems, and economies. In India, the burden of pollution is particularly severe, affecting millions of people and causing substantial economic costs. Addressing pollution requires comprehensive strategies that include stricter regulations, improved waste management practices and increased public awareness. By understanding the various types of pollution and their impacts, we can take steps towards creating a healthier and more sustainable environment for future generations.

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Chapter - 2

# Global Warming and Health: An Abridged Overview

*Manoj Kumar Sundarka, Krishna Kumar Lohani, Abhishek Kumar*

**Introduction:**

Global warming and climate change are increasingly relevant topics as all living organisms, including humans, are part of a vast ecosystem. We encounter various terminologies surrounding global warming, including climate change. We can name a few such as carbon emissions, carbon footprints, greenhouse gases, gaseous pollution, among others and their impact on health and the atmosphere. These terms have surfaced in various settings, most recently at the G20 summit in New Delhi. These instances have led us to question whether we truly understand the subject of climate change. As health professionals, we feel the need to explore this subject and understand its impact on health, as well as whether there are simple measures in place to reduce the impact. We believe that raising awareness of the subject is important. Our aim is to share the facts in simple terms with others who may be less familiar with this topic.

Climate change is being discussed on every platform, whether it be health, business, politics, environmentalism, education and more.[1] The reason is that everyone senses a slow-growing malignant situation that, if not addressed now, could heavily burden our next generations. Being aware of climate change, global warming and the consequences is crucial. It is a man-made problem and could ultimately threaten our existence. We have observed increasing climatic catastrophes, heat-related health hazards, an increment in viral diseases and mental illnesses in the past few decades due to accelerated global temperature rise. In preparing the manuscript, we sought help from available information in print, digital sources, informal discussions and seminars to gain a simple and clear understanding of the topic.

**What Does Global Warming Mean?**

The world heats up in response to the accumulation of carbon dioxide and other greenhouse gases in the atmosphere. Since the Industrial Revolution, the global annual temperature has increased by just over 1°C. Since 1981, the rate of temperature rise has more than doubled. Over the last 40 years, the global annual temperature has risen by an average of 0.18°C per decade.[2] Climate scientists have now concluded that we must limit global warming to 1.5°C by 2040 if we are to avoid a future marked by extreme droughts, wildfires, floods, tropical storms, health problems and other disasters collectively referred to as climate change.[2] Global warming also results in rising sea levels due to the melting of polar ice caps. This presents a danger to the survival of major coastal cities like Mumbai, New York City, Dubai etc. and could cost heavily in terms of the economy and lives.[1]

Climate change impacts human health in both direct and indirect ways. Extreme weather conditions

can directly cause injury, illness and even death. Indirectly, it could affect health through alterations to the environment. For example, worsening air pollution levels can have negative impacts on respiratory and cardiovascular conditions.[3] Increases in precipitation, storm surges and sea temperatures can lead to more water-related illnesses. Climate change can also affect food safety, exposing people to contaminated foods that can result in food borne illnesses.[3] Changes in temperature and rainfall can alter the survival, distribution and behaviour of insects and other species, leading to changes in infectious diseases. Climate change can adversely affect mental health and well-being.

**Concept of Greenhouse Gases:**

Certain gases prevent heat from escaping the atmosphere by absorbing radiation, thus keeping the planet warm. These gases include carbon dioxide, methane and nitrous oxide, collectively known as "greenhouse gases." Reducing personal greenhouse gas emissions can be achieved by adopting more sustainable energy sources such as wind, solar and nuclear power, as well as adopting energy-efficient practices like using LED bulbs and utilising solar panels to generate electricity for water and space heating. However, these measures can sometimes be expensive.

The United States Environmental Protection Agency (EPA) provides information on emissions of the main greenhouse gases. It shows that about 81% of the total greenhouse gases emitted in 2018 were carbon dioxide, 10% were methane and 7% were nitrous oxide.[4] The proportion further changed in 2020 (Figure 1).

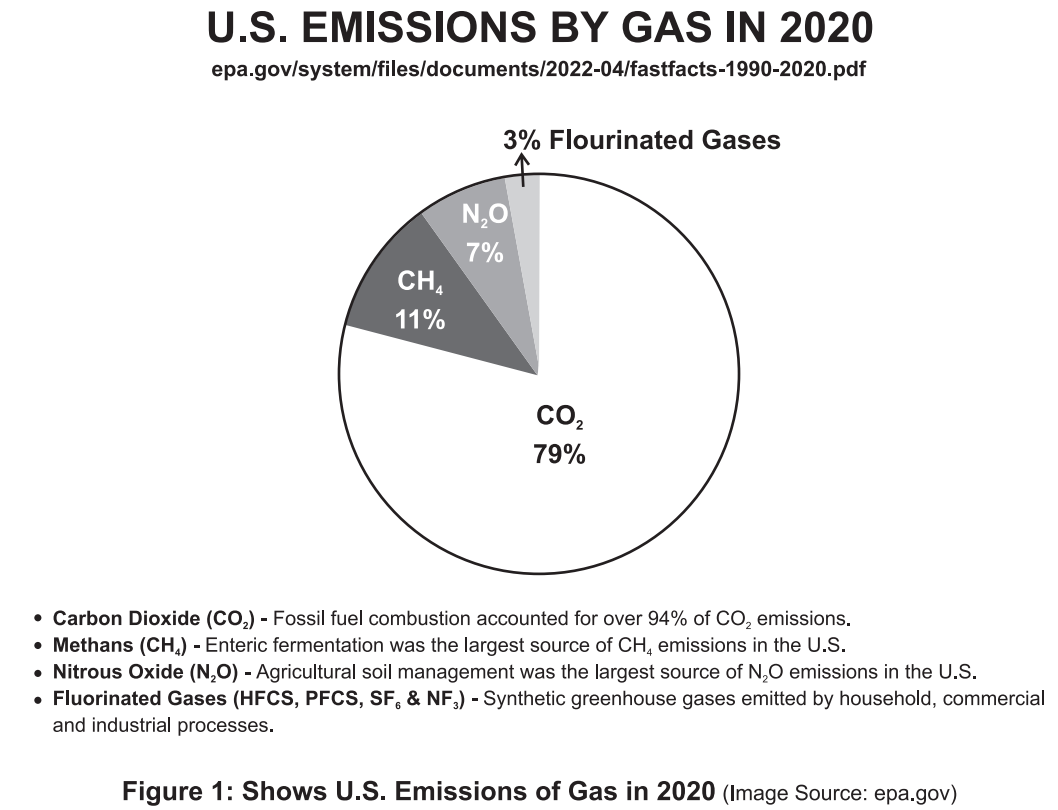



**Figure 1: Shows U.S. Emissions of Gas in 2020** (Image Source: epa.gov)

A carbon footprint can be made up of emissions of any of these greenhouse gases, but as $CO_2$ contributes the most and carbon is the chief component of it, for convenience, the term "carbon footprint" is used. Hence, carbon dioxide emissions, often referred to as carbon emissions, are the primary contributors to global warming.[4] Waste decomposition often produce methane, a potent contributor to greenhouse gas emissions. Adhering to the motto of "Reduce, Reuse & Recycle" can play a crucial role in curbing emissions. Therefore, we should gear towards efficient manufacturing processes to minimise waste.

**Concept of Carbon Cycle and $CO_2$ Movement:**

The carbon cycle is a natural system of recycling carbon atoms that exist among plants, animals, microbes, underground minerals and the atmosphere. Carbon plays a crucial role in enabling life on earth by forming complex molecules like DNA and proteins. In the form of carbon dioxide ($CO_2$), it plays a vital role in regulating the temperature of earth's atmosphere. As only a small number of atoms enter earth from space, our planet is considered a closed system, meaning it neither gains nor loses carbon. However, carbon is in constant motion.

"Carbon sinks" are places where carbon is stored away from the atmosphere, such as in rocks, sediments, the ocean and living organisms.[5] There are four natural processes in the carbon cycle: plant photosynthesis, decomposition plants, animals, organic matter, waste, etc., respiration by living organisms and plants and finally fossil fuel combustion. It is worth noting that even plant respiration adds $CO_2$ to the atmosphere when there is no sunlight.

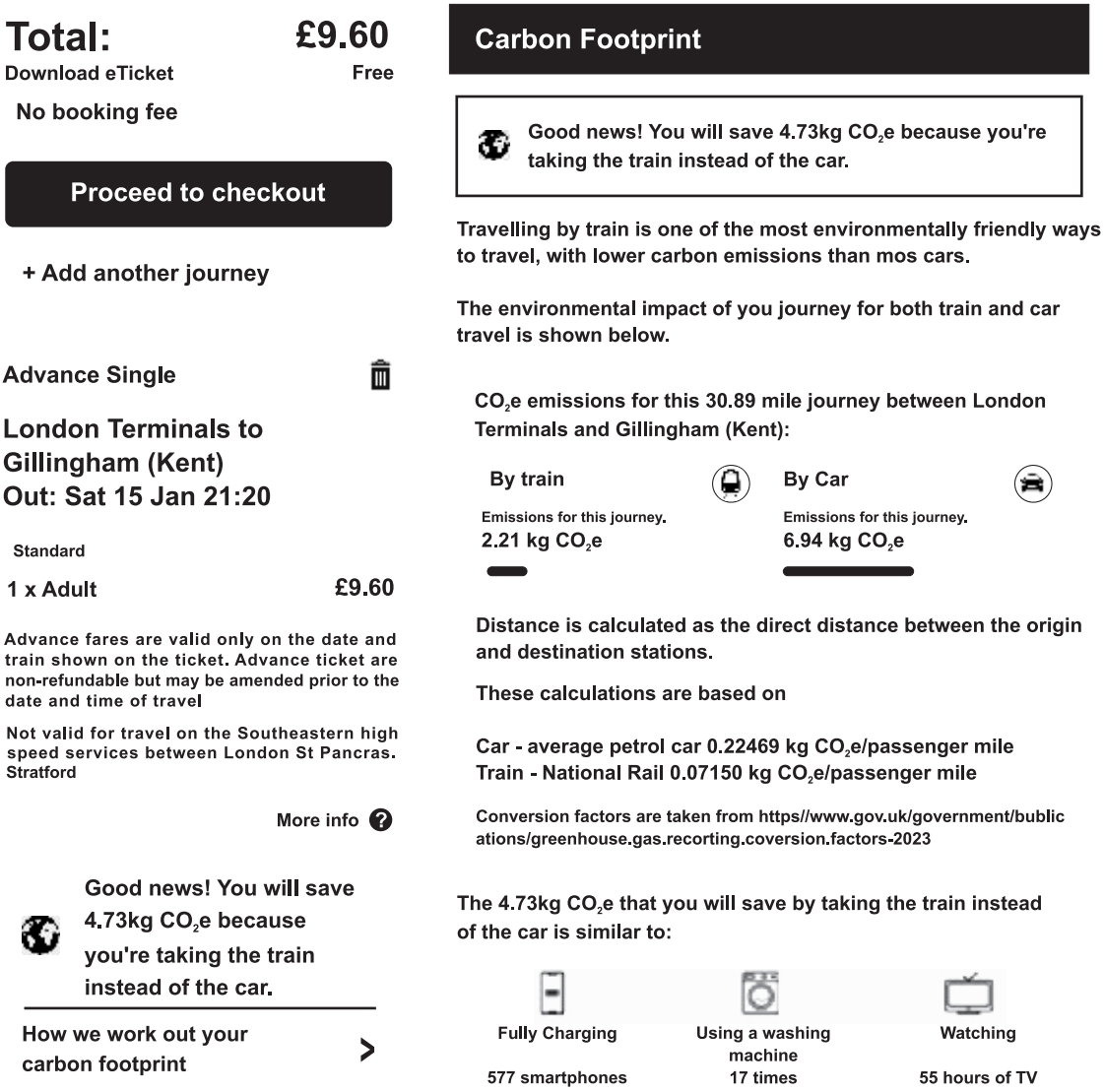
**Carbon Footprints:**

A carbon footprint is not made by one's foot but by their actions. The term refers to the total amount of carbon emissions and other greenhouse gases released into the environment. Almost every activity a person conducts emits some amount of carbon dioxide and leaves behind carbon footprints (Figure 2). A carbon footprint is relevant to climate change as it records the emission of greenhouse gases, which are largely caused by human production and consumption activities.

It is broadly categorised into two types: direct emissions or primary footprints and indirect emissions or secondary footprints. The primary footprint results from activities that have an immediate impact on the environment, e.g., burning coal for electricity production. The secondary footprint or indirect emissions, refers to emissions that are caused indirectly by certain activities related to human consumption.[6] When an individual buys a product, all emissions released into the environment due to its manufacturing, transportation and utilisation are considered indirect emissions. For example, using an electric kettle in London, which was manufactured in Japan, will need many steps to finally reach the user. On average, the size of a person's individual carbon footprint is proportional to their wealth.

A carbon footprint can be calculated by summing all the greenhouse gas emissions that had to take place for a product to be produced or for an activity to take place. Each activity and product have its own carbon footprint. A person's overall carbon footprint is the sum of all the products they buy, the activities they engage in and more. The unit used to quantify a carbon footprint is metric tonnes of carbon dioxide equivalent $CO_2e$. To demonstrate this concept, consider the following activities which could count towards one tonne of carbon footprint: driving 2,500 miles in an average gasoline

passenger vehicle, charging 120,000 smart phones, consuming 500 litres of diesel in an activity or eating 138 meat-based meals.[7] Globally, the average annual carbon footprint per person is close to 4 tonnes. To have the best chance of avoiding a 2°C rise in global temperatures, this number needs to drop to under 2 tonnes by 2050.[8]



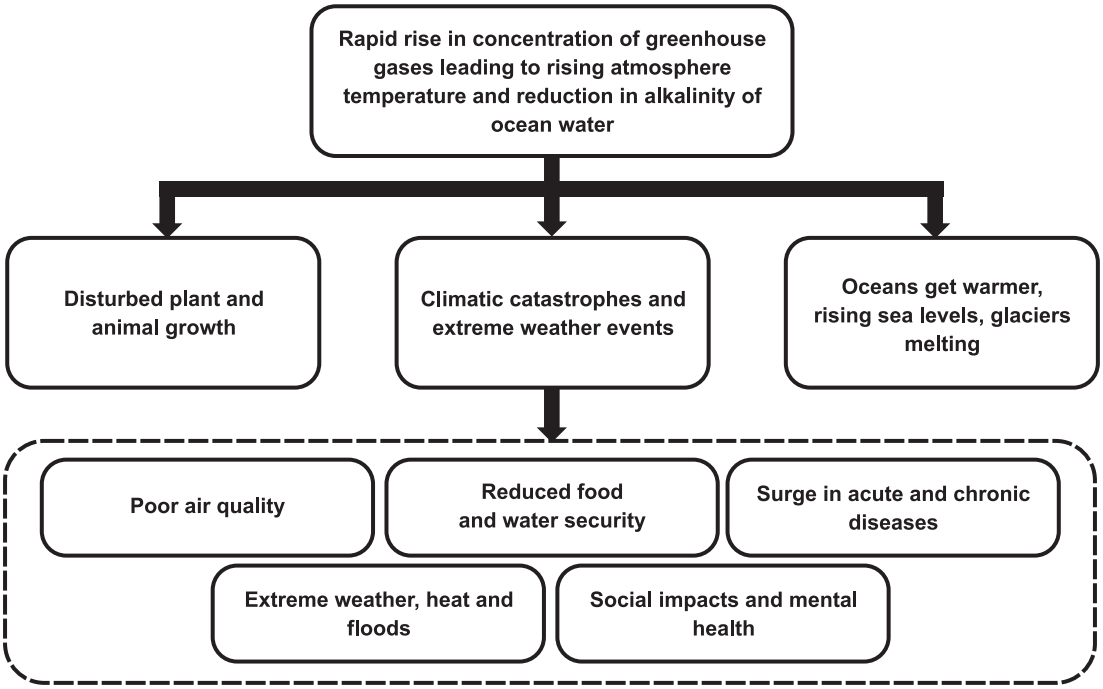

Doctors and healthcare professionals are leaders in society and have deep ties in the community. Their awareness of the subject and opportunistic preventative advice and intervention could go a long way. Even a small willingness to change could go a long way. For example, the author decided to travel by train instead of a car from London to Gillingham, a 45-mile journey, leading to a significant reduction in $CO_2$ emissions for this single activity. So, every step/action of change is rewarding.

**Figure 2: Travelling by Train vs. Car Carbon Emission Reduction.**

(Image Source: southeasternrailway.co.uk, MK Sundarka)

### Global Warming's Impact on Health and Climate:

Exposure to climate-related hazards can include biological, chemical or physical stressors and can differ in time, locations, populations and severity. These are referred to as exposure pathways. These threats can occur simultaneously, resulting in compounding health impacts (Figure 3). Climate change threats may also accumulate over time, leading to longer-term changes in resilience and health.[3]




These factors could be responsible for health hazards such as heat stroke, eye and joint disorders, the risk of cardiovascular and respiratory illnesses, an increased likelihood of waterborne diseases, salmonella in food, lengthened seasons and warmer winters. These conditions elevate the risk of exposure, infection, accidents, and the emergency of new bugs or diseases with changing pattems, posing a threat to human health.

**Figure 3: Global Warming- Impact on Health.** (Image Source: Tushar S. York, United Kingdom)

Rising temperatures will lead to an increase in heat-related illnesses and deaths, such as heat stroke. Wildfires and decreasing precipitation will lead to an increase in ozone and particulate matter, elevating the risk of cardiovascular and respiratory illnesses and deaths. Increased coastal and inland flooding expose populations to negative health impacts before, during and after events. Increases in water temperature will alter the timing and location of certain microorganisms, increasing the risk of waterborne diseases. Rising temperatures will also increase the prevalence of salmonella in food, lengthen seasons and create warm winters, increasing the risk of exposure and infection. Changes in exposure to climate or weather-related disasters cause or exacerbate mental health-related consequences, with greater risks for certain populations.[9]

Over the past two decades, deaths caused by the modern forms of pollution have increased by 66%, driven by industrialisation, fossil fuel combustion, uninhibited urbanisation, population growth and an absence of adequate national or international chemical policy.[3]

The National Environment Research Council in the UK published an article in 2018, 'The Planet Earth', stating particulate matter (PM) emissions are serious air pollutants that would cost the UK taxpayer £15 billion each year for treating related health conditions and other issues caused by PM.[10] Combustion of carbon-containing materials such as coal, biomass, wood, household and industrial waste, diesel, petrol and natural gas, which power our cars, heat our homes and generate electricity, produces PM emissions. Nowadays, most human activity requires electricity, including heating our homes without the combustion of wood, coal and natural gas, requires electricity.

Only solar, wind, wave and hydro renewables can produce clean electricity without PM emissions, but they may face challenges in meeting our ever-increasing demands for electricity. Nuclear energy can address this demand, but it is expensive and subject to controversy.[11] Adapting to a simpler lifestyle, reducing the use of unnecessary products, living close to nature, avoiding vehicles for short distances, sharing transport and reducing waste are helpful in decreasing both carbon and PM emissions in the atmosphere, either directly or indirectly.[3]

Climate change can affect human health by changing the severity, duration or frequency of health problems and by creating unprecedented or unanticipated health problems or health threats in places or populations where they have not previously occurred.[3]

**Strategies to Counter Climate Change:**

**At the Individual Level:** Simple actions such as a positive determination to minimise luxury, reduce consumption of fossil fuels, reuse consumables where possible and minimise waste can make a significant impact. Recycling items that could be reprocessed or reformed using energy-efficient methods is also crucial. For instance, using a bidet instead of toilet paper or opting for a cotton handkerchief instead of disposable tissues are examples of eco-friendly practices. Sharing a car for transportation to work or leisure activities directly reduces the carbon load. Healthcare professionals and doctors, being leaders in society, can play a vital role by raising awareness of environmental issues. Incorporating opportunistic preventive advice and interventions related to carbon reduction into medical practice can have a positive influence. Encouraging simple habits, such as asking patients to walk to the clinic rather than drive when feasible, not only reduces their direct and indirect carbon footprint but also promotes cardiovascular and metabolic health. Although these actions may seem small individually, their collective impact can be substantial (Figure 2). Organizing small educational groups to increase awareness and encourage simple practices that benefit the climate and the planet is also valuable.

**At Organisational, National & International Levels:** To address and manage environmental concerns on a larger scale, there is a need for effective mechanisms to reduce $CO_2$ emissions. This can be achieved either by directly capturing $CO_2$ that has already mixed in the atmosphere or by intercepting released $CO_2$ before it mixes in the air. If stakeholders are unable or unwilling to reduce their carbon footprint, a viable alternative is to balance the input and output of $CO_2$ in the atmosphere to prevent further global warming. Achieving a sustainable future requires a collective understanding of the need to minimize greenhouse gases, equating to reducing the carbon

footprint.[6] This involves efforts to reduce industry exhaust, fossil fuel burning and other human activities that contribute to $CO_2$ emissions. The Paris Agreement, signed by 195 nations in December 2015, is a significant global initiative aimed at strengthening the response to the threats of climate change and global warming.[6]

**Carbon Capture and Storage (CCS) and Direct Air Capture (DAC):**

Global warming is predominantly attributed to the significant quantities of carbon dioxide ($CO_2$) released into the atmosphere from industrial processes. To mitigate this, it is critical to intercept and sequester these greenhouse gases prior to their atmospheric release. CCS is the trapping of carbon emissions after they have been emitted but before they enter our atmosphere. Direct air capture, as the terminology suggests, refers to the process of capturing $CO_2$ directly from ambient air or from a mixture of air combined with flue gas exhaust already present in the air.[5]

Both CCS and DAC methodologies necessitate an additional step post-capture, the sequestration of the captured $CO_2$. This involves compressing the $CO_2$ and injecting it under pressure into depleted oil and natural gas reservoirs, both subaquatic and terrestrial. Such sequestration is deemed permanent due to the lack of pathways for the $CO_2$ to return to the atmosphere.[11] An alternative approach is the permanent sequestration of $CO_2$, either subterraneous or at the surface, via an accelerated mineral carbonation process. There are innovative techniques to use these minerals in making roads and highways. The Intergovernmental Panel on Climate Change (IPCC) identifies mineral carbonation as an optimal method for enduring carbon sequestration due to its enhanced security profile.[12]

Current annual global $CO_2$ emissions stand at approximately 40 gigatonnes. Sincere and genuine efforts are needed to combat climate change, prioritising public health, climate equity and environmental justice through the mitigation of air and water pollution. While nature plays a role, in its natural state, mineral carbonation is a slow process, taking thousands to millions of years to significantly reduce the rising $CO_2$ levels from man-made emissions. Therefore, a scalable, fast and reliable system is needed to address this issue.[11] The IPCC has set clear targets, emphasising the need to halve $CO_2$ emissions by 2030 and aim to remove at least 10 gigatonnes per year by 2050.[12] The World Bank highlights incentives that encourage emission reduction, such as removing fossil fuel subsidies, introducing carbon pricing, increasing energy efficiency standards and implementing auctions for the lowest-cost renewable energy.[4] A significant method for reducing emissions involves the implementation of strict government laws globally, including taxing companies for their emissions. However, governments may express concerns about the potential negative economic impacts of such measures to protect the environment.

**Carbon Neutrality, Net Zero and Carbon Offsetting:**

Being "carbon neutral" signifies that an individual, business or national economy emits the same amount of carbon dioxide into the atmosphere as they offset through various means, such as direct air capture or reforestation. The concept has evolved into official 'net-zero' initiatives, where the goal is to ensure that the amount of greenhouse gases added to the atmosphere is less than or equal to what is removed.[13] Carbon offsets provide a mechanism for individuals and businesses to invest in projects that contribute to carbon reduction and obtain "carbon credit" certificates. One carbon credit typically represents the removal of one metric ton of carbon dioxide.[14] Examples of carbon offset projects include tree planting, wetlands restoration and farmland management.

These initiatives play a crucial role in addressing climate change by compensating for greenhouse gas emissions, particularly in sectors where significant emission reduction is challenging.[1]

However, the term "eco-colonialism" or "carbon colonialism" describes a situation where a more developed country imposes environmental policies on a less developed country, often at the expense of the latter's natural resources. This phenomenon can occur not only internationally but also within the same country among different geographic regions.[15]

To tackle these global concerns, various efforts are being made at different levels. An emerging technology from Clean Air Tech Limited in the United Kingdom, known as the ZAP-C3 Reactor uses the KANTA process and offers a promising solution. This innovation combines direct air capture and accelerated mineral carbonisation, enabling the capture and aboveground permanent sequestration of $CO_2$. Additionally, it captures particulate matter and reduces other pollutants in air and flue gas exhaust while producing sustainable products, all in a single step. The technology is patented and ongoing efforts are underway to validate its claims at scale.[11]

**The Impact of Consumption:**

Embracing a plant-based diet holds significant potential for contributing to environmental well-being. To sustain the global population of approximately 8 billion people 7.884 billion in 2021, an estimated 7% of the planet's landmass would be required for food production. However, the current reality is that we are utilizing an immense 38% of the planet's landmass for this purpose. This disproportionate use is primarily due to the greater land requirements for meat production compared to plant-based production. The maintenance of each acre of land necessitates energy, resulting in carbon emissions through various activities and movements.[16]

On a national level, carbon footprints vary significantly, with Malawi at the bottom end and the USA at the other. For instance, in the USA, the average annual carbon footprint per person is around 20 tonnes, contrasting starkly with Europe’s 10 tonnes and India’s 1 tonne. The honest evaluation of our approach is a challenging question. While the subject has gained attention across various platforms, including media, political discussions, government policies, NGOs and public meetings, the practical concern is that reducing modernisation, advanced developments and production could pose a threat to the economy. However, it is crucial to balance this harsh reality with the sacrifice necessary for a healthier climate in the future. Individuals need to decide their demands and what to pass on to future generations. Every individual is responsible for their consumption of products and should be willing to reduce and change their lifestyle. This collective effort is crucial for saving the planet and should not solely rely on the government. India, for instance, has set a target of achieving net-zero by 2070.[1] The triad of pollution, climate change and biodiversity loss are the key global environmental issues of our time. These issues are intricately linked and solutions to each will benefit the others.

**Conclusion:**

Climate changes have significant impacts on our health, wealth and surroundings. Carbon dioxide plays a vital role in our atmosphere by helping regulate earth's temperature. Each individual actively contributes to their carbon footprint, whether directly or indirectly. Major contributors to our carbon footprint include transportation, electricity, home heating, home cooling and increasing affluence, which leads to greater production. The need of the hour is to actively reduce our carbon footprints. The increasing temperature of the atmosphere and the planet raises many health concerns.

Climate scientists urge limiting global warming to 1.5°C by 2040 to avoid catastrophic consequences like extreme weather events. Global warming also results in rising sea levels, threatening major cities in coastal areas. Various efforts are underway worldwide to combat the ongoing harm to our planet caused by this man-made issue. Whether these attempts are genuine or merely superficial is a different discussion, but various technologies, methods and government policies aim to control the magnitude of this threat. Reducing waste production, reusing materials and enhancing recycling are all helpful strategies. Adopting a plant-based diet goes a long way in supporting the planet with sensible use of landmass and low emissions of greenhouse gases. The goal should be achieving zero emissions rather than settling for net-zero carbon emissions to preserve the planet's health. Globally, the average annual carbon footprint is close to 4 tonnes per person. The rapid accumulation of $CO_2$, the major contributor to greenhouse gases, is causing global warming, leading to climate catastrophes and various health hazards. Changing our practices by recycling, altering our diets to reduce meat consumption, cutting down on unnecessary consumption and promoting reforestation are crucial steps. Switching to renewable energy sources, conserving water and planting trees are favourable strategies. The three golden words to keep in mind are to reduce, reuse and recycle. While various technologies, methods and government policies aim to control the size of this threat, the ultimate goal should be to achieve “zero emissions” rather than settling for “net-zero” or “carbon offsetting”. Every individual is responsible for their consumption and should be willing to change their lifestyle to prevent further destruction of our lovely planet and secure its health and survival.

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Chapter - 3

# Climate Change and Cardiovascular Health

*Vitull K Gupta, Meghna Gupta, Manpreet Singh Brar*

**Introduction:**

Climate change (CC) is said to be the greatest existential challenge to planet earth, environment, economy and human health. World Health Organisation (WHO) has sounded an alert that CC is a fundamental threat to human health, affecting all aspects of natural and human systems both directly and indirectly, increasing the risk of noncommunicable diseases (NCDs), infectious diseases, health emergencies and deaths along with impacting health workforce and infrastructure with reduced capacity for provide universal health coverage (UHC). The Intergovernmental Panel on Climate Change's (IPCC) Sixth Assessment Report (AR6) suggests that 3.6 billion people already residing in highly susceptible areas to CC endure the harshest health impacts especially low-income countries and small island developing states (SIDS) despite contributing minimally to global emissions. It further concluded that it will be harder to adapt with increased global heating as the risks of CC is appearing faster and will become severe, sooner than previously expected, with 15 times higher death rate from extreme weather events than in the last decade in vulnerable regions.[1]

**What is Climate Change?**

Climate change and global warming are generally used interchangeably but global warming means only increase in temperature of earth's surface and oceans. CC refers to both global warming and its effects on earth's climate and weather patterns. CC is caused by increase in greenhouse gases like carbon dioxide ($CO_2$) from deforestation, fossil fuel burning and various industrial processes, methane ($CH_4$) from agriculture, landfills and natural gas production, nitrous oxide (NOx) from industrial and agricultural activities, combustion of fossil fuels, solid waste and fluorinated gases. CC has increased the intensity and frequency of extreme weather events like droughts, hurricanes, heavy rainfall and heat waves. Melting ice caps and glaciers has caused an increase in sea levels threatening coastal population. Marine life has been affected by ocean acidification caused by increased concentrations of carbonic acid due to increased levels of $CO_2$ in the atmosphere. CC is threatening biodiversity with changing habitats and species extinction. CC as WHO has warned is impacting human health like never before with severe economic consequences. Worldwide in 2019, the emission of anthropogenic greenhouse gases was equivalent to 59 billion tonnes of $CO_2$. Of these emissions, $CO_2$ constituted about 75%, methane about 18%, nitrous oxide about 4% and fluorinated gases constituted 2%.[2]

## Global Warming:

Climate cycled through ice ages for millions of years with average global temperature varying between 1 °C warmer and 5–6 °C colder and stabilized in the present interglacial period starting 11,700 years ago. Thermometer records of temperature began to provide global coverage in about 1850 and from that time to 1970s there was little net global warming because the warming effect of greenhouse gases was neutralised by cooling or global dimming effect by the presence of sulfate particles, hanging in atmosphere as aerosols acting as tiny mirrors reflecting sunlight. They also acted as nuclei to make water droplets condensing into clouds reflecting incoming sunlight back into space. But after 1970, with increased level of greenhouse gases along with decreased sulfur particles led to a marked increase in global temperature.[3]

Worldwide data documented surface temperature increase of about 0.2 °C per decade and average increase of 1.15 °C [1.00–1.25 °C] in surface temperature was recorded from 2013 to 2022 as compared to 1850-1900. The IPCC, Sixth Assessment Report (2023) projected that by 2100 global warming is very likely to reach 1.0-1.8 °C if there is very low emission of greenhouse gases, 2.1-3.5 °C with intermediate emissions and an increase by 3.3-5.7 °C is expected if the emission of green house gases is very high. In 2015, under Paris Agreement, nations pledged to keep global warming well under 2 °C, but limiting global warming to 1.5 °C will require to reduce the emissions by half, till 2030 and achieving net-zero emissions by 2050.[4,5,6]

In this chapter we will be focusing on CC and cardiovascular diseases (CVDs).

## Climate Change and Cardiovascular Diseases:

WHO and The Lancet Countdown International Collaboration on Health and Climate Change has outlined the effects of CC on human health through extreme weather events, extremes of temperature, air pollution, malnutrition, infectious diseases and other factors such as migration, displacement, psychological and social factors.[7,8]

In this chapter we will review as to how CC affects cardiovascular (CV) health beyond air pollution as effects of air pollution on CVDs have been discussed in other specific chapters.

Vulnerability and extent of heat exposure determines the impact of increasing temperatures on human health. Vulnerability means susceptibility to be adversely affected by CC, lack of capacity to cope, adapt and susceptibility to harm. Vulnerability may change and differs across societies, communities, countries and regions. Vulnerability may be modulated by several factors like age, air conditioning, health expenditure and prevalence of comorbid diseases like NCDs and psychiatric disorders.[9]

Extremes of temperature, especially excessive heat is the cardinal component of CC which affects virtually all body organ systems and is responsible for about 40% of all heat-related deaths in warm season.[10] Analyses of daily death rates have documented association of increased CVD mortality with both high and low temperatures.[11] Well established association has been observed between extreme temperatures and CV mortality, myocardial infarction (MI) and hospitalization.[12] High temperatures in 2019, lead to 93000 deaths from CVDs and >2 million disability-adjusted life years (DALY).[13] Data suggested that between 1995 and 2020, heat-related deaths in the elderly (>65 years) more than doubled with the elderly dying of CV events more frequently than of other heat-

related causes. Research published in Circulation 2022 included adults 20 years or older from 3,108 US counties observed increase in extreme heat events due to CC.[14]

Results showed association of extreme heat with about 5,958 additional CVD deaths (95% CI, 1847-10,069) during 2008 and 2017 summer months and 0.12% (95% CI, 0.04%-0.21%; P =.004) increase in the monthly CVD death rate was observed with each additional day of extreme heat per month. Study concluded that higher adult CV mortality rates were associated with extreme-heat days in the contiguous US between 2008 and 2017 and as extreme-heat events increase, CV mortality may continue to increase.[15]

Chen et al analyzed KORA Myocardial Infarction Registry data and observed increased relative risk (RR) of heat-related MI in Augsburg, a German city from 0.93 (95% CI, 0.78–1.12) in 1987 to 2000 to 1.14 (95% CI, 1.00–1.29) in 2001 to 2014, with similar observation for recurrent and non-ST-segment elevation MI. Patients of diabetes mellitus (DM) and hyperlipidemia showed greater and increased vulnerability to heat-related MI risk than other groups.[16] CC is leading to destructive windstorms and post hurricane mortality data shows significant impact with CV mortality representing about 11% of deaths, followed by deaths related to drowning and trauma or injuries.[17] Hospitalization records a week after landfall of Hurricane Katrina in Orleans Parrish in 2005 showed increased CVD rates from pre-Katrina baseline incidents of 7.4±2.7 and 7.1±2.8 cases/d per 10000 people for black patients and white patients to 26.3±23.7 and 16.6±11.7 cases/d per 10000 people ($P$<0.001) for black patients and white patients, respectively.[18] After Hurricane Sandy in 2012, increased MI incidence and mortality was observed. On analysis of data from highly impacted areas by Hurricane Sandy and regional data preceding the hurricane from the past 5 years, a 22% increase in incidence of MI and a 31% increase in 30-day mortality from MI was observed.[19]

Agewall et al showed increased CV risks with both hot and cold temperatures. Temperature drop from 5°C to -5°C resulted in 22% increase in death from ischemic heart disease (IHD) (RR, 1.22; 95% CI, 1.07-1.38) and 19% increase in CV-related death (RR, 1.19; 95% CI, 1.04-1.36). In patients with pre-existing CVD at baseline, temperature increase from 15°C to 24°C resulted in 25% (RR, 1.25; 95% CI, 1.12-1.39) increased risk of death from CVD and 30% (RR, 1.30; 95% CI, 1.10-1.53) risk of death from stroke.[20] CC not only influences the temperatures but also adversely influences other environmental conditions through natural disasters like wildfires influencing air pollution. Ample scientific data exists to show association of particulate matter (PM) with CVD morbidity and mortality.[21] A Russian study in 2010 showed that air pollution from wildfires associated with high temperatures had in excess of an additive effect contributed to >2000 deaths and concluded that interactions between wildfire air pollution and high temperatures should be considered in risk stratification of health effects of CC.[22] A nationwide study from Italy observed that heat related mortality tripled with high levels of fine PM as compared to low levels of fine PM suggesting high risk of heat-related mortality in association with high levels of $PM_{10}$ (particulate matter with aerodynamic diameter ≤ 10 µm) and ozone.[23] Increased CV mortality risk was observed with association of air pollution and heat exposure, CV mortality risk at low $PM_{10}$ levels was observed to be 7.04% (95% CI: 0.51–9.69) and CV mortality risk increased by 13.69% (95% CI: 1.84–26.91) at high $PM_{10}$ levels.[24]

### Pathophysiological Mechanisms:

Human body temperature is regulated by several mechanisms of ventilation dissipating heat like direct contact with a surface, evaporation by sweating, radiation and respiration, exhaling warm air and inhaling cool air assisted by several neurohormonal factors. Among humans, wide variation in capacity to tolerate heat stress has been documented.

Figure 1 shows the factors contributing to the CV risk of CC including global warming, heat events, air pollution, age, socioeconomic factors and health status.[25]

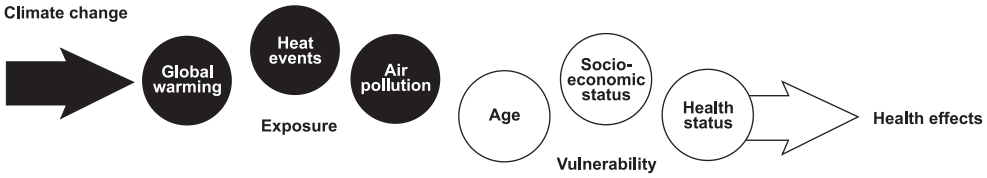


**Figure.1: Factors Contributing to the CV Risk of Climate Change**[25]

Global warming causes increased frequency of extreme heat events, increasing CV risk. CV risk is further increased by air pollution, age of individual, low socioeconomic status of an individual and health status, along with co-morbidities make an individual vulnerable to increased CV risk because of CC. CC also adversely affects agricultural production, food security and political stability, particularly among vulnerable communities and regions and adversely affects health of population including CV health.

CC can significantly influence CV system by various contributing factors influencing CV risk through direct and indirect mechanisms. Direct effects are induced by heat waves, air pollution and extreme weather or disaster events and indirect effects are induced by changes in diet and nutrition, physical inactivity, infectious diseases and socioeconomic factors. (Figure 2)[9]

Several pathophysiological mechanisms[9, 26, 27, 28] have been proposed to explain the associations between CV events and heat exposure, the signature component of climate change. Conventional heat-related illnesses include muscle cramps, heat exhaustion and heat stroke. Heat exposure, increases the core body temperature and regulatory mechanisms of body tries to lower the core body temperature by increasing cutaneous blood flow and sweating under the influence of the hypothalamus, body's thermostat by activating the autonomic nervous system. Sympathetic nervous system is activated to maintain cardiac output by increasing the heart rate and stroke volume. Blood pressure may decrease because of peripheral vasodilatation and dehydration. Dehydration because of sweating in turn may cause haemoconcentration and a prothrombotic state because of decrease in plasma volume, increase in concentration of platelets, red blood cells and blood viscosity. Studies have shown that heat exposure or heat stress induces release of cytokines like interleukin 1 and interleukin 6, influencing the local and systemic inflammatory responses which may lead to endothelial dysfunction. Infections further increase the heat-related inflammatory responses. All these mechanisms together lead to prothrombic state and ischemia increasing risk of CV events as well as worsening of pre existing CVDs. Increase in total cardiac

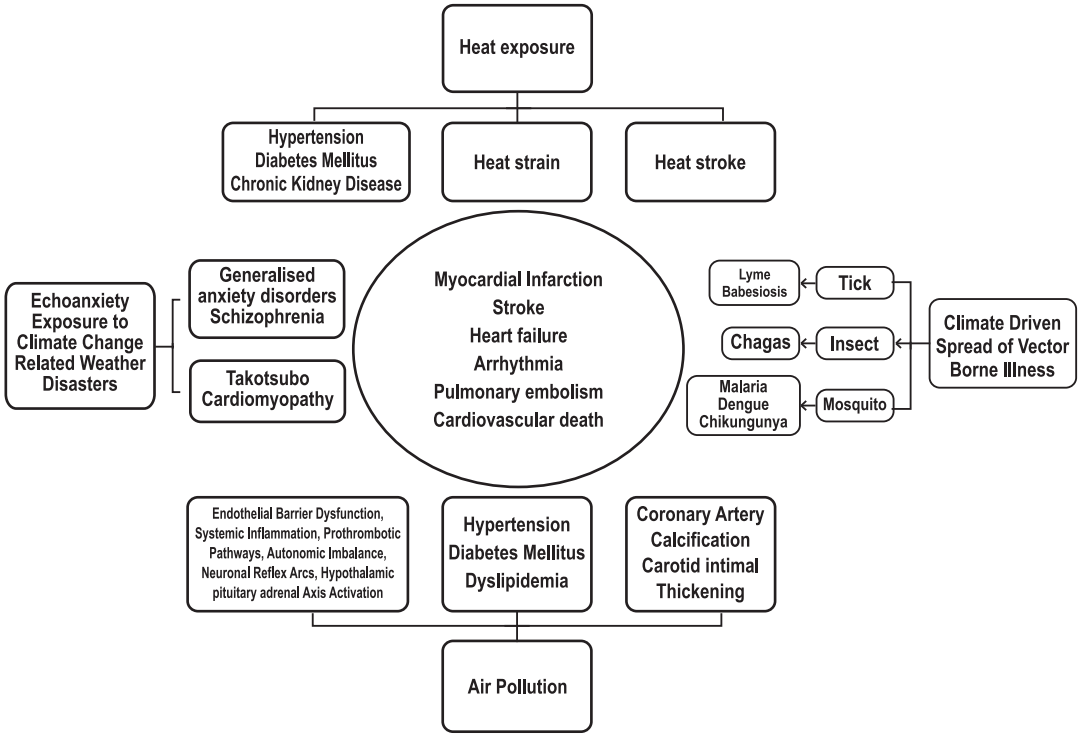


**Figure 2: Climate Change and Cardiovascular Disease.**[9]

output because of increased heart rate and myocardial contractility, lead to increased myocardial $O_2$ demand which may cause myocardial ischaemia in vulnerable population like the elderly and people with pre-existing CVDs.

Certain drugs like diuretics and beta-blockers can interfere with thermoregulation and heat dissipation further increasing the incidence of CV events. More over cutaneous vasodilation under the influence of heat stress reduces peripheral vascular resistance causing redistribution of blood volume towards the skin resulting in compensatory increased cardiac output and myocardial contractility causing increased myocardial oxygen demand, predisposing to ischemic events in individuals with limited coronary flow reserve and disseminating intravascular coagulation. Combined together, these responses may predispose an individual, more so the vulnerable population for greater risk of adverse CV events and worse outcomes during extreme heat exposure.

Figure 3 shows the pathophysiological mechanisms in response to extreme heat and relationship between extreme heat and adverse CV outcomes.[29]

In heatstroke related deaths, heart failure (HF) has been implicated as an independent prognostic factor because patients lack the ability to compensate for the heat exposure related increased CV demands like increased cardiac output and strain, peripheral oedema and arrhythmias. More over increase in levels of predictors of HF prognosis and severity, the B-type natriuretic peptide and C-reactive protein were found to be associated with higher temperatures.[30]

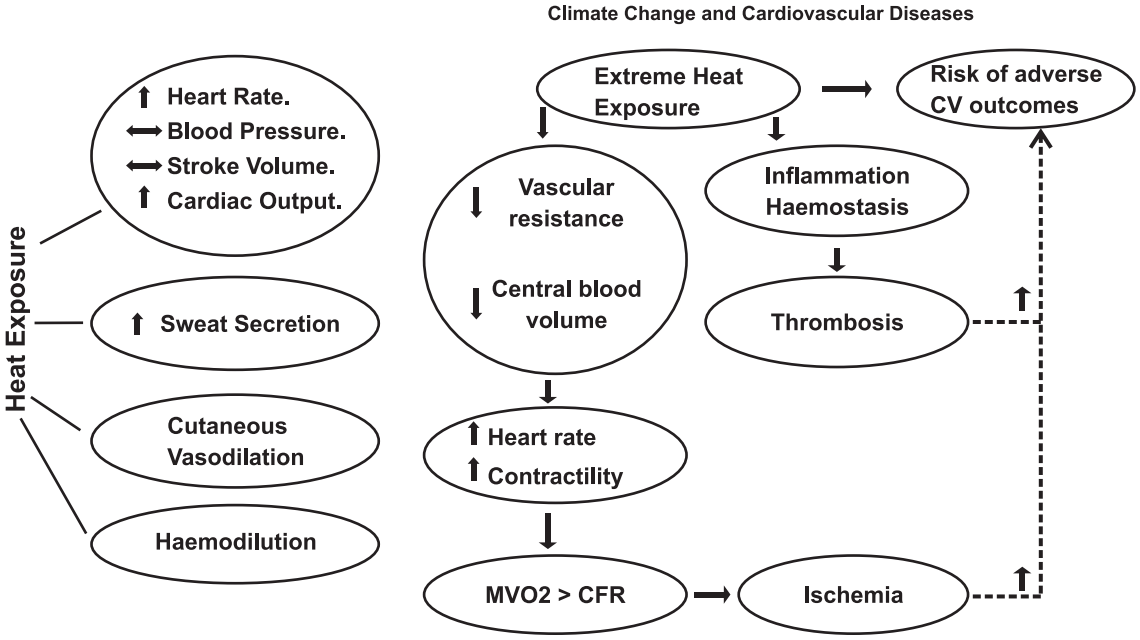


**Figure 3: Pathophysiological Relationship Between Extreme Heat and Adverse Cardiovascular Outcomes.**[29]

**Management of Climate Change related CVDs:** [9, 25, 26, 27, 28]

Management of CC related CVDs requires an integrated approach involving individual preparedness, public health interventions, healthcare system resilience and adaptation, community engagement and policy and regulatory measures. Management of CC related overall public health outcomes and particularly CV health can be addressed by considering both the environmental and health aspects of CC.

**Individual Measures:** Individual measures include behavioural changes, health monitoring and preparedness. Protection from heat by seeking shade or air-conditioning is an important measure for individual protection. Air conditioning can rapidly reduce heat but is relatively expensive and people in low and middle income countries can't afford it. Moreover substantial electricity is required which intern is generated by fossil fuels adding to CC leading to a vicious cycle. Alternatively, people can use electric fans, cold showers or baths, applying cold cloth to the body. Sufficient hydration and avoiding strenuous activities during peak heat is protective. Health monitoring is an important protective measure including regular CV health check-ups especially in predisposed individuals with comorbidities and CV risk factors. Effective management of patients at risk as well as pre existing CVDs include adjustments in medication, awareness about heat-related risks of interactions of medications, loss of effectiveness, adverse side effects especially sweat reduction by medications should be stressed. Emergency kits with necessary medications, cooling materials and water are useful individual measures for CV risk protection.

**Public Health Interventions:** Public health interventions include heat action plans, air quality improvement and promotion of clean energy. Implementation of public alerts and heat waves

warning systems, establishment of heat shelters and air-conditioned centers for vulnerable people, provision of clean drinking water in public places, regular air quality monitoring and issue of public health advisories, policies to reduce emissions from industries and vehicles and promotion of renewable energy sources are important public health interventions for management of CC related CVDs.

**Health Education and Awareness:** Health education and awareness include public campaigns to educate people about the risks of heat and CC on CVDs and measures to mitigate them. Lifestyle advice promoting CVD risk factors control, heart-healthy behaviours like balanced diets, weight reduction, regular exercise, moderation of alcohol intake and cessation of smoking.

**Healthcare System Adaptations:** Healthcare system adaptations include infrastructure resilience, building training and capacity along with access to health care. Health care facility upgrading with backup systems to ensure capability to handle extreme weather events related CV health issues. Training and capacity building by educating health care providers for effective preventive and management strategies for CC related CV issues and emergency preparedness by developing and practicing emergency response plans for extreme weather CV events. Easy, universal and equitable access to health care can be provided by expanding telemedicine services and mobile clinics during extreme CC related CV events especially for underserved and vulnerable populations.

**Community Actions:** Community actions are largely focused to mitigate CC by effective urban planning, increasing green spaces and affordable and efficient public transportation. Such community actions include planting trees to increase greenery, reducing heat islands and improving air quality. Installation of green roofs and walls will provide cooling effects and air purification. Promotion of affordable and easily accessible public transport will help reduce vehicle emissions. All round health benefits with mitigation of CC can be earned by developing safe biking and walking facilities to encourage physical activity and reduce reliance on vehicles. Developing community support networks, neighbourhood watch and local health initiatives will help to watch health status of vulnerable people during extreme weather events and promote local health initiatives focusing on heart health and climate change awareness.

**Policy and Regulatory Measures:** Policy and regulatory measures include forming and implementation of environmental regulations, climate action plans with international cooperation. Emission standards should be strictly enforced for industries and vehicles and policies to promote the use of renewable energy sources should be encouraged and implemented. International, national and local climate action plans should be developed and implemented to address the public health impacts of CC. Allocation of adequate funds for research on the health impacts of CC and the development of mitigation strategies should have prime focus. Such mitigation strategies may not be successful without international cooperation, global agreements and knowledge sharing like the Paris Agreement to reduce global greenhouse gas emissions.

**Conclusion:**

Climate change is a rapidly growing threat to human health including CV health around the world. CC related CVDs can be prevented. This chapter reviewed the global threat of CC, its impact on CV health, factors contributing to the CV risk of CC, pathophysiology, mechanisms and management of

CC related CVDs. Currently, the combined effects of global warming, air pollution, individual age, socioeconomic status and health status are resulting in an increase in heat-related morbidity and mortality, which is expected to increase in the coming decades. Evidence suggests that CC contributes significantly to CVD risk in population and exacerbation of pre existing CVD in vulnerable population, highlighting the urgent need to implement integrated CC action plans including individual preparedness, public health interventions, healthcare system resilience and adaptation, community engagement, policy and regulatory measures. Management of CC related overall public health outcomes and particularly CV health can be addressed by considering both the environmental and health aspects of CC at national and international levels, emphasizing the urgency to implement policy measures to achieve the Paris Agreement. CC also impacts agricultural production, food security and political stability, particularly among vulnerable communities and regions. Large research gaps in quantifying the impacts of CC on CV health remain and given the complex and multidisciplinary nature of the grave planetary problem, we are only going to benefit from interdisciplinary collaborations of all stakeholders. For CC the slogan should be 'Now or Never'.

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Chapter - 4

# Air Pollution and Non-Communicable Diseases: An Overview

*Gurpreet Singh Wander, Abhishek*

**Introduction:**

Air pollution is a significant factor contributing to respiratory diseases and related infections. It ranks as the second leading risk factor for disease burden in India, surpassed only by malnutrition.[1] The challenge that air pollution poses to human and environmental health is substantial and global in scale. It includes emission of greenhouse gases through the combustion of fossil fuels for energy, industrial processes and transportation, which are the primary drivers of human-induced climate change. This combustion, coupled with emissions from vehicles, heating and lighting, releases a variety of pollutants into the atmosphere.[1] These pollutants, which include nitrogen oxides (NO), carbon monoxide (CO), black carbon, sulphur dioxide ($SO_3$), ozone ($O_3$), methane and particulate matter (PM), not only impact the Earth's ecological systems but also contribute to the burden of chronic and non-communicable diseases (NCDs), leading to significant economic and societal costs.[2] Air pollution can trigger immediate symptoms upon exposure, such as coughing, tearing, difficulty in breathing and angina. However, it also has the potential to inflict long-term, more subtle damage. Individuals often remain unaware of the detrimental effects of prolonged exposure on their health or the exacerbation of their existing medical conditions.[1] The polluted air, entering the body through the respiratory tract, can have systemic effects, potentially harming various organs. This emphasizes the pervasive nature of air pollution and its far-reaching impact on human health. With this overview, this chapter will provide a succinct summary of air pollution and its effects on NCDs in India.

**Components of Air Pollution:**

The World Health Organization (WHO) has recognized climate change as one of the most significant health threats of the 21st century and air pollution as the single most substantial environmental health risk.[3] Air pollution is characterized as any substance present in the air that could potentially harm humans, animals, vegetation or materials.[3] India, in particular, experiences one of the highest levels of exposure to air pollution worldwide.[1] The primary constituents of air pollution encompass ambient PM pollution, household air pollution and to a lesser degree, ozone in the troposphere, which is the atmosphere's lowest layer.[1] The primary sources of ambient PM pollution in India comprise various factors such as thermal power production relying on coal combustion, emissions from industrial activities, construction projects, brick kilns, vehicles, road dust, biomass burning in residential and commercial areas, waste burning, agricultural stubble burning and the use of diesel generators.[1] Household air pollution primarily stems from the burning

of solid fuels for cooking and to a lesser extent, heating.[4] These fuels mainly include wood, dung, agricultural residues, coal and charcoal. Ground-level ambient ozone is generated when nitrogen oxides and volatile organic compounds, emitted from transport vehicles, power plants, factories and other sources, react under sunlight.[1] Rapidly developing regions face the dual challenge of exposure to both ambient and household air pollution.[5] There has been an increasing focus on addressing air pollution in India by the government and other stakeholders in recent times. Researchers also project a continuing increase in ambient PM pollution in India in the foreseeable future.

**Estimation of Exposure to Air Pollution:**

PM is typically classified by its size or aerodynamic diameter; $PM_{10}$ denotes particles with a diameter of less than 10 μm; $PM_{2.5}$ particles have a diameter of less than 2.5 μm; and $PM_{0.1}$ particle have a diameter of less than 0.1 μm.[6] The annual average concentration of $PM_{2.5}$ in the air serves as a metric for exposure to ambient PM pollution. In India, estimates of ambient $PM_{2.5}$ exposure are derived from a combination of multiple satellite-based aerosol optical depth data and a chemical transport model, calibrated with ground-level $PM_{2.5}$ monitoring data.[6] When only average $PM_{10}$ concentration data were available, $PM_{2.5}$ concentrations were derived using ratios between $PM_{10}$ and $PM_{2.5}$. The Global Burden of Disease Study (GBD) 2017 incorporated a significantly larger number of ground measurements compared to previous iterations, with 185 sites for $PM_{2.5}$ measurements and 184 sites for $PM_{10}$ measurements in India.[6] Exposure to household air pollution is measured by the $PM_{2.5}$ concentration resulting from the use of solid cooking fuels, such as wood, dung, agricultural residues, coal and charcoal.[6] This is determined based on the proportion of the population using these fuels. Average $PM_{2.5}$ exposures from solid fuel use for different household members were derived from studies that measured 24-hour kitchen and living areas.[6] The concentration of ambient $PM_{2.5}$ for each location was subtracted from these exposure estimates to provide an estimate of the incremental exposure due to household solid fuel use for cooking. This approach yielded independent estimates for $PM_{2.5}$ exposure due to ambient PM and household solid fuel use.[6] Ozone exposure was defined as the highest seasonal (6-month) mean daily maximum 8-hour average concentrations of ozone in the air. These exposure estimates in GBD 2017 incorporated a new comprehensive global ozone ground measurement database.[6] The burden attributable to ambient ozone pollution was estimated using chemical transport models.[6]

**Mechanism of Air Pollution Causing Damage to Organs:**

The influence on human tissue exerted by gases is dependent on several factors, including their water solubility, concentration, capacity to oxidize tissue and the susceptibility of the individual affected.[7] $SO_2$ due to its high solubility in water, primarily inflicts damage on the upper airways and skin. In contrast, $NO_2$ and $O_3$, being less soluble, can penetrate deeper into the lung.[7] CO, which is highly soluble and non-irritating, readily enters the bloodstream. Its toxicity primarily stems from its ability to compete successfully with oxygen in binding to haemoglobin, leading to tissue hypoxia.[7] The effects of CO are acute: a 2-day increase of mean CO levels of 1 mg/m³ was associated with a 1.2% increase in total deaths in a large European study.[7] Nitric oxide also binds to haemoglobin and

other iron-containing proteins, but it generally acts only a short distance from its contact point due to its binding affinity. Large particles can be visible as dust or haze with appropriate lighting, small particles are invisible. Particles of a considerable size can have an impact on mucous membranes and the upper airways, leading to symptoms such as coughing and tearing. Fine particles ($PM_{2.5}$) effortlessly enter lung alveoli. The ultrafine particles are easily taken up by cells and transported through the bloodstream, exposing nearly all cells throughout the body.[7] Ultrafine particles, therefore, have greater systemic toxicity (as shown in Table 1).[7]

**Table 1: Different Type of Air Pollutants and their Effects**

| Pollutant | Injury Determinant | Tissue damage |
|---|---|---|
| **Sulphur dioxide** | Highly soluble. | Upper airway and skin damage. |
| **Carbon monoxide**<br>**Ozone**<br>**Nitrogen dioxide** | Less soluble. | Tissue hypoxia, bronchial and bronchiolar injury, deeper lung penetration. |
| **$PM_{10}$, $PM_{2.5}$, $PM_{0.1}$** | Size, structure, and composition determine toxicity. | Large particle- Mucous membrane, upper airways.<br>Small particle: bronchioles & alveoli.<br>Ultrafine particles: Systemic tissue reactions. |

The adverse effects of PM extend beyond its size and are closely tied to its structure and composition. For example, highly acidic particles are more noxious. The inflammation, usually in the lungs, causes oxidative stress.[7] Oxidative stress entails lipid peroxidation, depletion of antioxidants and activation of pro-inflammatory signalling. The pro-inflammatory signalling sets off a cascade of events that may affect distant organs. The capacity to induce oxidative stress is proportional to the surface area of ultrafine particles. Elevated exposure to particulates is linked with increased levels of inflammatory markers which include plasma viscosity, C-reactive protein, circulating blood leukocytes, platelets and fibrinogen.[7]

**Mortalities and Morbidities Due to Air Pollution:**

In 2017, India, despite constituting 18% of the global population, bore a disproportionate burden of global Disability-Adjusted Life Years (DALYs) attributable to air pollution, accounting for 26%.[1] A significant 8% of India's overall disease burden and 11% of premature deaths among individuals below the age of 70 were directly linked to air pollution.[1] The deleterious impact of air pollution in India was estimated to result in 1.24 million deaths during the same year.[1] Notably, ambient PM pollution contributed to 0.67 million deaths, while household air pollution was responsible for 0.48 million deaths.[1] NCDs attributable to air pollution encompass a spectrum of serious health conditions, notably heart disease, stroke, chronic obstructive pulmonary disease and lung cancer. The deleterious health effects of air pollution might surpass the previously estimated 5 million NCD-related deaths annually, as emerging evidence suggests a more substantial impact of these diseases at prevailing exposure levels.[1] This is emphasized by recent studies indicating heightened

health risks associated with current levels of air pollution, thus warranting a re-evaluation of the existing mortality estimates.[1] These findings necessitate concerted efforts toward implementing effective policies and interventions to ameliorate the health outcomes associated with air pollution on a global scale.[1]

**NCDs and Air Pollution:**

In 2017, the annual population-weighted mean exposure to ambient PM in India was 89.9 µg/m³, which is the highest in the world.[1] A staggering 76.8% of the population experienced exposure levels exceeding the prescribed limit established by the National Ambient Air Quality Standards in India, set at 40 µg/m³.[1] In the year 2016, chronic respiratory diseases constituted 10.9% of overall mortality and 6.4% of total DALYs in India.[8] Two notable chronic respiratory illnesses, namely chronic obstructive pulmonary disease (COPD) and asthma, constituted 75.6% and 20% of the overall DALYs attributed to chronic respiratory diseases in India for the same year.[10] Significantly, air pollution emerged as the primary risk factor for COPD. In 2016, cardiovascular diseases constituted 28.1% of total mortality and 14.1% of DALYs in India, a notable increase from 1990 when these figures stood at 15.2% and 6.9%, respectively.[9] The identified overlapping risk factors for cardiovascular diseases in 2016 encompassed dietary risks, elevated systolic blood pressure, air pollution, elevated total cholesterol, tobacco consumption, elevated fasting plasma glucose and increased body mass.[1] This data emphasizes the evolving epidemiological landscape and highlights the imperative for targeted interventions to mitigate the burden of cardiovascular diseases in the Indian population. While less extensively explored, air pollution has been correlated with various gastrointestinal (GI) conditions, encompassing inflammatory bowel disease, enteritis, gastric ulcer and appendicitis. However, no overall association was established between exposure to air pollutants and the risk of inflammatory bowel disease.[10] Numerous investigations have indicated an increased risk of metabolic syndrome in adults exposed to elevated ambient $PM_{10}$ levels.[11] It appears that air pollution plays a role in the accumulation of visceral adipose tissue or the transition from brown to white adipose tissue, exacerbating insulin resistance, oxidative stress and systemic inflammation this leads to harm various organs as shown in the table 2.[11]

**Prevention of Air Pollution and NCDs:**

Mitigating ambient PM pollution necessitates concerted efforts across various sectors and the integration of these initiatives for maximal efficacy.[1] Numerous studies have assessed the contributions of diverse sources to PM pollution in distinct regions of India, providing valuable insights to inform targeted interventions.[1] Governmental initiatives implemented in recent years aim to curtail air pollution, encompassing measures such as reducing PM emissions from coal power plants, lowering energy consumption in energy-intensive industries (Ministry of Power), setting emission standards for the brick manufacturing industry, managing agricultural residues to reduce stubble burning (Ministry of Environment), enforcing stringent vehicle emissions regulations, upgrading vehicles to fuel-efficient standards (Ministry of Road Transport and Highways; Ministry of Petroleum and Natural Gas) and enhancing public transport availability (Ministry of Urban Development).[1] Integration of air pollution reduction mechanisms into the Smart Cities Mission, launched by the Government of India, is imperative. Even though approximately two-thirds of

**Table 2:Effect of Air Pollution on Various Organs**

| Organs | Effects |
|---|---|
| **Brain** | Stroke, Dementia, Parkinson's Disease |
| **Eye** | Conjunctivitis, Dry Eye, Cataracts |
| **Heart** | Ischemic Heart Disease, Hypertension, Congestive Heart Failure, Arrhythmias |
| **Lung** | Chronic Obstructive Lung Disease, Asthma, Lung Cancer, Bronchitis |
| **Nose** | Allergic Rhinitis |
| **Liver** | Hepatic Steatosis, Hepatocellular Cancer |
| **Blood** | Leukaemia, Anaemia |
| **Fat** | Metabolic Syndrome |
| **Pancreas** | Diabetes Mellitus Type 1 and Type 2 |
| **Joints** | Rheumatic Disease |
| **Bone** | Osteoporosis, Fractures |
| **Skin** | Atopic Skin Disease, Skin Aging, Urticaria, Acne |

India's electricity is generated from fossil fuels, predominantly coal, the country has committed, under the Paris Climate Agreement, to sourcing 40% of its electricity from renewable sources by 2030.[1] Extending policies implemented at the regional level could prove effective in managing PM emissions. For instance, initiatives like adopting compressed natural gas in vehicles in Delhi, offering subsidies to encourage alternative technologies for composting agricultural waste instead of burning in Punjab and mandating the use of fly ash in construction within 100 km of coal or lignite thermal plants in Maharashtra could be replicated in other states.[1] The Clean Air for Delhi Campaign initiated in early 2018 paved the way for the National Clean Air Programme, focusing on public awareness and improved coordination among implementing agencies for nationwide air pollution control.[1] Additional initiatives, including Intended Nationally Determined Contributions targeting a 33–35% reduction in PM emission intensity by 2030, the promotion of electric public transport fleets and the adoption of Bharat Stage VI vehicle emission standards, demonstrate positive momentum, albeit requiring time for substantial effects to materialize.[12] High ambient PM pollution levels during winter in north India attract media and public attention, emphasizing acute health problems, while the more enduring adverse health effects of persistently elevated pollution levels throughout the year remain insufficiently acknowledged.[1] A heightened awareness of the gradual yet substantial impact of ambient PM and household air pollution among policymakers and the general public is crucial to bolstering air pollution control efforts in India. Governmental endeavours to reduce solid fuel use for combating household air pollution encompass the Pradhan Mantri Ujjwala Yojana, initiated in May 2016 by the Prime Minister of India.[13] This scheme, designed to provide clean and safe cooking fuel (liquefied petroleum gas) to 50 million low-income households by March 2019, exceeded its original target in August 2018. Subsequently, the government expanded the goal to reach 80 million households through an increased budget of

US$1.8 billion.[1] Despite these initiatives, the limited number of $PM_{2.5}$ ground monitoring stations in India, particularly in rural areas, poses a significant constraint on air quality management and research. Recent efforts to expand automatic continuous ambient air quality monitoring stations across the country, along with proposals in the National Clean Air Programme to establish rural monitoring stations and increase the number of stations measuring $PM_{2.5}$, are anticipated to enhance air pollution estimates in India.[14] Addressing the scarcity of data on ozone exposure is essential, as is the imperative to strengthen evidence generation regarding the association of air pollution with health loss in India.[1] The paucity of long-term cohort studies reporting adverse health effects of air pollution in the Indian context underscores the need for intensified research efforts in this critical domain.

**Conclusion:**

India must adopt a comprehensive approach encompassing both short-term and long-term policies and mechanisms to effectively mitigate the elevated levels of air pollution, which pose a significant impediment to the nation's sustained development. Notably, there has been a commendable surge in the discourse surrounding air pollution in India, with increased engagement from the media, public and various stakeholders. Policymakers demonstrate a pronounced inclination to address this critical issue. It is imperative to emphasize that beyond the immediate health benefits to human populations, the reduction of air pollution in India holds the potential for broader positive repercussions across the ecosystem, encompassing animal and plant health. Integrating the planning and execution of air pollution control measures will not only contribute to human well-being but also foster the preservation of biodiversity and the overall ecological balance. This perspective reinforces the urgency and significance of concerted efforts to address air pollution in India comprehensively, aligning with sustainable development goals and ensuring the well-being of both present and future generations.

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Chapter - 5

# Air Pollution and Cardiovascular Health in India

*Harinder K. Bali, Navdeep S Sidhu*

**Introduction:**

Environmental pollution is a major, often overlooked, global public health problem and is themost prominent preventable cause of premature death and disability.[1] Recent developments and newer understandings have stressed upon the importance of viewing the "pollutome" (the health influences of all types of pollution) as an important subset of the "exposome" (all the external influences and their interactions, impacting the human health), to develop an integrated framework that enables a better understanding of the true scope of the problem and its health consequences.[1] Environmental pollution has been linked to the development and/or worsening of a myriad of clinical problems including the cardiovascular diseases (CVD), cardiometabolic diseases, respiratory diseases, cognitive disorders and poor pregnancy outcomes.[1, 2] Among the various types of pollution, air pollution is the largest contributor towards a negative impact on the human health, mainly related to the its perennial, persistent and pervasive exposure.[3]

**Air Pollution: Composition and Origin**

Air pollution can be viewed as a complex, heterogeneous mixture of harmful chemicals and its major components are the particulate matter (PM) and gaseous air pollutants. Particulate matter consist of solid and liquid particles suspended in air and are sub categorized according to their mean aerodynamic diameter: $PM_{10}$ (thoracic particles)- all particles less than 10 µm; $PM_{2.5}$ (fine particles)- all particles less than 2.5 µm; $PM_{10-2.5}$ (coarse particles)- particles between 2.5-10 µm and ultrafine particles (UFP)-all particles less than 0.1 µm. The levels of $PM_{10}$ and $PM_{2.5}$ are quantified in terms of mass per volume of air ($gm/m^3$), whereas those of UFPs as number/$cm^3$. Primary particulate matter like diesel soot is directly emitted into the environmental air, whereas secondary particles are formed in the air by physicochemical reactions of the gasses like sulfate and nitrate formation from sulfur dioxide ($SO_2$) and gaseous nitric acid, respectively.[4,5] Although there are numerous chemicals making up the PM fraction of air pollution and varying continuously in space and time, the major components include nitrates, sulfates, inorganic and organic carbons, volatile and semivolatile organic compounds, biological compounds (pollens, cell fragments, endotoxins) and various metals (like nickel, iron, copper, zinc, vanadium etc.). The predominant gaseous air pollutants include nitrogen oxides (like nitric oxide, nitrogen dioxide, nitrogen trioxide, nitrogen tetroxide, dinitrogen pentoxide), sulfur dioxide ($SO_2$), carbon monoxide (CO), and ozone ($O_3$).[4, 5] Among the various components of the air pollution, the $PM_{2.5}$ is the most well studied component, having a large body of evidence to support its negative effect on human health.[1] From epidemiological perspective, the air pollution is typically quantified in terms of ambient particulate matter concentrations, household air pollution and less commonly, the tropospheric ozone. The major natural and anthropogenic activities acting as the sources of air pollutants include motor

vehicles (especially those using fossil fuels), industrial processes like combustion, smelting and other metallurgical processes, power generation, construction-demolition activities, agricultural debris burning, volcanic eruptions, household wood burning, windblown dust and forest fires.[6]

**Scope of the Problem:**

Air pollution is the 4th leading cause of global mortality, after malnutrition, hypertension and tobacco use.[7] Nearly 99% of worlds' population lives in places with "unhealthy air", as defined by the World Health Organization (WHO) standards. Globally, about 6.7 million premature deaths are reported annually due to air pollution. About 89% of these occur in the middle- and low income countries, with South Asia, Africa and the Middle-east being the most severely affected regions.[8] Besides the mortality impact, air pollution is responsible for nearly 100 million global disability-adjusted life years (DALYs) and a staggering USD 5 trillion loss to the global economy annually.[9] As per WHO estimates for the year 2019, of the total air pollution related premature deaths, the largest proportion (37%) were due to IHD and stroke. Chronic obstructive pulmonary disease (COPD) was responsible for 18% of these deaths, lower respiratory infections for 23% of these deaths and respiratory tract cancer for 11% of these deaths.[8]

**Indian Scenario:**

India, the worlds' most populous country, has the dubious distinction of having the highest number of cities in the top 100 polluted cities in the world and its capital, New Delhi is persistently ranked among the top 5 polluted cities in the world for many years.[10] Increasing economic development, industrialization and rising numbers of motor vehicles with consequent ever-increasing dependence on fossil fuels to meet the energy demands of the nation, has resulted in tremendous strain on our environment, especially by increasing the severity of air pollution. We face a dual challenge in terms of air pollution, with industrial and vehicular emissions contributing to the worsening ambient air pollution and continued use of solid cooking fuels in many households contributing to the household air pollution.[11]

The Global Burden of Disease (GBD) study is an ongoing project to collect comprehensive data for the global disease burden and the contributing risk factors for more than 200 countries of the world, including India. According to GBD 2019 estimates of air pollution attributed disease burden (APADB), air pollution was responsible for nearly 1.67 million premature deaths in India, which were 17.8% of the country's total deaths in this year. Out of these deaths, 0.98 million were related to ambient air pollution, while 0.61 million were related to household air pollution.[12] Ischemic heart disease (IHD) was the second most common cause of these deaths, with COPD being the leading one (Figure 1, A). Air pollution contributed to 11.5% of the country's total DALYs in 2019, with IHD being the most prominent cause, followed by COPD (Figure 1, B). In the same year, the nation's economic loss related to lost productivity, attributable to air pollution was to the tune of USD 36.8 billion, nearly 1.36% of the gross domestic product (GDP). Out of this, USD 28.8 billion was related to lost productivity due to premature deaths and USD 8.0 billion was from lost productivity associated with morbidity related to the air pollution.[12] From 1990 to 2019, the deaths attributable to ambient air pollution rose by 115%, whereas those attributable to household air pollution fell by 64% and those attributable to ambient ozone pollution rose by 139%.[12]

There is considerable heterogeneity in Indian states in terms of severity and patterns of air pollution due to differences in the degree of epidemiological transition among various states, with states like Kerala, Goa and Tamil Nadu displaying marked transitions in terms of economic development, urbanization/industrialization and lifestyle changes, while states like Uttar Pradesh, Bihar and

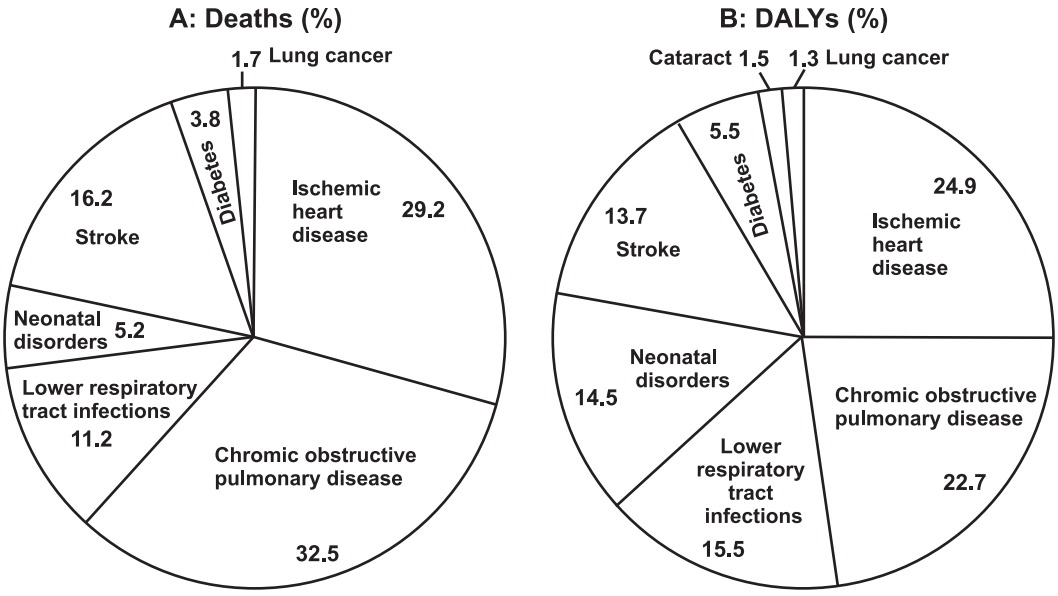


**Figure 1: Causes of Mortality (A) and DALYs (B) Attributable to Air Pollution in India in 2019[12]**

Jharkhand showing lesser degrees of epidemiological transition.[13] In 2019, the annual average population-weighted mean $PM_{2.5}$ (a method of quantifying ambient PM related air pollution), was 91.7 µg/m$^3$, with a wide variation from 15.8 µg/m$^3$ in Kerala, to a whooping 217.6 µg/m$^3$ in Delhi- nearly 14-fold difference.[12] The use of solid cooking fuel in many eastern states like Bihar, Jharkhand, Orissa, Chhattisgarh is in more than 70% of the households, whereas some states like Punjab, Maharashtra, Andhra Pradesh have much lower levels of less than 30% of the households using solid cooking fuels. Solid cooking fuel is the major cause of household air pollution, besides contributing significantly to the ambient air pollution.[12] The concentrations of ambient ozone also varied widely between the different regions of the country. It was lowest in Arunachal Pradesh [47.4 parts per billion (ppb)] and highest (76.6 ppb) in Jammu-Kashmir and Ladakh. The economic loss (in terms of state's GDP), attributable to air pollution also varied widely between the Indian states, with lowest levels in some north-eastern states of Sikkim (0.67% of the state's GDP), Mizoram (0.7%) and Arunachal Pradesh (0.74%), while it was highest in states having low per-capita GDP like Uttar pradesh (2.15%), Bihar (1.95%), Rajasthan (1.70%), Madhya Pradesh (1.70%) and Chattisgarh (1.55%). The economic loss in terms of per capita income loss was highest in Delhi, followed by Haryana.[12]

Classically air pollution has often been viewed mainly as an urban problem, localized to big cities or towns with significant industrialization and motorization. Recent studies have challenged this notion and have shown amicably that the air quality in many of the peri urban and rural areas is nearly as bad as in the big cities especially in the highly polluted Indo-Gangetic plains of the North-West India.[14,15] Karambelas et al studied the impacts of $PM_{2.5}$ and ozone levels on human health in urban vs non urban areas of North India, where they defined 'urban' as cities or towns having a population of more than one lakh. The authors found that, although the majority of premature deaths related to air pollution occurred in the rural areas, given the larger population of rural areas, this difference translated into 6.4 premature deaths per 10 000 population in urban areas vs 5.6 per

10 000 in rural areas. In this study, IHD was the leading cause of premature mortality, followed by stroke.[14] Similarly, Ravishankara et al have shown that there is little, if any, difference in the impact of air pollution on premature deaths in urban vs rural areas, not only in the highly polluted Indo-Gangetic plains of North India but also in the other less polluted regions of the country.[15] These studies underscore the importance of extending the air quality monitoring services to rural areas, where they are nearly non-existent at present and need to adopt a pan-India approach towards air pollution control.

As the present distribution of the Indian population is markedly skewed with a preponderance of younger population, it is estimated that this may have resulted in masking the true cardio-pulmonary effects of the air pollution, many of which are manifested after a latent period of many years or decades. It is estimated that even if the $PM_{2.5}$ are kept constant at the current levels, the aging of the Indian population would result in a 21% increase in the $PM_{2.5}$ attributable per capita mortality by 2030. To keep this mortality constant, there is a need to reduce the $PM_{2.5}$ levels by 20-30% over the next 15 years, thus calling for an urgent action at various levels to control the levels of air pollution.[16]

Interesting observations were noted during the lockdown phase of COVID-19 pandemic, when markedly reduced human activity resulted in significantly decreased levels of air pollution in various parts of the country, with a massive 50% reduction in $PM_{2.5}$ levels in Delhi. The levels of air pollution rose back to the pre-COVID levels after the easing of restrictions, thus underscoring the huge negative impact of human activity on our environment.[17] Moreover, the elevated levels of air pollution has been linked with heightened mortality and morbidity from COVID-19, thus stressing upon the need to adopt clean environmental policies as a method to boost the health of general population and mitigate the negative effects of various diseases including pandemics.[18]

**Air Pollution and Cardiovascular Health:**

Mounting body of evidence supports a strong association between air pollution and adverse health effects, including CVD (Figure 2). Many observational studies have consistently linked high level of air pollution, particularly $PM_{2.5}$, with coronary artery calcification, subclinical atherosclerosis, rapid growth of atherosclerotic plaques and increased vulnerability of atherosclerotic plaques, manifesting as acute coronary syndromes (ACS).[1,2] Exposure to polluted air over long term is associated with the development of atherosclerosis, as manifested by increased intima-media thickness and also with coronary vasomotor disturbances. Even a short term exposure to highly polluted air is linked with an enhanced incidence of ACS, especially ST-elevation myocardial infarction and its attendant mortality, especially in the elderly population with pre-existing coronary artery disease or multiple cardiac risk factors. An increase of 5 $\mu g/m^3$ in the ambient annual mean $PM_{2.5}$ levels has been associated with a 13% increase in ACS events and an increase of 10 $\mu g/m^3$ in annual mean $PM_{10}$ levels have resulted in 12% increase in ACS events in a meta-analysis consisting of 11 European studies.[19]

Similar to the IHD, the association between air pollution and stroke is well documented. Data from GBD 2019 reported a staggering 1.14 million worldwide deaths from stroke attributable to $PM_{2.5}$ air pollution.[20] In a meta-analysis of 68 studies with 23 million participants, a positive association was found between exposure to various components of air pollution (especially $PM_{2.5}$,$PM_{10}$ , $NO_2$ , $SO_2$) and stroke incidence, hospital admission rates and mortality. [21] Recently Kulick et al, in a study of 155,410 postmenopausal women, found a hazard ratio of 2.14 (95% CI: 1.87-2.44) for all types of cerebrovascular accidents on comparison of highest vs lowest quartiles of PM2.5 levels. Also there

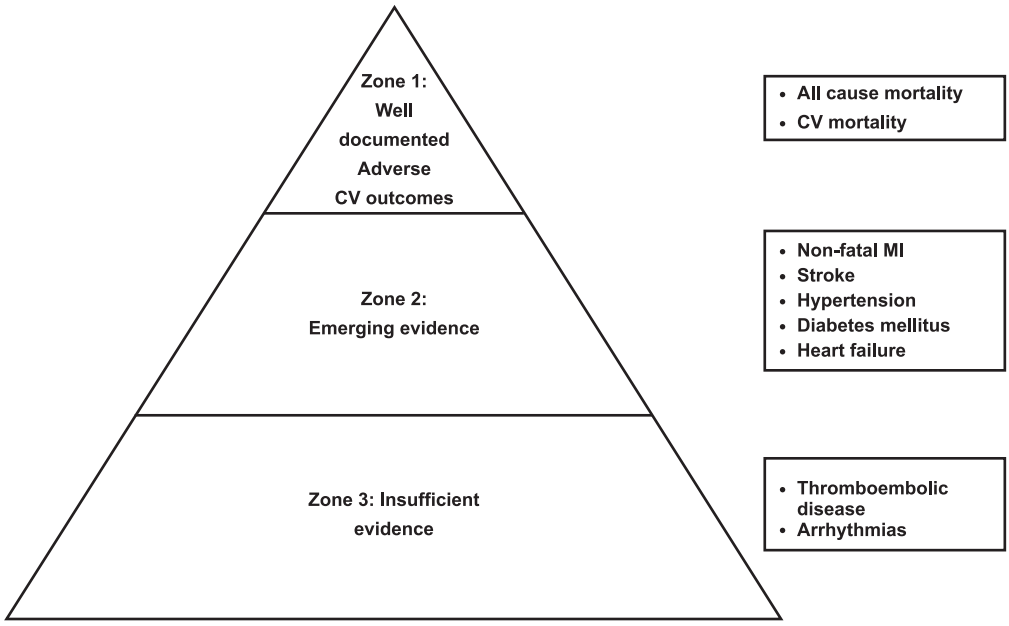


**Figure 2: Air Pollution and Cardiovascular Diseases: Zones of Evidence.**

(Adapted from Rajagopalan S, et. al.[2]) Abbreviations- CV: cardiovascular, MI: myocardial infarction)

was a less robust, but statistically significant association between stroke and $PM_{10}$ and $NO_2$ levels in this study.[22]

Exposure to polluted air, especially particulate matter, both on a short term and long term basis, is linked with elevated risk of incident heart failure and heart failure related admissions and mortality. Shah et al, in a meta analysis published in 2013, reported that a short term elevation in $PM_{2.5}$ and $PM_{10}$ concentration by 10 $\mu g/m^3$ resulted in 2.12% and 1.63% increase in heart failure hospitalizations and mortality, respectively.[23] In a recent meta-analysis of 51 studies with more than 7 million participants, a rise in the levels of various air pollutants ($PM_{2.5}$, $PM_{10}$, ozone, CO, $NO_2$, $SO_2$) was positively correlated with heart failure hospitalizations and mortality.[24]

There is an emerging evidence of association between air pollution and atrial (especially atrial fibrillation) and ventricular arrhythmias. In patients with previously implanted cardiac defibrillators, higher $PM_{2.5}$ and $PM_{10}$ levels have been linked with elevated risk of atrial fibrillation and ventricular arrhythmias.[25] It has been found that patients with previous myocardial infarction were more susceptible to PM induced arrhythmias.[26] Even in healthy individuals without any structural disease, exposure to high $PM_{2.5}$ levels even for a brief period, has been linked with increased incidence of atrial fibrillation and ventricular premature complexes (VPCs).[27,28]

Many studies have shown that elevated levels of air pollutants, especially particulate matter, are linked with an increased risk of developing CVD risk factors like hypertension, dyslipidemia and diabetes. Niu et al, in their meta-analysis of 41 studies, reported that increased levels of PM significantly enhanced the risk of hypertension. In this study, an elevation of 10 $\mu g/m^3$ in $PM_1$, $PM_{2.5}$ levels was associated with 1.76 mm Hg and 0.63 mm Hg elevation in systolic blood pressure respectively, and elevation of 10 $\mu g/m^3$ in $PM_1$, $PM_{2.5}$, $PM_{10}$ levels was associated in 1.16 mm Hg,

0.31 mm Hg and 1.17 mm Hg elevation in diastolic blood pressure respectively.[29] In a cohort study from urban Delhi by Prabhakaran et al, it was found that higher PM exposures were linked with higher systolic blood pressure levels and elevated risk of incident hypertension.[30] Various studies have shown robust correlation between increased levels of PM and elevated blood cholesterol, low density lipoprotein cholesterol (LDL-C) and triglyceride levels.[31] According to the data from GBD 2019, $PM_{2.5}$ was the third leading cause of diabetes mellitus, with nearly 20% of global diabetes burden being attributable to it and 13.4% of diabetic deaths occurring due to $PM_{2.5}$.[32]

**Mechanisms of Air Pollution Related CV Disease:**

There are many potential pathophysiological pathways related to the deleterious effects of air pollution on CV health, the major being oxidative damage, systemic inflammation and endothelial dysfunction (Figure 3). The deposition of particulate matter in the lung tissue is associated with the development of local inflammation, which is often amplified in the form of systemic inflammation, elicitation of prothrombotic mechanisms, dysfunction of hypothalamic-pituitary-adrenal axis and disturbances in the autonomic nervous system tone. Smaller particles like $PM_{2.5}$ (or with lesser sizes) are able to directly cross the alveolar-capillary barrier and elicit various downstream effector pathways like endothelial disturbances, hypercoagulability, sympathetic activation and plaque instability. Exposure to high levels of $PM_{2.5}$ have been associated with arterial inflammation, leukocyte activation and elevated levels of circulatory stress hormones and inflammatory cytokines. It has also been linked to epigenetic changes in many organ systems, with downstream adverse consequences on the CV health.[2, 33]

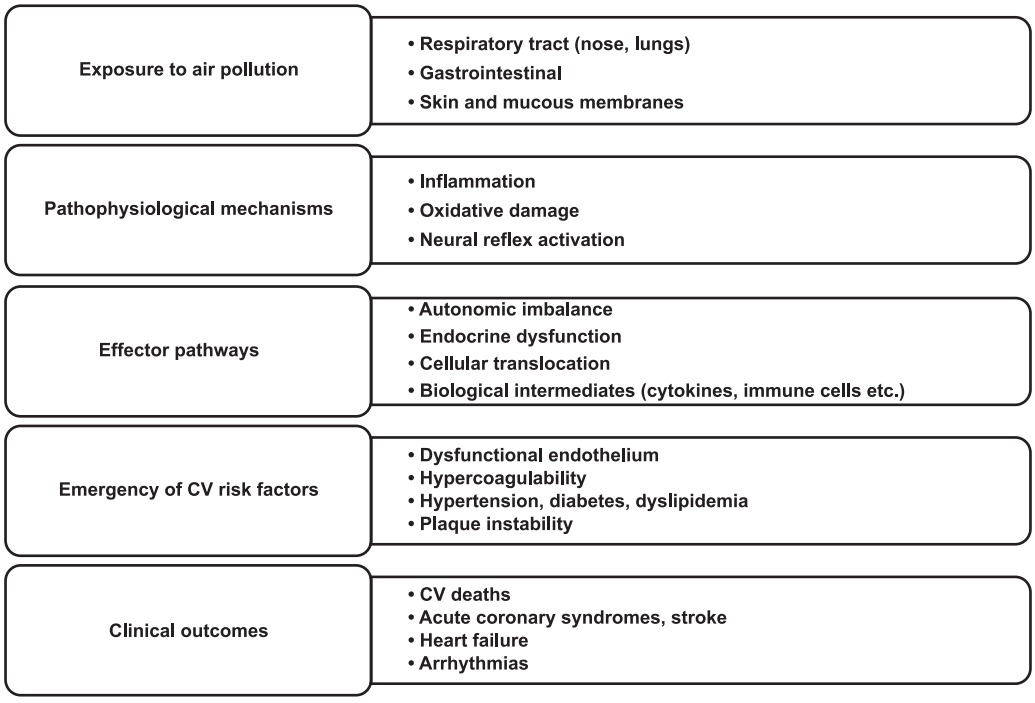


**Figure 3: Mechanisms of Adverse Cardiovascular Outcomes Related to Air Pollution**[33]

## Pollution Mitigation Strategies and the Way forward:

Given a large body of evidence linking air pollution with adverse cardiovascular health and an enormous susceptible population in our country, the need to further strengthen the monitoring and control strategies in our country can't be overemphasized. The Government of India has initiated a variety of initiatives in this direction.[12] The "National Air Quality Monitoring Programme" was launched in 1984 to monitor the air quality and operates 779 monitoring stations across 29 states and Union territories. In 2019, the "National Clean Air Programme" was initiated to spread awareness among the general public about the hazards of air pollution and to coordinate various air pollution control efforts at various levels and across various sectors. To control the levels of household air pollution, many schemes have been launched by the government to decrease the dependence on solid fuel for household cooking, including the "Unnat Chulha Abhiyan" and the "Pradhan Mantri Ujjwala Yojana programme".[12] However, there is a need for a more robust effort at individual and community level, alongwith better policy making and its strict implementation to curb the menace of air pollution in the country.

## Conclusion:

There is a large body of scientific evidence, both global as well as from India, to suggest about the deleterious consequences of air pollution on the human cardiovascular system. High levels of air pollution has been linked with a variety of CV diseases including IHD, stroke, heart failure and arrhythmias, besides being associated with the development of many CV risk factors like hypertension, dyslipidemia and diabetes mellitus. There is a need for collective effort at individual and institutional levels to combat the increasing levels of air pollution.

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Chapter - 6

# Air Pollution and Hypertension

*Narsingh Verma, Shivam Verma*

**Introduction:**

Air pollution, whether from household sources or ambient particulate matter, represents a significant threat to public health worldwide, contributing significantly to premature illness and death. The connection between fine particulate matter ($PM_{2.5}$) and cardiovascular diseases is well-established, with even short-term exposure to heightened PM levels increasing the risk of heart attacks, strokes and other cardiovascular events. This risk escalates with prolonged exposure. Furthermore, gases such as carbon monoxide, nitrogen oxides and ozone also contribute to cardiovascular morbidity and mortality.

From a biological perspective, inhaling these pollutants disrupts the body's autonomic balance and triggers the release of inflammatory and oxidative substances into the bloodstream. These substances can lead to various adverse cardiovascular effects, including elevated blood pressure (BP). Since, high BP is a leading risk factor for cardiovascular mortality, the potential for air pollution to exacerbate BP levels poses a significant concern for public health.[1]

The objective of this chapter is to consolidate recent evidence specifically from human studies, excluding animal and toxicological research, to elucidate the relationship between air pollution exposure and changes in BP. By focusing on human studies, the chapter aims to provide a clear understanding of the direct impact of air pollution on BP levels in individuals. This understanding is crucial for informing policymakers, healthcare professionals and the public about the risks associated with air pollution and devising strategies to mitigate its detrimental effects on cardiovascular health.

**Air Pollution:**

Air pollution and particulate matter constitute a pressing environmental and public health concern in India. Rapid industrialization, urbanization, vehicular emissions, agricultural activities and biomass burning contribute significantly to the deteriorating air quality across the country. Particulate matter, especially $PM_{2.5}$ and $PM_{10}$, pose severe health risks as they can penetrate deep into the respiratory system, leading to respiratory illnesses, cardiovascular diseases and even premature death. In India, cities like Delhi, Kolkata and Mumbai frequently experience hazardous levels of air pollution, particularly during winter months when weather conditions exacerbate the problem. Efforts to mitigate air pollution include regulatory measures, such as vehicle emission standards and industrial emissions controls, as well as initiatives to promote cleaner fuels and renewable energy sources. However, addressing this complex issue requires concerted efforts from government,

industries and individuals to reduce emissions and safeguard public health and the environment. Air pollution, particularly the presence of high levels of particulate matter in the air, has been strongly linked to a range of health issues with cardiovascular diseases being a significant concern in India. Particulate matter, especially $PM_{2.5}$, can enter the bloodstream through the lungs, triggering systemic inflammation and oxidative stress. These mechanisms can lead to the development and progression of cardiovascular diseases such as hypertension, coronary artery disease, stroke and heart failure. Additionally, the deposition of fine particulate matter in the arteries can accelerate atherosclerosis, narrowing blood vessels and increasing the risk of heart attacks and strokes. Studies have shown a clear correlation between exposure to air pollution and increased morbidity and mortality rates from cardiovascular diseases, particularly among vulnerable populations such as the elderly and individuals with pre-existing health conditions. Therefore, addressing air pollution is crucial not only for improving overall public health but also for reducing the burden of cardiovascular diseases and associated healthcare costs in India. Efforts to combat air pollution must prioritize measures that effectively reduce particulate matter emissions and protect cardiovascular health, including stricter regulations on emissions, promotion of clean energy alternatives and public awareness campaigns highlighting the link between air quality and cardiovascular diseases.[2]

**Hypertension:**

Hypertension, commonly known as high blood pressure, is a significant public health concern in India, contributing to the burden of cardiovascular diseases and associated morbidity and mortality. Hypertension is a significant health concern in India, with a prevalence of around 29.8% among adults aged 18-69 years, as per the 2017-2018 India Hypertension Survey by the Indian Council of Medical Research (ICMR). Urbanization, sedentary lifestyle, poor dietary choices, stress and obesity contribute to its increasing prevalence, particularly in urban areas. While hypertension traditionally affects older adults more, its occurrence among younger age groups is rising due to lifestyle factors. Gender differences also exist, with some studies indicating higher prevalence among men, though this varies across regions and demographics.

Overall, hypertension represents a significant public health challenge in India, requiring comprehensive strategies for prevention, early detection and management to reduce its impact on population health and healthcare systems.

The mechanisms underlying the association between air pollution and hypertension are complex and multifactorial. One proposed mechanism is that air pollutants can induce systemic inflammation and oxidative stress, which can damage blood vessels, impair endothelial function and disrupt the regulation of blood pressure. Additionally, air pollution may affect the autonomic nervous system, leading to increased sympathetic activity and altered heart rate variability, which can contribute to hypertension.[3]

It's important to note that while there is growing evidence of the association between air pollution and hypertension, further research is needed to fully understand the causal relationship and to identify specific pollutants and mechanisms involved. Nevertheless, reducing exposure to air pollution through policies aimed at reducing emissions from vehicles and industries, as well as

promoting clean energy sources and urban planning strategies, can potentially help mitigate the burden of hypertension and its related health risks. Individuals can also take steps to minimize their exposure to air pollution by staying indoors during periods of high pollution, using air purifiers and advocating for cleaner air policies in their communities.

**Biological Mechanisms:**

While we do not aim to comprehensively review all animal and basic science mechanistic studies concerning the biological pathways linking air pollution and blood pressure (BP), we will highlight some recent and influential findings that have significantly impacted the field since the previous review.

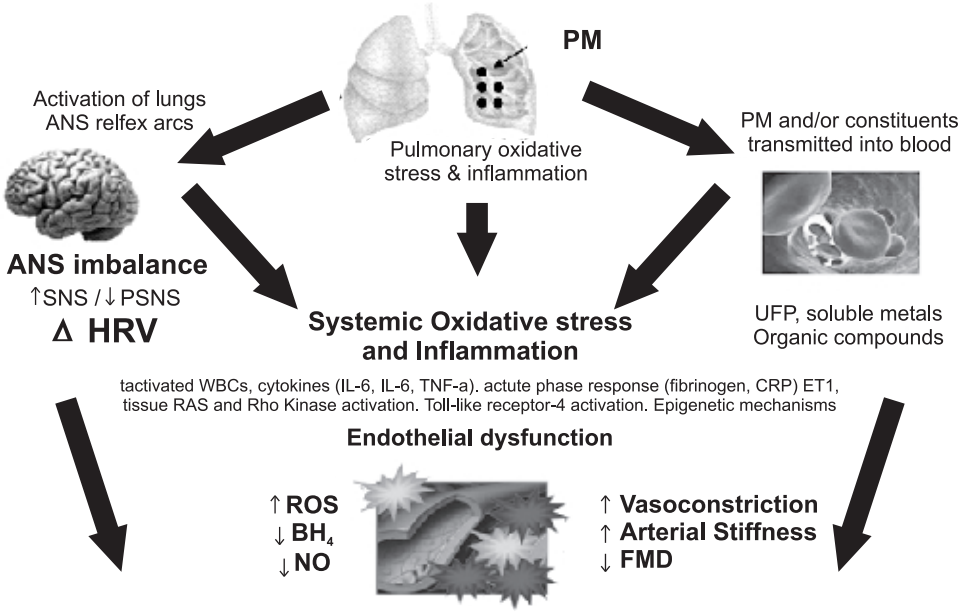


**Figure I : Mechanisms by which PM Air Pollution may Affect Vascular Function & Increase Blood Pressure.**

Abbrevations: CRP. C-reactive protein: $ET_1$, cndothelin; HRV, heart rate variability; 1l-1, interleukin 1; 1L-6, interleukin 6; NO, nitric oxide; BH4, tetrahydro-biopterin; PM, particulate matter; PSNS, parasympathetic nervous system; RAS, renin angiotensin system; ROS, reactive oxygen species; SNS, sympatheric nervous system: TNF-a, tumor necrosis factor alpha; UFP, ultra-fine particles; WBS, white blood cells.

Adopted from : Giorgini P, Di Giosia P, Grassi D, Rubenfire M, Brook RD, Ferri C. Air Pollution Exposure and Blood Pressure: An Updated Review of the Literature. Curr Pharm Des. 2016:22(1):28-51. doi: 10.2174/1381612822666151109111712. [4]

Observational and experimental studies have proposed several potential biological pathways through which inhaled pollutants may adversely affect the cardiovascular system. Broadly, these pathways can be categorized into three main mechanisms. Firstly, pollutants can disrupt the autonomic nervous system (ANS) balance, favoring sympathetic over parasympathetic tone. This effect may be initiated by sensory receptors in the lungs responding to irritants, leading to stimulation of afferent nerves. Secondly, breathing polluted air may stimulate the generation and

release of proinflammatory mediators and vasculo-active molecules from various sources, particularly lung cells. These substances can enter the systemic circulation, causing systemic inflammation and adverse vascular effects. Thirdly, soluble constituents such as metals and nano-sized particles may translocate across the alveolar membrane and directly influence the vascular endothelium.

The relevance of each pathway may vary depending on factors such as the duration of exposure, characteristics of the pollutants, individual susceptibility and the degree of overlap in their adverse effects. Overall, air pollution can lead to increases in BP through a biphasic mechanism. Initially, there may be a rapid response within minutes to hours due to acute ANS imbalance. Subsequently, BP may rise further due to increased arterial vasoconstrictor responsiveness, driven by endothelial dysfunction, oxidative stress and inflammation.

These insights highlight the complex interplay between air pollution and cardiovascular health, underscoring the importance of understanding the underlying biological mechanisms to develop effective strategies for mitigating the detrimental effects of air pollution on BP and overall cardiovascular function.

1. **Autonomic Nervous System Imbalance:** Air pollution affects the autonomic nervous system (ANS) through various mechanisms, leading to dysregulation of sympathetic and parasympathetic activity. This dysregulation can contribute to cardiovascular diseases, including hypertension. Here's how air pollution influences the ANS:

a) Direct Inhalation and Pulmonary Effects: When air pollution particles are inhaled, they can directly affect the respiratory system. The presence of pollutants in the airways stimulates sensory receptors, triggering reflex responses that activate the autonomic nervous system. This activation occurs primarily through the stimulation of pulmonary sensory nerves, which relay signals to the brainstem, particularly the nucleus tractus solitarius (NTS), where autonomic regulation occurs.

b) Sympathetic Nervous System Activation: Exposure to air pollutants, especially fine particulate matter ($PM_{2.5}$) and nitrogen dioxide ($NO_2$), has been linked to increased sympathetic nervous system (SNS) activity. $PM_{2.5}$ can penetrate deep into the lungs and enter the bloodstream, leading to systemic effects. $NO_2$, a common component of traffic-related air pollution, can directly stimulate sympathetic nerves in the lungs and airways. The activation of the SNS results in the release of catecholamines such as adrenaline and noradrenaline, leading to increased heart rate, vasoconstriction and elevated blood pressure.

c) Baroreceptor Dysfunction: Baroreceptors are specialized sensory receptors located in the walls of blood vessels and the heart, which detect changes in blood pressure. They play a crucial role in regulating autonomic activity by providing feedback to the central nervous system. Prolonged exposure to air pollution can impair baroreceptor function, reducing their sensitivity to changes in blood pressure. This dysfunction leads to blunted baroreflex responses and contributes to autonomic imbalance, with increased sympathetic and decreased parasympathetic activity.

d) Heart Rate Variability (HRV): Heart rate variability (HRV) is a measure of the variation in the time intervals between successive heart beats, reflecting the dynamic interplay between sympathetic and parasympathetic influences on the heart. Reduced HRV, characterized by decreased parasympathetic tone and increased sympathetic dominance, has been observed in individuals exposed to air pollution. This alteration in HRV profile is indicative of autonomic dysfunction and is associated with adverse cardiovascular outcomes, including hypertension, arrhythmias and sudden cardiac events.

e) Inflammatory Response: Air pollution exposure triggers systemic inflammation, characterized by the release of pro-inflammatory cytokines, chemokines and reactive oxygen species (ROS). Inflammatory mediators can directly affect autonomic function by altering neurotransmitter release and receptor sensitivity in the central and peripheral nervous systems. Chronic inflammation contributes to autonomic dysregulation, endothelial dysfunction and vascular remodeling, all of which play a role in the development and progression of hypertension.

In summary, air pollution affects the autonomic nervous system through direct inhalation, activation of sympathetic pathways, impairment of baroreceptor function, alterations in heart rate variability and induction of inflammation. These effects contribute to autonomic dysfunction, which in turn increases the risk of cardiovascular diseases, including hypertension. Understanding the mechanisms by which air pollution influences the autonomic nervous system is critical for developing strategies to mitigate its adverse health effects.[5]

2. **Vascular Dysfunction:** Air pollution can cause vascular dysfunction through various mechanisms, leading to endothelial dysfunction, oxidative stress, inflammation and alterations in vascular tone and structure. Here's a detailed overview of how air pollution contributes to vascular dysfunction:

a) Endothelial Dysfunction: The endothelium, a single layer of cells lining blood vessels, plays a crucial role in regulating vascular tone, blood flow and maintaining vascular homeostasis. Exposure to air pollution, particularly fine particulate matter ($PM_{2.5}$), nitrogen dioxide ($NO_2$) and ozone ($O_3$), can directly damage the endothelium, leading to endothelial dysfunction. $PM_{2.5}$ and $NO_2$ can penetrate deep into the lungs and enter the bloodstream, where they induce systemic effects. These pollutants trigger oxidative stress and inflammation within the endothelium, impairing nitric oxide (NO) bioavailability and endothelium-dependent vasodilation. Endothelial dysfunction is characterized by decreased NO production, increased expression of adhesion molecules and enhanced endothelial permeability, all of which contribute to vascular dysfunction and the development of cardiovascular diseases, including hypertension.

b) Oxidative Stress: Air pollution exposure promotes the generation of reactive oxygen species (ROS) and reactive nitrogen species (RNS) within the vascular endothelium. $PM_{2.5}$ and other pollutants contain redox-active components, such as transition metals and organic compounds, which can directly induce ROS/RNS production through redox cycling and mitochondrial dysfunction. ROS/RNS react with cellular components, including lipids, proteins and DNA, leading to oxidative damage and endothelial dysfunction. Additionally, oxidative stress can impair antioxidant defense mechanisms, further exacerbating vascular dysfunction

and promoting the development of hypertension and atherosclerosis.

c) Inflammation: Air pollution exposure triggers a systemic inflammatory response characterized by the release of pro-inflammatory cytokines, chemokines and adhesion molecules. Inflammatory mediators activate endothelial cells, leukocytes and vascular smooth muscle cells, leading to endothelial activation and vascular inflammation. $PM_{2.5}$ and $NO_2$ can directly activate toll-like receptors (TLRs) and nuclear factor-kappa B (NF-κB) signaling pathways in endothelial cells, promoting the expression of inflammatory genes and adhesion molecules. Chronic inflammation contributes to endothelial dysfunction, oxidative stress and vascular remodeling, ultimately leading to increased vascular resistance and blood pressure.

d) Vascular Tone Regulation: Air pollution can dysregulate vascular tone by altering the balance between vasoconstrictors and vasodilators in the vascular wall. $PM_{2.5}$ and $NO_2$ can stimulate the production of vasoconstrictor molecules such as endothelin-1 (ET-1) and thromboxane A2 (TXA2), while simultaneously inhibiting the release of vasodilators such as nitric oxide (NO) and prostacyclin (PGI2). This imbalance shifts the vascular tone towards vasoconstriction, resulting in increased peripheral vascular resistance and elevated blood pressure. Additionally, air pollution-induced endothelial dysfunction and oxidative stress impair vasodilator responses to physiological stimuli, further contributing to vascular dysfunction.

e) Vascular Remodeling: Chronic exposure to air pollution can induce vascular remodeling, characterized by structural alterations in blood vessels, including hypertrophy, fibrosis and remodeling of the vascular wall. $PM_{2.5}$ and $NO_2$ promote the proliferation and migration of vascular smooth muscle cells (VSMCs), leading to vascular hypertrophy and narrowing of the vascular lumen. Inflammatory cytokines and growth factors released in response to air pollution stimulate extracellular matrix (ECM) deposition and remodeling, further exacerbating vascular dysfunction. Vascular remodeling contributes to increased arterial stiffness, decreased compliance and impaired vascular function, ultimately leading to hypertension and cardiovascular disease.

In summary, air pollution causes vascular dysfunction through multiple pathways, including endothelial dysfunction, oxidative stress, inflammation, dysregulation of vascular tone and vascular remodeling. These mechanisms contribute to the development and progression of hypertension and other cardiovascular diseases, highlighting the importance of mitigating air pollution to protect vascular health.[6]

3. **Epigenetic Pathways:** Air pollution can affect epigenetic pathways involved in blood pressure regulation, leading to long-term alterations in gene expression patterns that contribute to the development and progression of hypertension. Epigenetics refers to heritable changes in gene expression that do not involve alterations in the underlying DNA sequence but are instead mediated by modifications to DNA or histone proteins. Here's how air pollution influences epigenetic pathways related to blood pressure regulation:

a) DNA Methylation: DNA methylation is a common epigenetic modification involving the addition of methyl groups to cytosine residues in DNA, typically occurring at CpG dinucleotides within gene promoter regions. Air pollution exposure has been associated with changes in DNA

methylation patterns of genes involved in blood pressure regulation. For example, studies have shown alterations in the methylation status of genes encoding for components of the renin-angiotensin-aldosterone system (RAAS), endothelial nitric oxide synthase (eNOS) and other vasoactive factors in response to air pollution. These changes in DNA methylation can influence gene expression levels, ultimately affecting blood pressure homeostasis.

b) Histone Modifications: Histone proteins undergo various post-translational modifications, such as acetylation, methylation, phosphorylation and ubiquitination, which regulate chromatin structure and gene expression. Air pollution exposure can perturb histone modification patterns, leading to alterations in the accessibility of chromatin and transcriptional activity of genes involved in blood pressure regulation. For instance, exposure to $PM_{2.5}$ has been shown to induce histone acetylation and methylation changes in vascular endothelial cells, leading to dysregulated expression of endothelial genes involved in vascular tone and endothelial function.

c) MicroRNA Regulation: MicroRNAs (miRNAs) are small non-coding RNA molecules that regulate gene expression by binding to target mRNAs and inhibiting their translation or promoting their degradation. Air pollution exposure can alter miRNA expression profiles in various cell types, including endothelial cells, vascular smooth muscle cells and immune cells. Dysregulated miRNA expression has been implicated in the pathogenesis of hypertension by targeting genes involved in vascular remodeling, inflammation and endothelial function. Air pollution-induced changes in miRNA expression may contribute to aberrant gene expression patterns associated with hypertension and cardiovascular diseases.

d) Long Non-coding RNAs (lncRNAs): Long non-coding RNAs (lncRNAs) are RNA molecules that do not encode proteins but play regulatory roles in gene expression and chromatin organization. Emerging evidence suggests that air pollution exposure can modulate lncRNA expression profiles in various cell types, including vascular cells and immune cells. Dysregulated expression of lncRNAs has been implicated in the pathogenesis of hypertension by influencing processes such as endothelial dysfunction, vascular inflammation and fibrosis. Air pollution-induced changes in lncRNA expression may contribute to altered gene regulatory networks involved in blood pressure regulation.

In summary, air pollution can influence epigenetic pathways of blood pressure regulation through alterations in DNA methylation, histone modifications, microRNA regulation and long non-coding RNA expression. These epigenetic changes can lead to dysregulated gene expression patterns in key pathways involved in vascular function, endothelial integrity, inflammation and blood pressure homeostasis, ultimately contributing to the development and progression of hypertension and cardiovascular diseases. Understanding the epigenetic mechanisms underlying the cardiovascular effects of air pollution is crucial for identifying novel therapeutic targets and developing interventions to mitigate the adverse health effects of environmental pollutants.[7]

**Conclusion:**

Air pollution poses a significant threat to cardiovascular health, particularly concerning hypertension, a leading risk factor for cardiovascular diseases. The intricate interplay between air pollutants and biological mechanisms discussed in this chapter highlights the multifaceted

pathways through which air pollution influences blood pressure regulation and cardiovascular function. From disruptions in autonomic nervous system balance to vascular dysfunction and epigenetic alterations, air pollution exerts its detrimental effects on blood pressure through diverse mechanisms. These mechanisms converge to promote endothelial dysfunction, oxidative stress, inflammation and vascular remodelling, ultimately contributing to the development and progression of hypertension and associated cardiovascular diseases.

The evidence presented underscores the urgent need for comprehensive strategies to mitigate air pollution and safeguard cardiovascular health. Policymakers, healthcare professionals and the public must recognize the significant health risks posed by air pollution and prioritize efforts to reduce emissions and improve air quality. Regulatory measures, such as stricter emission standards and promotion of clean energy sources, are crucial steps in this direction.

Furthermore, public awareness and education campaigns are essential to inform individuals about the link between air pollution and hypertension, empowering them to take proactive measures to minimize exposure and protect their cardiovascular health. Collaborative efforts involving government, industries, healthcare providers and communities are imperative to address this pressing environmental and public health challenge effectively.

By understanding the complex interplay between air pollution and hypertension at both the biological and epidemiological levels, we can develop targeted interventions and policies to mitigate the adverse health effects of environmental pollutants and reduce the burden of hypertension and cardiovascular diseases on global health systems and populations.

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Chapter - 7

# Air Pollution and Atherogenesis and Ischemic Heart Disease

*Girish Mathur, Ashutosh Chaturvedi*

**Introduction:**

The etiopathogenesis of the majority of cardiovascular disorders is multifaceted and involves age, infections, lifestyle choices, genetic susceptibility and environmental variables. An increasing body of research suggests that air pollution both causes and accelerates the development of cardiovascular illnesses.

People who are known to have cardiovascular disease, diabetes, pulmonary illnesses, the elderly and expectant mothers are especially susceptible to the negative effects of air pollution.[1] Moreover, it is well recognized that air pollution raises mortality from cardiovascular and all causes. Although it is challenging to determine the precise number of deaths brought on by pollution, the World Health Organization calculates that indoor and outdoor ambient air pollution causes at least 7 million premature deaths annually.[2] Cardiovascular problems are the primary cause of these fatalities. The chemical makeup of the pollutants, exposure concentration, length of exposure, comorbidities, individual vulnerability and variations in atmospheric factors like humidity, temperature and others all influence the cardiovascular response to air pollution.[3]

Particulate matter and gaseous components make up air pollution. Among gaseous pollutants, nitrogen oxides (nitrogen dioxide and nitric oxide), sulfur dioxide, carbon monoxide, benzene and ozone are the substances that are most frequently examined. The most prevalent cardiovascular illnesses in adults that are linked to long-term exposure to outdoor air pollution are the subject of this narrative overview. The possible mechanisms underpinning the links between long-term exposure to air pollution and clinical consequences that have been identified are also covered.

**Size and Composition of Ambient Particles:** Aerodynamic diameter (AD) 2.5 to 10μm ($PM_{10}$) for coarse particles, < 2.5μm ($PM_{2.5}$) for fine particles and < 0.1μm for ultrafine particles (UFPs) are the three types of ambient particles. Particle's chemical compositions vary widely and are influenced by a wide range of source-specific, geographical and meteorological factors. In general, ambient particles consist of biological elements (bacteria, spores and pollens), elemental and organic carbon, crystal materials, inorganic components (sulfates, nitrates, ammonium, chloride, trace metals) and adsorbed volatile and semi-volatile organic chemicals. Furthermore, ambient aerosols can be produced by combining ambient particles with atmospheric gases such as carbon monoxide [CO], ozone, sulfur and nitric oxides.[4]

Both natural and human activities produce particulate air pollution. The road and agricultural dust, tyre wear emissions, wood combustion, building and demolition debris and mining operations are

the sources of $PM_{10}$ particles associated with human activity. $PM_{10}$ originates from wind-blown dust and wildfires. The primary sources of fine particles are industrial processes, fuel combustion and gas-to-particle transformations. Power plants, metal processing and oil refinery facilities, mobility sources' brake and tailpipe emissions, combustion of home fuels and wildfires are among the main producers of $PM_{2.5}$. The main causes of UFPs are mobile sources' tailpipe emissions, which include cars, airplanes and marine vessels.

**Pathophysiological Mechanisms of Cardiovascular System Toxicity Due to Chronic Exposure to Particulate Air Pollutants:**

The ability of fine particulate matter ($PM_{2.5}$, aerodynamic diameter <2.5 μm), ultrafine particulate matter (aerodynamic diameter ≤0.1 μm) and some gaseous chemicals to penetrate from the lungs into the bloodstream is currently acknowledged as a potential mechanism, even though the precise mechanisms of the effects of air pollutants on the cardiovascular system through the respiratory tract are still being investigated.[5] Because of its high deposition in the alveoli, large reactive surface area, increased ability to bind harmful chemicals, potential to activate inflammatory cells that can enter the bloodstream and accumulation in peripheral organs, ultrafine particulate matter poses a particular risk to human health.[6] Crucially, not every air-quality monitoring station across the globe regularly measures the concentration of ultrafine particulate matter. Moreover, endotoxins and other chemicals that are not frequently assessed are included in the category of air pollutants. These substances can interact with gaseous components and particulate matter, making it challenging to determine the health impacts.[7]

The respiratory system and the conjunctiva of the eyes are the direct routes of exposure to air pollution. Although the precise percentage of pollutants that enter the body through the gastrointestinal tract is still unknown, the gastrointestinal tract may also be affected.[8] Certain air pollutants can enter the environment through the soil, water, plants and animals. They can then enter the human body through food, where they can build up and have an impact on the cardiovascular system.

The following patho-mechanisms are hypothesized to be responsible for the detrimental effects of air pollution on the cardiovascular system based on research on humans, animals and experimental animals as well as epidemiological studies:

1. Particulate matter and gaseous pollutants can activate local inflammatory responses in the lungs, which can lead to systemic inflammation mediated by cytokines.[9]
2. Fine particulate matter and specific gaseous chemicals that can enter the bloodstream from the lungs and cause inflammation, endothelial dysfunction, prothrombotic state and thrombosis are known to promote systemic inflammation.[10]
3. Stimulation of lung sensory receptors, which causes an autonomic nervous system imbalance and predominant sympathetic activation, ultimately leading to heart rhythm abnormalities and vasoconstriction. But when it comes to the variables examined and the outcomes, there are significant differences throughout the research.[11]
4. Reactive oxygen species production in cells and tissues, oxidative stress activation and oxidative DNA damage.[12]

5. Direct interactions between fine particulate matter and target cells and tissues, such as heart and artery walls, nevertheless, there is ongoing debate on this pathomechanism.[13]
6. Increased insulin resistance and elevated levels of a few stress chemicals, such as cortisol, norepinephrine and adrenaline.[14]
7. Changes in the composition of the gut microbiota, which may encourage atherosclerosis, inflammation and metabolic diseases such diabetes, metabolic syndrome and obesity.[15]
8. The respiratory mucosa swells and becomes more permeable, which makes it easier for potentially cardiotropic microorganisms to enter the body.

The suggested pathomechanisms underpinning air pollution's detrimental effects on the cardiovascular system are depicted in Figure 1.[16] It is thought that each of these processes may have a role in the onset and advancement of heart failure, arterial hypertension, stroke, atherosclerosis and cardiac arrhythmias, which can all result in mortality. The results of the existing studies' analysis mostly point to the negative effects of air pollution on the cardiovascular system.

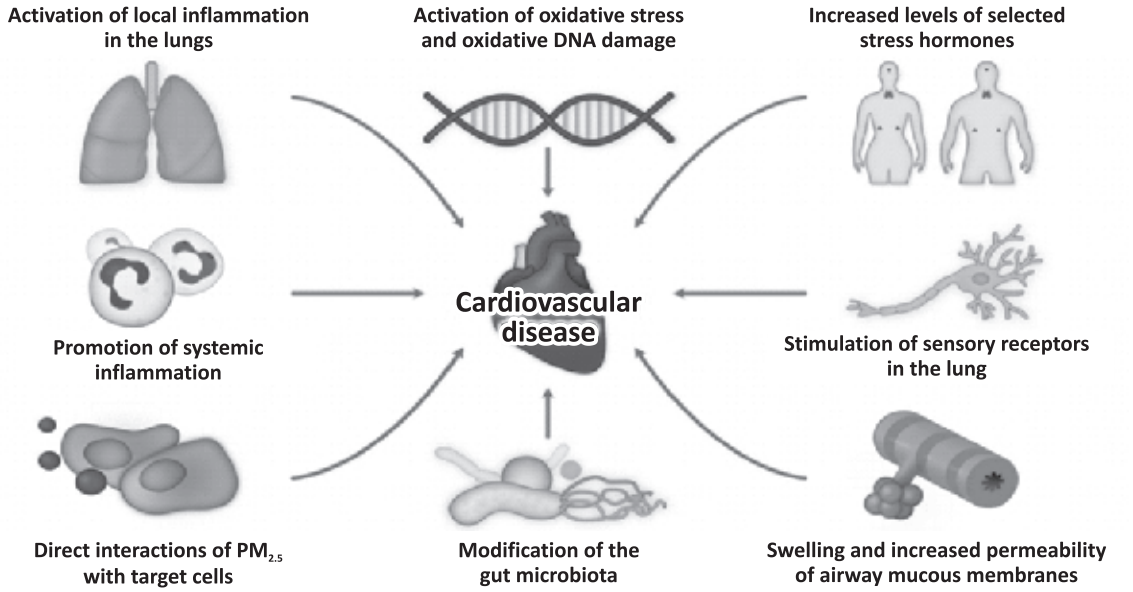


**Figure 1: Postulated Pathomechanisms Underlying the Adverse Cardiovascular Effects of Air Pollution.**

In human investigations, exposure to particle air pollution led to endothelial dysfunction and acute vasoconstriction, elevated blood coagulability, elevated levels of C-reactive protein and other inflammatory markers and worsened myocardial ischemia.[17,18] Elevated levels of C-reactive protein serve as both an independent predictor of cardiovascular disease and a biomarker of systemic inflammation.[19] One well-known risk factor for atherosclerosis development is systemic inflammation. Ischemic heart disease can be caused by or made worse by pro-thrombotic alterations in blood, endothelial dysfunction and abrupt changes in vascular tone.[20] (Figure 2).[21]

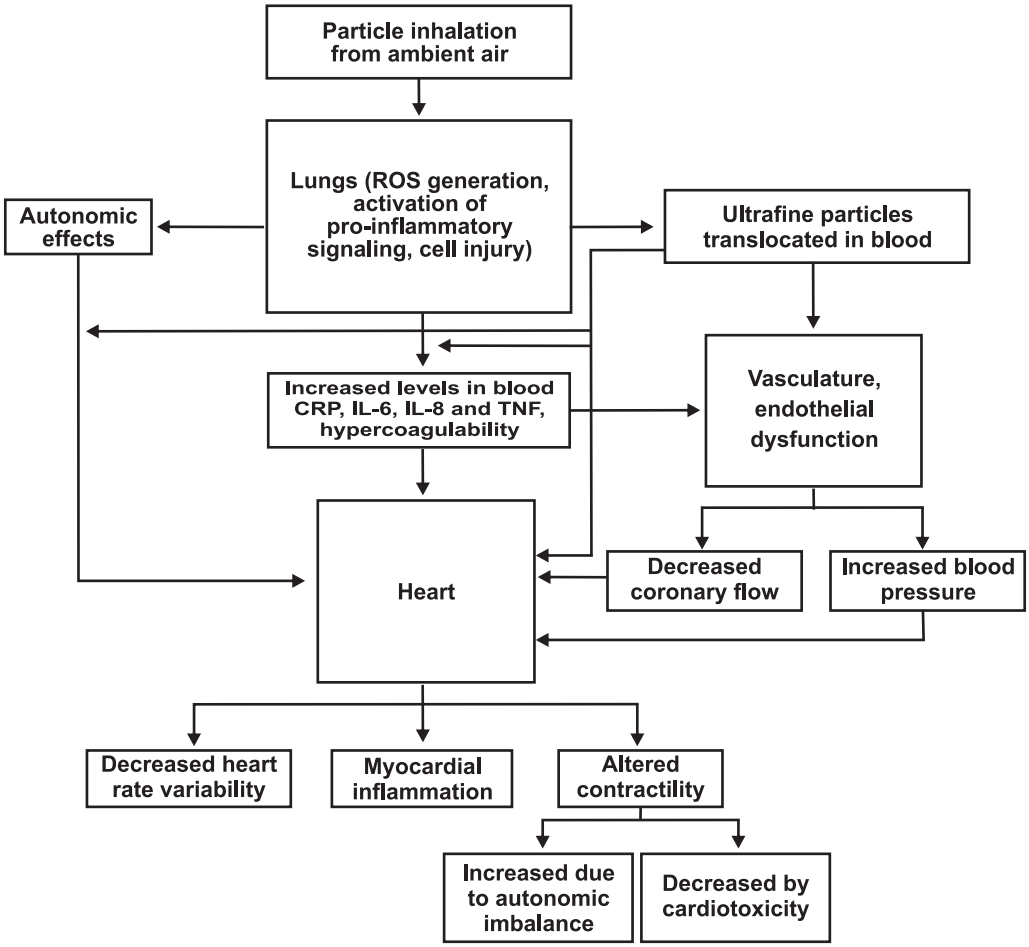


**Figure 2. Micro-mechanisms of Lung and Circulation Mediated Cardiovascular Toxicity of Particulate Air Pollutants.**

(CRP = C-reactive protein; IL = interleukin; TNF = tumor necrosis factor. Figure illustration by Rob Flewell.)

**Long Term Exposure to Air Pollution:**

**Morbidity and Mortality:** Long-term exposure to elevated air pollution levels is known to significantly increase morbidity, as evidenced by accelerated progression of atherosclerosis. This conclusion is supported by strong epidemiological evidence from available cohort studies, primarily conducted in Europe, the USA and Canada.[22,23]

Additionally, a number of epidemiological studies discovered a link between long-term fine particulate matter exposure and lower cardiovascular death rates. These studies give information on the life-shortening effects of air pollution, encompass years of exposure and involve large numbers of people. A wide range of potential confounders were included in the majority of these investigations and when co-pollutant models were corrected for $NO_2$, ozone or $SO_2$, the observed results did not alter or even went up.

The general population may be more susceptible to cardiovascular illness caused by air pollution in

a number of different ways. Individuals with diabetes, older adults and those with pre-existing cardiovascular disease fall into these categories.[24, 25] In comparison to active individuals who inhaled filtered air, a controlled human investigation including 20 males with past MI found that inhaling diluted diesel exhaust particles (ambient concentration 300 μg/$m^3$, median AD 54 nm) caused increased ST-segment depression during activity.[18]

It is challenging to pinpoint the exact component or components that induce cardiovascular toxicity since the chemical makeup of ambient particles differs significantly between different geographical locations. According to research on animals, particulate matter (PM), carbonaceous material and transition metals mediate some of the cardio toxic effects of PM.[26] It has been demonstrated that the gaseous components of ambient aerosols, ozone [$O_3$], $SO_2$, $NO_2$ and CO, increase the risk of acute MI, elevate hospital admissions for heart attacks overall and worsen exercise-induced angina in individuals with stable angina.[27] The majority of these air pollution constituents come from industrial and automotive sources.

The HSCS [Harvard Six Cities investigation], a large-scale investigation that examined the mortality of 8,111 persons over the age of 14 to 16 in six U.S. cities, showed a strong correlation between $PM_{2.5}$ levels and lung cancer as well as cardiopulmonary mortality.[28]

For every 10-μg/$m^3$ increase in $PM_{2.5}$, long-term exposure to air pollution was linked to an increased mortality risk in the categories of ischemic heart disease (risk ratio 1.18), combined dysrhythmias, heart failure and cardiac arrest (risk ratio 1.13), according to a meta-analysis of data gathered during the ACS for the years 1979 through 2000.[29] A 10-year study conducted in five major European cities and a 4-year study conducted in 204 U.S. counties found a positive correlation between higher air pollution levels and hospital admissions for cardiovascular illnesses.

An increase in $PM_{10}$ by 10 μg/$m^3$ was found to be associated with a 0.72% increase in daily admissions for congestive heart failure (CHF) in the epidemiological investigation conducted by Wellenius et al.[30] in seven U.S. cities, which included 292,918 hospital admissions for the condition.

An analysis of 373,566 emergency cardiovascular admissions in London hospitals between April 1, 1987 and March 31, 1994 revealed positive correlations between angina and black smoke, as well as between myocardial infarction (MI) and atmospheric gases nitrogen dioxide [$NO_2$], carbon dioxide [$CO_2$] and sulfur dioxide [$SO_2$]. The authors came to the conclusion that at least 6,000 patients may have been rescued by exposure avoidance measures.[31]

The results of the multicenter European study of cohorts of air pollution effects (ESCAPE), a 13-nation project with 367,251 participants, stand out among the many cohort studies. It showed that for every 5 μg/$m^3$ increase in $PM_{2.5}$ concentrations, there was an increased hazard ratio for all-cause mortality of 1.07 (95% confidence interval, 1.02–1.13).[32] The impact of $PM_{2.5}$ on all-cause mortality in this study was roughly twice as high as in earlier estimates. Liu et al.[33] found no concentration below which carbon monoxide exposure had no effect on the cardiovascular system in their time-series research of 272 major Chinese cities. They also found a connection between carbon monoxide concentrations and cardiovascular mortality.

A 10 μg/$m^3$ increase in long-term fine particulate matter exposure was linked to a 24% (hazard ratio, 1.24; 95% confidence interval, 1.09–1.41) and 76% (hazard ratio, 1.76; 95% confidence interval,

1.25–2.47) increase in the risk of cardiovascular events and cardiovascular mortality, respectively, in the Woman's Health Initiative study, which included nearly 66,000 healthy postmenopausal women from 36 cities in the USA.[34]

According to a meta-analysis by Hoeket et. al.[35], there is an average 6% (95% confidence range, 4–8) increase in all-cause mortality and an 11% (95% confidence interval, 5–16) increase in cardiovascular mortality for every 10-μg/$m^3$ rise in the yearly $PM_{2.5}$ concentration. According to a different meta-analysis conducted by Bourdrelet et. al.[36], death linked to coronary artery disease was most closely correlated with air pollution with $PM_{2.5}$.

The health effects of exposure to pollutant concentrations below the existing upper limits established by the World Health Organization and the European Union are not well-established enough. According to a recent meta-analysis of six sizable European administrative cohorts studying the effects of low-level air pollution, exposure to $PM_{2.5}$, nitrogen dioxide and black carbon was significantly positively associated with mortality from natural, respiratory, cardiovascular and lung cancers. The study in Europe (ELAPSE) project included nearly 27 million participants, contributing over 240 million person-years.

**Conclusion:**

According to data from the literature, one of the main causes of cardiovascular death and morbidity is exposure to fine particulate matter and some gaseous pollutants. The effects of air pollution on mortality from all causes and cardiovascular disease are best supported by available data. Nonetheless, research findings are not always constant and data dependability varies throughout investigations. The range of particle matter's physical and chemical characteristics (size, mass and reactivity), as well as the sources of emissions and associated gaseous contaminants, account for the discrepancies observed among investigations. Studies also vary in how they estimate exposure, use statistical and demographic methodologies and account for confounding or moderating variables. Furthermore, there is no proof of a safe threshold below which there are no adverse health consequences for many air contaminants due to the wide range of individual susceptibilities.

It may be possible to identify specific causal agents that can be better regulated by researching the epidemiology and mechanisms of air pollution-related health effects, such as cardiovascular toxicity. This will increase the efficacy of our efforts to lower the risk of developing air pollution-related health problems.

Physicians ought to be at the forefront of informing legislators and the public about the dangers of air pollution. Combining the available knowledge with real-world possibilities to regulate emission sources is also crucial. The only way to safeguard the environment, uphold the human right to health preservation and create the best strategies for lowering air pollution with a view to assessing the results attained is through interdisciplinary cooperation.

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Chapter - 8

# Air Pollution and Heart Failure

*H K Chopra, A K Pancholia*

**Introduction:**

Heart Failure (HF) is a complex syndrome with cardiac structural or functional impairment and is often the terminal stage of various cardiovascular diseases (CVDs). Owing to the aging of the population its prevalence is high with considerable mortality. According to the Global Burden of Disease Study in 2019, air pollution in urban and rural areas was responsible for ~ 6:6 million premature deaths,[1] mainly as a result of exposure to fine and ultrafine particulate matter with an aerodynamic diameter of ≤ 2:5μm ($PM_{2:5}$ and UFP, respectively). Various experimental and observational studies have shown the link between air pollution and CVDs such as coronary artery disease,[2] stroke[3] and myocardial infarction.[4]

**Pathomechanisms of the link between Air Pollution and CVD including Heart Failure: (Figure 1)**[5]

Following pathomechanisms are hypothesised to underlie the adverse effects of air pollution on cardiovascular system (CVS):

1. Cytokine mediated inflammation by activation of inflammatory response in the lungs.
2. Penetration of fine particulate matter and certain gaseous chemicals from the lungs into the bloodstream and initiate inflammation, endothelial dysfunction, prothrombotic state and thrombosis.
3. Autonomic nervous system imbalance with predominant sympathetic activation, resulting in vasoconstriction and arrhythmia.
4. Activation of oxidative stress.
5. Direct effect of fine particulate matter to the target cells and tissues.
6. Increased levels of stress hormones (epinephrine, norepinephrine and cortisol).
7. Modification of gut microbiota composition, which may promote inflammation, atherosclerosis and metabolic disorders such as obesity, metabolic syndrome and diabetes.

Studies in the past showed a close association of short term exposure to air pollution and HF but these were from high-income countries (HICs) with lower concentrations of air pollutants (e.g., $PM_{2:5}$, concentration ranging from 4.5 to 20:5μg/m³). Over the past decade, numerous studies have provided new evidence on the link between long term air pollution and HF and these are from low and middle-income countries (LMICs). Compared with the HICs, the air quality in LMICs is often

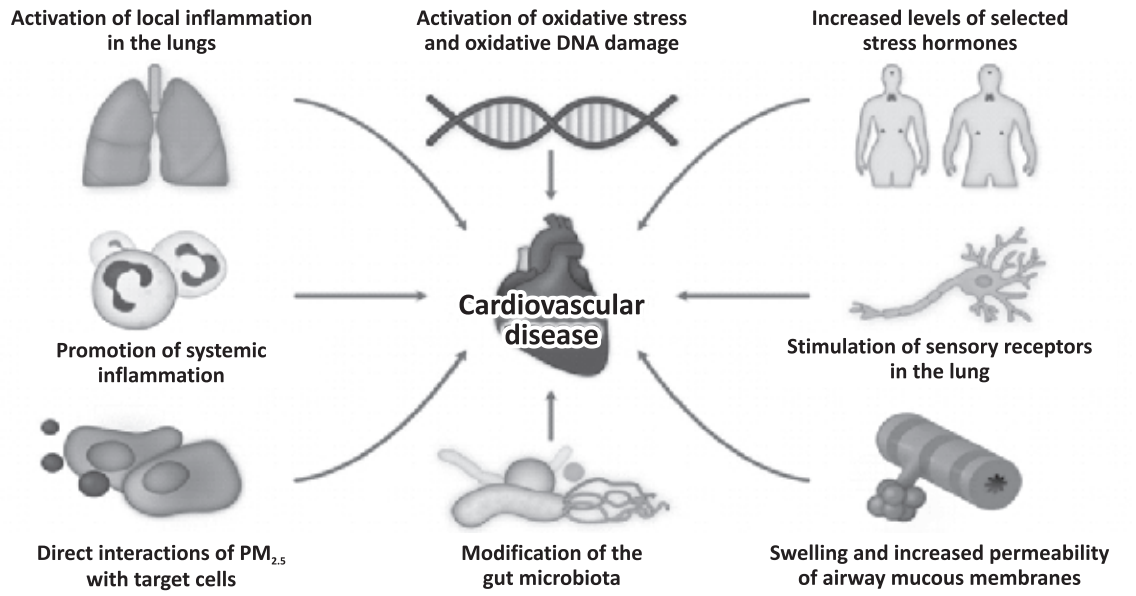


**Figure 1: Postulated Pathomechanisms adverse of Cardiovascular effects of Air Pollution.**[5]

worse and many LMICs have annual average $PM_{2:5}$ concentrations well above 20 μg/m³.[6] A significant positive association between $PM_{2:5}$ concentration and HF hospitalizations was observed in 26 Chinese cities with an average annual $PM_{2:5}$ concentration of 63:5 μg/m³.[7]

**Effect of Chronic Exposure to Air Pollution on Heart Failure:**

Studies showed a positive link between long-term exposure of particulate matter and selected gaseous pollutants and the risk of death or hospitalization from heart failure.[8]

**Pathophysiological Mechanisms:** The link between exposure to air pollution and worsening of the underlying heart failure has not been fully known. Probably chemical pollutants irritate the lower airways, consequently enhancing pulmonary vasoconstriction and increasing right ventricular diastolic filling pressures. This, in turn, can result in pressure overload, which may be fundamental for the deterioration of heart failure. After entering the blood, they are also responsible for increase in peripheral vascular resistance and blood pressure, with subsequent increase in afterload, prothrombotic state and secondary hypoxia. At the cellular level, these various mechanisms involve free radical production, oxidative stress, cytokine release, inflammation, endotoxins mediated damage, stimulation of capsaicin receptors, autonomic nervous system activity.[9] All of these pathophysiological mechanisms can contribute to the exacerbation of HF. Increase in coarse particulate matter, nitrogen dioxide, ultrafine particulate matter and ozone, led to a higher rate of hospitalizations for exacerbation of preexisting HF.[10, 11] Recent analysis from Female Nurse Cohort[12] revealed an enhanced risk of heart failure incidence in persons exposed to high levels of two pollutants ($PM_{2:5}$, nitrogen dioxide) and concomitant road traffic noise during the mean time exposure of about 3 years. There are some limitations of the studies of long term exposure of air pollutants. Regardless of the primary cause, the data on the diagnosis of HF were derived from the

record of hospital discharges or death certificates in which HF was very frequently listed as a secondary and direct cause of death. Even in patients with previous diagnosis of chronic HF, to identify the exact cause of the HF exacerbation is challenging. In the above studies, none of these confounders were included in the analysis.

**Short-Term Exposure of Air Pollutants and HF:**

Short term exposure of almost all the gaseous and particulate pollutants showed significantly positive associations with HF. A 10-μg/m³ increment of $PM_{2:5}$ and $PM_{10}$ was estimated to result in a 1.8% and 1.6% increase in risk of HF hospitalization and mortality, respectively.[13]

A clear temporal trend of a gradual reduction in RR was observed within the 3rd day of exposure, but the adverse impact of pollutants on HF remained for 7 days. After grouping by the national economic status, the HF risks associated with each pollutant [$PM_{2:5}$, $PM_{10}$, $NO_2$, sulpur dioxide ($SO_2$), carbon mono-oxide (CO) and ozone ($O_3$)] in LMICs were higher than those in HICs. It was found to be larger in Asia compared to that in Europe and America. Additional stratified analyses for short-term exposure studies after grouping by the national economic status, the HF risks associated with each pollutant ($PM_{2:5}$, $PM_{10}$, $NO_2$, $SO_2$, CO and $O_3$) in LMICs were higher than those in HICs.

**Air pollution and Heart Failure, Relationship with the Ejection Fraction:**

In a small study of 353 patients[14] in a tertiary care hospital with a diagnosis of HF demonstrates that short term nitrogen dioxide exposure is independently associated with admission in the HF with preserved ejection fraction population, even superior to classical described predictors, such as age, sex, hypertension and left ventricular ejection fraction.

**Conclusion:**

HF, particularly acute decompensated HF is a common occurrence with morbidity and high mortality. There is a close link between exposure to gaseous and particulate air pollutant and adverse outcomes in heart failure. It has been observed more in the low and middle income countries compared to that in high income countries. There is an urgent need of more high-quality studies to establish the effect of air pollution on heart failure outcomes in these countries. We need to have more national and international intervention to explore proper causality and biological mechanisms of the link in order to address this pervasive public health issue.

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Chapter - 9

# Air Pollution and Metabolic Health in India

*Thyparambil Aravindakshan Pramod Kumar, Viswanathan Mohan*

**Introduction:**

Metabolic disorders are a wide range of diseases that affect normal metabolic functioning and regulation. There are many metabolic orders. However, the most common of them is obesity, hypertension and diabetes.[1] The growing incidence has raised a public health concern globally. According to World Health Organisation, air pollution is considered a driving factor for metabolic health issues. Each year 4.2 million people die prematurely by disease caused by ambient air pollution.[2] Of these deaths, 38% are due to ischemic heart diseases, 20% to stroke, 18% to chronic obstructive pulmonary disease (COPD), 18% to acute lower respiratory infections and 6% to lung cancer. Low- and middle-income countries suffer the highest exposure and the greatest burden of these health impacts.[2] Inhalation of air pollution is a triggering factor for oxidative stress, systemic inflammation and imbalance in autonomic nervous system, which can lead to endothelium dysfunction and insulin resistance.[3, 4] Exposure to fine particular matter ($PM_{2.5}$) has shown to increase the risk of metabolic disorders, including obesity, type 2 diabetes (T2D) and insulin resistance. It alters glucose metabolism, induce inflammation and alter gut microbiota.[5, 6] While respiratory and cardiovascular events are well documented there is a growing interest in metabolic health. This review aims provide a comprehensive overview of the links between air pollution and metabolic disorders by going deeper into biological mechanism, epidemiological evidence and public health implications.

**Mechanism of Air Pollution Impact on Metabolic Health: (Figure 1)**

**Oxidative Stress and Inflammation:** Oxidation damage has led to several degenerative and non-degenerative diseases, including cardiovascular diseases (CVD) and pulmonary diseases, diabetes and Alzheimer's disease. Oxidation stress resulting from an imbalance between the formation of reactivate oxygen species (ROS) formation and individual antioxidant activity potentially does lead to damage of lipid metabolism, proteins and macromolecules such as DNA and RNA.[7] This causes stress and activates NF-κB, resulting in increased production of pro-inflammatory cytokines. Prolonged exposure to air pollution can disrupt insulin signalling and lipid metabolism, leading to the development of metabolic diseases such as diabetes and obesity.[8]

**Endocrine Disruption:** Hormone receptors and signalling pathways can be disrupted by air pollutants such as heavy metals, endocrine-disrupting chemicals (EDCs) and polycyclic aromatic hydrocarbons (PAHs). Obesity, diabetes and metabolic syndrome are examples of metabolic illnesses that are exacerbated by this interference, which throws off hormonal balance and metabolic homeostasis.[9] These pollutants have the ability to imitate or block hormones, resulting in imbalances that impact metabolism, growth, development and reproduction.[10] EDC found in

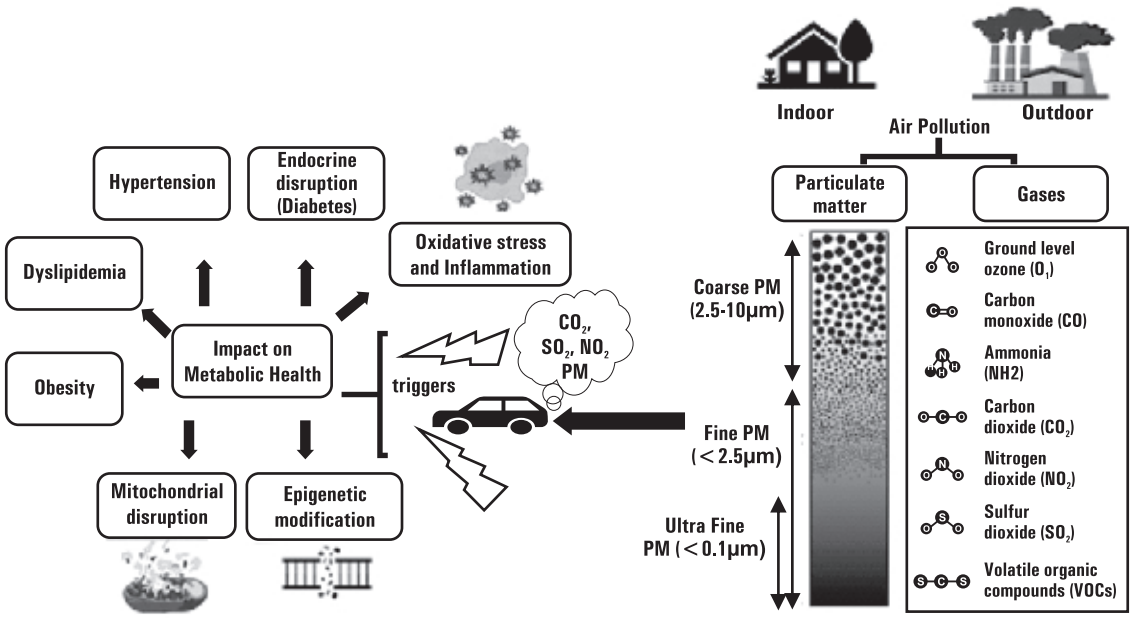


**Figure 1: Impact of Air Pollution on Metabolic Health**

contaminated air, have been connected to disorders like thyroid dysfunction, decreased fertility and anomalies in development. These pollutants work through a variety of pathways, including direct contact with hormone receptors, oxidative stress, ozone and inflammation.[11]

**Mitochondrial Dysfunction:** $PM_{2.5}$, ozone ($O_3$) and nitrogen oxides ($NO_2$) can penetrate the respiratory system and enter the bloodstream, directly impacting mitochondria—the cellular powerhouses responsible for energy production.[12] Specifically, it has been demonstrated in multiple cell models that repeated exposure to high concentrations of $PM_{2.5}$ greatly changes the formation of ROS in the mitochondria, depolarization of the membrane potential, oxidative phosphorylation and ATP. These changes disrupt metabolic processes, contributing to conditions such as obesity, diabetes and cardiovascular diseases, underscoring the importance of addressing air pollution to improve metabolic health outcomes.[13]

**Epigenetic Modifications:** Epigenetic alterations can influence gene expression without changing the nucleotide sequence, resulting in long-lasting effects on metabolic pathways.[14] Air pollution-induced DNA methylation can silence or activate essential metabolic genes, regulating processes such as glucose metabolism, lipid synthesis and insulin signaling. Histone modifications, including acetylation and methylation, might alter chromatin shape and accessibility, impacting gene expression. Furthermore, variations in microRNA (miRNA) and long non-coding RNA (lncRNA) levels can post-transcriptionally affect gene expression, affecting metabolic balance.[15]

Exposure to $PM_{2.5}$ has been linked to hypermethylation of insulin receptor substrate (IRS) genes, which impairs insulin signaling and increases the risk of T2D.[16] Similarly, histone modifications at the promoters of inflammatory cytokine genes can increase expression, contributing to chronic inflammation and metabolic syndrome. These epigenetic changes can be inherited, signaling that the impacts of air pollution on metabolic health may last for several generations.[17]

## Epidemiological Evidence Linking Air Pollution to Metabolic Health:

**Obesity:** Air pollutants may directly influence adipose tissue biology by altering adipocyte differentiation and function. $PM_{2.5}$, for instance, is a component cause of severe abnormal metabolism of obesity, potentially increasing the accumulation of fat tissue.[18] Prenatal exposure to air pollution has been associated with higher newborn weight and changes in anthropometric measurements in the first six months after birth, which could influence long-term growth trajectories and raise the risk of childhood obesity.[19] According to a study done in China, 1 µg/m³ (1.54%) increase in average $PM_{2.5}$ concentrations over the past 12 months has significant health impacts. This increase in air pollution results in a 0.27% rise in body mass index (BMI) and leads to higher rates of overweight and obesity, with increases of 0.82 and 0.27 percentage points, respectively.[20]

**Type 2 Diabetes:** Several studies have found a link between exposure to pollutants such $PM_{2.5}$, $NO_2$ and $O_3$ in the development of metabolic diseases. These pollutants can cause systemic inflammation and oxidative stress, which are known to decrease insulin sensitivity and glucose metabolism, increasing the risk of developing T2D.[21] A recent study from India[22] examined the link between $PM_{2.5}$ exposure and glycemic markers, as well as the incidence of T2D, in Delhi and Chennai. The study, part of the Centre for Cardiometabolic Risk Reduction in South-Asia surveillance (CARRS) project, tracked 12,064 adults in these cities over seven years. Daily average ambient $PM_{2.5}$ concentrations were determined using a hybrid satellite-based exposure model and ground monitoring assessments. The findings revealed that a 10 µg/m³ increase in monthly average $PM_{2.5}$ exposure was associated with a 0.4 mg/dL rise in fasting plasma glucose (FPG) and a 0.021 unit increase in HbA1c. Additionally, a 10 µg/m³ increase in average annual $PM_{2.5}$ exposure was linked to a 22% higher risk of developing T2D.[22] Another study in US veterans investigated the association between $PM_{2.5}$ air pollution and the risk of incident diabetes in a longitudinal cohort of 1,729,108 participants, followed for a median of 8.5 years. Adjusted models indicated that a 10 µg/m³ increase in $PM_{2.5}$ was linked to a 15% higher risk of diabetes (HR 1.15, 95% CI 1.08-1.22)[23] with a higher burden in low-income and lower-to-middle-income countries. Reducing $PM_{2.5}$ exposure could yield significant health benefits.[24]

**Metabolic Syndrome:** Long-term exposure to air pollution, which correlates with systemic inflammation and elevated CRP levels (OR = 1.049, 95% CI: 1.035-1.064 per 1.90 mg/L increase), are associated with an increased prevalence of metabolic syndrome (MetS).[25] A meta-analysis of 24 studies showed an increase of 10 µg/$m^3$ in annual concentrations of $PM_1$, $PM_{2.5}$, $PM_{10}$, $NO_2$, $SO_2$ and $O_3$ was associated with a 29% increase in MetS risk.[26]

**Dyslipidemia and Hypertension:** Ambient $PM_{2.5}$ exposure in Chennai and Delhi has been associated to changes in lipid levels, with increased $PM_{2.5}$ raising LDL-cholesterol (LDL-C) and total cholesterol (TC) in both cities. Triglycerides increased with rising $PM_{2.5}$ levels in Delhi, but stabilized in Chennai after a certain point. HDL-cholesterol (HDL-C) levels rose with short-term exposure but fell with long-term exposure in both cities.[27] These findings underscore the importance of tailored measures to alleviate the impact of air pollution on lipid metabolism and cardiovascular health in South Asia. Another study showed a link between elevated systolic blood pressure and an increased risk of incident hypertension and both short- and long-term exposure to high levels of $PM_{2.5}$ in urban Delhi. In particular, for each interquartile range difference in monthly and annual exposures, systolic blood pressure increased by 1.77 mm Hg and 3.33 mm Hg, respectively.[28] The

incidence of incident hypertension increased by 1.53× to 1.59× with prolonged exposure; the effects were particularly noticeable in people with larger waist-hip ratios. These results highlight how crucial it is to lower ambient air pollution in order to lower the risk of cardiovascular disease.

**Vulnerable Populations:**

**Children:** Long-term exposure to $PM_{2.5}$ has been linked to insulin resistance and obesity in children, potentially predisposing them to metabolic syndrome later in life.[29] Exposure to air pollution increases the risk of obesity in all age groups, including children and adolescents. A meta-analysis of 15 studies found that each 10 μg/$m^3$ increase in $PM_1$, $PM_{2.5}$, $PM_{10}$ and $NO_2$ increased obesity risk among children and adolescents by 41%, 28%, 12% and 11%, respectively.[30] These findings underscore the critical need for policies and interventions aimed at reducing air pollution to mitigate the growing burden of obesity in younger populations.

**Elderly:** Elderly individuals represent a highly susceptible population in terms of the effects of air pollution on metabolic health.[31] Long-term exposure to $PM_{2.5}$ is being linked to insulin resistance, systemic inflammation and cardiovascular illnesses, all of which are components of metabolic syndrome common in aging populations.[32] Long-term exposure to $PM_{2.5}$ has been associated with insulin resistance, systemic inflammation and cardiovascular diseases, all of which are components of metabolic syndrome prevalent in aging populations.[33]

**Socioeconomic Disparities:** Studies repeatedly suggests that people from lower socioeconomic backgrounds likely to live in places where air pollutants including $O_3$, $NO_2$ and PM are more prevalent. In underprivileged populations, this exposure raises the prevalence of metabolic syndrome and its associated complications, such as obesity, insulin resistance and hypertension. [34, 35] These health inequities are further exacerbated by elements like inadequate nutrition, higher stress levels and restricted access to healthcare. Comprehensive policies that increase access to healthcare and good living circumstances, prioritize environmental justice and lower pollution levels in underprivileged neighbourhoods are needed to address these disparities.

**Public Health Implications and Interventions:**

**Regulatory Policies:** Robust regulatory measures are required to prevent the detrimental impacts on populations pertaining to air pollution and metabolic health, as they have public health consequences. The main goal of regulatory actions should be to lower emissions of key pollutants like PM, $NO_2$, $SO_2$ and $O_3$ by enforcing stringent emission guidelines for residential, commercial and transportation sources.[36] The incidence of metabolic syndrome and related disorders, such as obesity, diabetes and cardiovascular illnesses, can be decreased by implementing these criteria, which will also help improve air quality.[37]

**Urban Planning:** Strategic urban planning interventions can significantly reduce air pollution exposure, thereby mitigating the risk of metabolic disorders. Introducing green spaces and urban forests in urban environments promotes physical activity among individuals, which may reduce obesity and enhance general metabolic health, as well as helps absorb pollutants and give cleaner air.[38] Promoting active transportation options, such as cycling and walking, through the development of safe and accessible infrastructure can reduce reliance on motor vehicles, subsequently lowering emissions of harmful pollutants.[39, 40]

**Public Awareness and Education:** Educational campaigns can educate the public about the causes of air pollution, the health risks associated with exposure and practical ways to reduce

personal exposure, such as using air purifiers, avoiding outdoor activities during peak pollution periods and supporting clean energy initiatives.[41] Incorporating knowledge about air pollution and its health consequences into curriculum at school can assist develop early awareness as well as encourage lifetime healthy choices. Community workshops and public seminars can be used to discuss air quality issues and encourage local participation in advocating for cleaner air. Collaborating with healthcare practitioners to create awareness about the health consequences of air pollution and preventive actions during medical consultations might help increase public knowledge and willingness to take action. This can help to reduce pollution and thereby prevent cardio metabolic diseases.[42, 43]

**Table 1: Future Research Directions**

| Study type | Aspect | Description |
|---|---|---|
| **Longitudinal studies** | Study duration | 5-20 years |
| | Sample size | Large cohorts of participants |
| | Key metrics | Incidence of diabetes, obesity, CVD |
| | Data sources | Air quality monitoring, health quality surveys |
| **Mechanistic studies** | Study models | Animal models (mice, rat), cell culture |
| | Mechanisms | Inflammation, oxidative stress, endocrine disruption |
| | Techniques | Genomics, proteomics, histology |
| | Outcomes | Biological pathways |
| **Intervention trials** | Trial duration | 1-5 years |
| | Sample size | Large cohorts of participants |
| | Interventions | Air purifiers, dietary supplements, policy change |
| | Outcomes | Changes in glucose, BMI, lipid profiles |
| **Geographic & Demographic validity** | Geographic focus | Urban vs. rural, different climate zones |
| | Demographic factors | Age, sex, socioeconomic status, race/ethnicity |
| | Data collection | GIS mapping, demographic surveys, air quality monitoring |
| | Key metrics | Variation in health outcomes based on location & demographics |

**Future Research Directions:**

Future research should focus on longitudinal studies to investigate long-term consequences, mechanistic studies to unravel biological processes, intervention trials to evaluate mitigation options and investigations into geographic and demographic variations to adapt treatments effectively. These research topics will provide a comprehensive framework to address the complicated interaction between air pollution and metabolic health, eventually directing public health policies and interventions. Table 1.

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Chapter - 10

# Air Pollution and Diabetes

*Banshi Saboo, Subhajyoti Ghosh*

**Introduction:**

Diabetes, a metabolic disorder influenced by genetic and environmental factors, contributes significantly to global disease burden. Rapid socioeconomic development has led to increased attention to the harmful health effects of air pollutants.[1] These pollutants include gaseous compounds like sulfur, nitrogen, carbon oxides, hydrocarbons and halogens, as well as atmospheric particulates like $PM_{10}$, $PM_{2.5}$ and ultrafine particles. According to the Global Burden of Disease Study 2017, air pollution ranks as the eighth leading risk factor for death, with 2.94 million deaths attributed to ambient particulate matter pollution globally.[2] Additionally, numerous studies have linked air pollution to metabolic syndrome and respiratory, cardiovascular and cerebrovascular diseases.[3]

The relationship between air pollution and Type 2 diabetes mellitus (T2DM) is that exposure to particulate matter (PM) air pollution, specifically $PM_{2.5}$, is associated with an increased risk of T2DM. This association has been supported by experimental and epidemiological studies. The burden of T2DM attributable to $PM_{2.5}$ air pollution is estimated to be approximately a fifth of the global burden of T2DM. Recent studies suggest air pollution may be linked to impaired glucose metabolism, insulin resistance and T2DM.[4] In 2019, the estimated death rate due to T2DM attributable to $PM_{2.5}$ exposure was 3.78 per 100,000 population and the estimated disability-adjusted life-years (DALYs) rate was 167 per 100,000 population. Approximately 13.4% of T2DM deaths and 13.6% of DALYs were contributed by ambient $PM_{2.5}$, while 6.5% of deaths and 5.9% of DALYs were contributed by household air pollution. The burden of T2DM attributable to air pollution is highest in Asia, sub-Saharan Africa and South America. The burden has increased by 50% since 1990, primarily due to population growth and aging. Reductions in household air pollution have been offset by increased ambient $PM_{2.5}$ pollution. Overall, air pollution is a major risk factor for T2DM and reducing air pollution may help reduce the global burden of the disease.

**Steps Involved in Calculation of Proportional Approach and Population Attributable Fractions (PAFs):**

The proportional approach and population attributable fractions (PAFs) were calculated using a combination of exposure data and relative risk estimates. Here is the step-by-step process:

1. **Exposure Assessment:** The study used the Data Integration Model for Air Quality (DIMAQ2) to estimate ambient air pollution exposure. This model integrated data from satellite-based measurements, ground measurements and chemical transport model simulations to generate

mean exposure for each location.

2. **Exposure-Response Curve:** The study derived an exposure-response curve using the meta-regression tool MR-BRT (meta-regression—Bayesian, regularised, trimmed). This curve represents the relationship between $PM_{2.5}$ exposure and T2DM risk. The curve showed a sharp increase in risk at lower exposures and a leveling off at higher exposures.
3. **Relative Risk Calculation:** The study used relative risk estimates from epidemiological studies to calculate the PAFs. The relative risk estimates were obtained from studies that assessed the impact of ambient air pollution and household air pollution on T2DM. These estimates were combined using the MR-BRT tool to account for between-study heterogeneity.
4. **Proportional Approach:** As individuals exposed to household sources of $PM_{2.5}$ are also exposed to ambient sources, a proportional approach was used to calculate PAFs for each risk factor. The mean annual ambient $PM_{2.5}$ exposure and the proportion of individuals exposed to PM from household solid fuel use were used to calculate a corresponding relative risk for each location.
5. **PAF Calculation: T**he PAF represents the proportion of cases that can be attributed to the risk factor. It was calculated using the formula PAF = (RR-1)/RR, where RR is the relative risk. The PAFs were initially determined for both ambient and household $PM_{2.5}$ pollution and then proportionally attributed to each source based on exposure data.
6. **Burden Estimation: T**he PAFs were then multiplied by deaths, disability-adjusted life-years (DALYs), years lived with disability (YLDs) and years of life lost (YLLs) for each location, age group, sex and year. This estimation was done for 204 countries and territories from 1990 to 2019.
7. **Uncertainty Analysis:** To account for uncertainties in the modeling, the study produced 1000 draws of all estimates and intermediate steps. The estimates were presented with 95% uncertainty intervals.

In summary, the proportional approach and PAFs were calculated by combining exposure data, relative risk estimates and population-level health outcomes to estimate the proportion of T2DM burden attributable to ambient and household $PM_{2.5}$ pollution.

**Epidemiological Evidence between Air Pollution and T2DM:**

**Effect on T2DM of Air Pollution Exposure, Duration and Dose Response:** Studies suggest a link between long-term exposure to ambient particulate matter and increased prevalence of T2DM. A cross-sectional study in Iran found a 5-year exposure to $PM_{10}$ associated with higher odds of developing T2DM.[5] Similarly, a Hong Kong cohort study demonstrated that long-term exposure to high levels of $PM_{2.5}$ increased the risk of T2DM prevalence and incidence.[6] However, some studies, like in Copenhagen or Arhus residents, did not find a consistent significant association between air pollution and T2DM.[7]

Another study shows association between $PM_{10}$ and IR in general population, but none for HbA1c.[8] Medium-term exposure to PM and accumulation mode particle number is positively linked with FBS levels and HbA1c in non-diabetic adults.[9] Short-term exposure to sulfur dioxide ($SO_2$) and carbon

monoxide (CO) is associated with increased presence of T2DM, longer hospital stays and higher expenses.[10] Studies reveal that medium-term exposures were most strongly associated with HbA1c.[11] Additionally, pollutants like $PM_{10}$, $O_3$ and $NO_2$ may increase IR depending on the lag period, but studies focusing only on older individuals may limit generalizability to younger populations.[12]

Recent studies have examined the dose-response relationship between air pollution and T2DM.[13] Bowe and colleagues found a substantial increase in T2DM risk with $PM_{2.5}$ concentrations above 2.4μg/$m^3$, with a moderate increase at concentrations above 10μg/$m^3$.[14] Significant dose-response relationships were also observed between HbA1c and $NO_2$ and $PM_{2.5}$ in T2DM participants and $NO_2$ in non-diabetic participants.[15] Tan and colleagues showed a dose-response relationship between FBS and $PM_{2.5}$ exposure duration.[16] These findings suggest that reduction in $PM_{2.5}$ exposure can yield health benefits.

Evidence from both "in vivo" and "in vitro" studies consistently link short-, medium- and long-term exposure to air pollution with increased inflammation.[17,18] Epidemiological studies support associations between air pollution exposure and increased inflammation, as well as disturbances in the autonomic nervous system, oxidative stress, inflammation, endoplasmic reticulum stress (ERS), apoptosis and broad metabolic derangements in glucose and insulin homeostasis. These changes provide biological plausibility for the association between $PM_{2.5}$ exposure and the risk of T2DM.[18, 19]

**Evidence from Human Studies:** Studies suggest that pollutants and high exposure to traffic-related particulate matter increases the pathogenesis of T1DM in young children. Long-term studies found that adults exposed to higher levels of traffic-related air pollutant containing nitrogen oxide were at increased risk of developing diabetes, with non-smokers, obese people and heart disease patients being more vulnerable. Traffic-related pollutants can lead to insulin resistance due to the production of oxidative stress. Additionally, short- and long-term increases in $NO_2$ and particulate matter exposure may result in elevated inflammatory biomarkers.

Another study found that, people residing near sites contaminated with higher levels of dioxin had higher levels of insulin resistance. People with highest dioxin levels had 5-fold higher IR as compared to lowest levels. As dioxins can concentrate in body fats, hence, obese individuals are more prone to having an increased dioxin body burden.

**Effects of Air Pollution:**

**Exposure on T2DM in Subpopulations:** Studies have examined the association between air pollution and T2DM among various sub-populations. Among older Americans, air pollution was associated with abnormal glucose metabolism and T2DM. Maternal exposure to $PM_{2.5}$ and $SO_2$ during pregnancy was linked to a higher risk of gestational DM in Taiwan and Sweden, but not consistently in the Netherlands or the US.[20] PM exposure may be particularly relevant for development of DM in women, especially non-smokers, obese individuals and those with heart disease.[21] Wholesome studies did not find significant associations between T2DM and air pollutants among women, a meta-analysis indicated a stronger association in women than in men.[22] Interestingly, higher fruit consumption and weight loss were associated with a decreased risk of diabetes mortality attributable to air pollution, especially for susceptible populations.[23]

**Exposure on T2DM in Countries With Different Economic Development Levels:** Studies in Canada, the US, Switzerland and Rome reveal a significant association between exposure to air pollutants like ultrafine particles, $NO_2$, $PM_{2.5}$, $PM_{10}$, ozone and nitrogen oxides and the risk of T2DM.[24, 25] In developed countries, some cohort studies found no significant link between PM exposure and T2DM. However, in China, cross-sectional studies revealed a significant association between $PM_{2.5}$ exposure and T2DM. Developing countries, especially China, show a high prevalence of both T2DM and air pollution, requiring further research to understand the relationship.[26]

Previous studies suggest populations in under-developed and developing countries may be more vulnerable to the effects of air pollution on T2DM.[27] Rapid industrialization in low-income and lower-to-middle income countries could increase the burden of T2DM-related health loss and death. Studies indicate a positive association between air pollution and T2DM risk, even in developed countries with lower pollution levels.

**The regions with the highest burden of T2DM caused by air pollution are:**

1. **Africa:** The burden of T2DM caused by air pollution is particularly high in sub-Saharan Africa, where most of the air pollution-attributable burden is due to household air pollution from solid fuels.
2. **Asia:** High burdens of T2DM caused by air pollution are estimated in Asia, including South Asia, Southeast Asia and East Asia. In these regions, the burden is mainly attributed to ambient $PM_{2.5}$ pollution.
3. **South America:** South America also has a high burden of T2DM caused by air pollution, with a significant contribution from ambient $PM_{2.5}$ pollution.

It is important to note that these regions have different contributions from ambient and household air pollution, with ambient air pollution playing a larger role globally, except in sub-Saharan Africa where household air pollution is the major contributor.

**Effects of Different Air Pollution Components:** Studies indicate that particle composition of air pollutants plays a crucial role in their association with T2DM.[28] Specific chemical components like elemental carbon and nitrate in $PM_{10}$ are linked to higher risks of T2DM complications.[29] Conversely, organic carbon is associated with lower T2DM rates. These findings suggest the importance of considering particle composition in evaluating the health effects of air pollution on T2DM.

**Possible Mechanisms of Air-Pollution- Induced Diabetes:**

**Inflammation may play a role in air-pollution- mediated glucose metabolism:** The primary site of action of air pollution is at the level of bronchioles and alveolar tissue, where the inflammatory process begins with release of cytokines as interleukin (IL)-8, IL-6, monocyte chemotactic protein-1 (MCP-1), macrophage inflammatory protein 2 (MIP2) and tumor necrosis factor-α (TNF-α). Thereby increase in level of C-reactive protein is seen leading to reduction of insulin sensitivity.[31]

Wang and colleagues suggested in their meta-analysis with 19,709 participants that significant dose–response association of IL-6 levels with T2DM relative risk (RR) 1.31 (95% CI 1.17–1.46).[32] Adipose tissues, being a major endocrine function responsible for lipid homeostasis and energy

balance.[33] The imbalance between WAT and BAT affects the balance of systemic energy and thus, may contribute to IR and adiposity development. Various studies on animal model confirmed that long-term ambient $PM_{2.5}$ exposure promotes IR, IGT, inflammation and mitochondrial alteration, which is a risk factor for T2DM development.[34] Exposure to $PM_{2.5}$ activates inflammatory response pathways mediated through JNK, NF-κB and TLR4, but inhibits insulin receptor substrate1 (IRS1)-mediated signal transduction. Furthermore, $PM_{2.5}$ exposure inhibited the expression of the peroxisome proliferator-activated receptors PPARγ and PPARα in the liver. Further investigation revealed that $PM_{2.5}$ resulted in significant increases in the expression of the proinflammatory genes TNF-α and IL-6 (M1), while there was no change in the expression of nitric oxidesynthase-2. In contrast, IL-10 and the alternative (M2) macrophage activation marker galactose-N-acetylgalactosamine-specific lectin (MgI1) were significantly down-regulated, suggesting that the inflammatory signaling pathway could be activated by $PM_{2.5}$.

Chen and colleaguesin their study has shown that pulmonary inflammation caused by lung-specific over expression of IKK2ca is sufficient to increase circulating levels of TNFα and IL-6, adipocyte expression of IL-6 mRNA and TNFα, aortic endothelial dysfunction and systemic IR. Lung- specific inflammation is sufficient to cause systemic inflammation and IR.[35] In conclusion, air pollution exposure may mediate the systemic inflammatory response, causing abnormal glucose tolerance, fat metabolism disorder and an increase in the IR index, which significantly increases the risk of diabetes.

**$PM_{2.5}$ Mediated Oxidative Stress in Insulin and Fat Metabolism:** Oxidative stress leads to an imbalance between reactive oxygen species (ROS)/reactive nitrogen species (RNS) and the ability of biological systems. ROS produced by induction of rodent tissue cells, under $PM_{2.5}$ exposure plays a crucial role in oxidative damage.[36] In pancreatic β-cells, ROS can lead to dysfunction, destruct mitochondrial structure and interfere with insulin signaling pathways, ultimately contributing to insulin resistance. Long-term $PM_{2.5}$ exposure activates oxidative stress pathways, affecting visceral adipose tissue, interfering fat metabolism and contributing to IR development.

**Endoplasmic Reticulum Stress involved in $PM_{2.5}$ induced Glucose Metabolism:** The endoplasmic reticulum plays a significant role in cellular homeostasis of the intracellular environment. ERS can be triggered by glucose deprivation, calcium regulation, redox regulation and viral infection or the over expression of proteins, which is a potential reason for IR.[37] Prolonged or intense ERS activates apoptotic signaling pathways like CHOP and IRE1-JNK. Airborne-mediated liver and pancreatic cell ERS may lead to development of T2DM. $PM_{2.5}$ induces inflammatory responses and activation of ERS in mouse WAT. Also, $PM_{2.5}$ may target the lung and liver, activate macrophages, ERS and UPR and stimulate lipogenesis, lipid deposition and adipocyte differentiation, along with visceral inflammation, IR, brown fat mitochondrial fat changes and ERS in the liver and eventually lead to diabetes.

**Effective Measures to Reduce Air Pollution:**

To conserve energy at home, work and everywhere else, consider carpooling, using public transportation, biking or walking whenever possible. Keep your car, bus and other engines properly turned and ensure that your tyres are properly inflated. Opt for environmentally safe paints and

cleaning products whenever possible and mulch or compost leaves and yard waste instead of burning them. Additionally, consider using gas logs instead of wood for an eco-friendlier option. During days when ozone levels are higher than usual, avoid excessive idling of your automobile, instead combine errands and reduce trips. Also, conserve electricity and do not set air conditioners to below 78 degrees.

**Conclusion:**

Existing epidemiological evidence suggests that T2DM-related biomarkers increase with increase in exposure duration and concentration of air pollutants. Experimental studies confirm the adverse effects of air pollution on T2DM via various molecular mechanisms. Further studies are required to establish effective control measures for air pollution to reduce the global burden of T2DM.

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Chapter - 11

# Air Pollution and Respiratory Disorders

*Vishal Chopra, Vidhu Mittal, Siddharth Chopra*

**Introduction:**

Air pollution is the leading environmental cause of human death, accounting for an estimated 9 million (16%) of all global deaths per year.[1] Air pollution refers to the presence of substances in the atmosphere that are harmful to human health, the environment and the climate. These pollutants can be in the form of gases, particulate matter or biological molecules and originate from various sources, both natural and anthropogenic (human-made).

**Major Pollutants:**

1. Particulate Matter (PM): Tiny particles or droplets in the air, which can penetrate deep into the respiratory system and cause health problems.
2. Nitrogen Oxides (NOx): Gases that contribute to the formation of smog and acid rain and can irritate the airways.
3. Sulfur Dioxide ($SO_2$): A gas that can cause acid rain, which harms ecosystems and structures and can affect respiratory health.
4. Carbon Monoxide (CO): A colourless, odourless gas, produced by incomplete combustion which can interfere with the oxygen-carrying capacity of blood.
5. Volatile Organic Compounds (VOCs): Organic chemicals that evaporate at room temperature and can cause health effects, from eye, nose and throat irritation to more serious effects including damage to the liver, kidney and central nervous system.
6. Ozone ($O_3$): At ground level, ozone is a major component of smog, harmful to lungs and plant life.

**Sources:** Air pollutants are released from various sources:

Natural: Volcanic eruptions, wildfires and dust storms.

Anthropogenic: Vehicle emissions, industrial discharge, agricultural activities and the burning of fossil fuels in power plants.

**Effects:** The effects of air pollution are wide-ranging and significant.

Health Impact: Air pollution is a major environmental risk to health, causing respiratory diseases, cardiovascular diseases and can even lead to premature death.

Environmental Damage: It can harm wildlife, damage forests and affect lakes and streams, leading to a loss of biodiversity.

Climate Change: Certain air pollutants, especially carbon dioxide ($CO_2$) and methane ($CH_4$), are greenhouse gases that contribute to global warming and climate change.

**Global Impact:**

- **Mortality:** Air pollution is responsible for millions of deaths annually worldwide. According to the WHO, around 7 million people die each year due to exposure to fine particles in polluted air, which penetrate deep into the lungs and cardiovascular system, causing diseases including stroke, heart disease, lung cancer, chronic obstructive pulmonary diseases (COPD) and respiratory infections, including pneumonia.[2]
- **Morbidity:** Beyond deaths, countless more suffer from non-fatal health issues due to polluted air, including asthma exacerbations, decreased lung function and other respiratory and cardiovascular conditions.

**Biological Pathway Leading to Respiratory Impact Due to Air Pollution:**

The impact of environmental pollution on respiratory health unfolds through a detailed biological sequence, particularly influenced by air contaminants like particulate matter, nitrogen dioxide, sulphur dioxide, ozone and volatile organic compounds. These elements initiate a cascade of biological reactions that can lead to a spectrum of respiratory conditions, from minor irritations and coughing to severe diseases such as chronic obstructive pulmonary disease (COPD), asthma and lung cancer. Below is a restructured explanation of this biological pathway:

**Initial Exposure to Pollutants:** The pathway begins when individuals breathe in air laden with harmful pollutants. Fine particulate matter, for instance, can evade the filtration mechanisms of the nose and throat, penetrating deeply into the lungs.

**Inflammatory Reaction:** The presence of the pollutants in the respiratory system triggers an inflammatory reaction. The body perceives these particles and gases as external threats, prompting an immune response to combat them. This involves the secretion of inflammatory agents like cytokines and chemokines, leading to inflammation and swelling in the airways and lung tissue. A positive association between air pollution and the prevalence of allergic rhinitis in children and adults has been seen especially in regards with high amount of particulate matter in the environment.[3]

**Oxidative Stress Induction:** Air pollutants can produce or induce the production of reactive oxygen species (ROS), causing oxidative stress. This condition arises when there's an imbalance between ROS production and the body's ability to neutralize these compounds or repair the damage they cause, further aggravating inflammation and harming lung cells and tissue.

**Deterioration of Lung Function:** Ongoing inflammation and oxidative stress can lead to structural modifications in the respiratory system. For example, asthma involves airway remodelling, where the walls of the airways thicken and lose elasticity, complicating the breathing process. In diseases like COPD, the structure of the air sacs and airways is compromised, diminishing the lungs' efficiency in oxygen exchange and carbon dioxide elimination.

**Heightened Risk of Respiratory Infections:** Pollution weakens the respiratory system's defences, making it more susceptible to infections. Pollutants can also disrupt the muco-ciliary

clearance system, responsible for expelling inhaled pathogens and debris from the lungs.

**Exacerbation of Existing Respiratory Issues:** Air pollution can worsen symptoms for those with pre-existing respiratory ailments such as asthma or COPD. Even low pollution levels can pose significant health risks to these vulnerable groups.

**Long-term Consequences:**

Long-term exposure to polluted air can cause chronic respiratory diseases,[4] contribute to the development of lung cancer and even impact other body organs and systems through systemic inflammation and oxidative stress initiated in the lungs. There has also been seen positive correlation with the traffic related air pollution (TRAP) and development of circulatory, ischemic heart disease and lung cancer mortality, asthma onset in children and adults and acute lower respiratory infections in children.[5, 6] An increasing number of studies have indicated that indoor air pollution, as well as lifestyle, contributes to the high prevalence rate of asthma and deterioration of pulmonary function.[7, 8, 9] It has also been seen that individual with pre-existing co-morbidities like cardiovascular diseases, hypertension, diabetes, cancer could be susceptible to effects of short-term air pollution.[10]

The air pollutants (carbon monoxide, cadmium, lead etc) which cause primarily non respiratory effects despite entering the body via respiratory route have not been discussed in this chapter.

1. **Particulate Matter:** PMs are usually carbon particles, with other chemical components, microbes and heavy metals deposit on their surface.[11] $PM_{10}$ and $PM_{2.5}$ are two frequently-used indices for PM monitoring. $PM_{2.5}$ is now used as a main indicator of risk to health from particulate pollution in the air quality indices (AQIs) in many countries. Motor vehicles, power plants, residential wood burning, forest fires, agricultural burning, some industrial processes and other combustion processes are believed the major sources of them.[12] It is believed that the largest single source of airborne PM from motor vehicles is derived from diesel exhaust. The relationship between exposure to ambient particle pollution concentrations and adverse respiratory effects was clearly demonstrated in a series of studies conducted in the Utah Valley by Pope (1989, 1991).[13] When a steel mill, which was the source of 90 % of local particle pollution emissions in the Utah Valley, was out of operation for one year, hospital admissions for bronchitis and asthma in the valley decreased by almost 50 % and were comparable to those in other regions not polluted by the mill. Once mill operation resumed, hospital admissions increased. The mortality rate in the valley showed a similarly positive association with particle pollution levels during the same period.

   There has also been seen a positive correlation of $PM_{2.5}$, $PM_1$ and $NO_2$ exposure (either short- or long-term) on heart failure risk.[14] It is also statistically significantly associated with higher rates of hospital admissions for natural causes, cardiovascular disease, respiratory disease and with emergency department visits for respiratory diseases.[15, 16]

   Though the respiratory system has remarkable resilience to air pollution via its repeated mobilization of defence and repair mechanisms, constant exposure to elevated particle pollution will contribute to reduced respiratory function, even in apparently healthy people.

Therefore, although we cannot completely avoid particle pollution exposure, taking simple steps to reduce exposure will reduce the severity of lung and systemic adverse health effects in both healthy and more sensitive people.

2. **Indoor Air Pollution:** The World Health Organization estimates that household air pollution (HAP) accounts for an estimated 4.3 million premature deaths annually and 110 million disability-adjusted life years lost.[17] Indoor air includes pollutants that penetrate from the outdoors, as well as sources that are unique to the indoor environment. Thus, indoor pollution differs from outdoor pollution in source, composition and concentration and as a result the effects of indoor air pollution cannot be easily extrapolated from studies of outdoor air pollution.[18] Biomass fuels, often referred to as solid fuels, include wood, dung, agricultural crop waste and coal. Biomass is the main domestic energy source for ~40% of all households and ~90% of rural households in LMICs. The burning of biomass fuel leads to release of gases like $NO_2$ and CO and particulate matter (PM). The respiratory illnesses are though more common in low middle income countries but these are equally debilitating in high income countries where population in rural areas are still using biomass fuel for heating their houses. There was an association between PM and fractional exhaled nitric oxide (FeNO), lung function, oxygen saturation, childhood asthma and symptoms of chronic obstructive pulmonary disease (COPD) patients. The other indoor air pollutant is volatile organic compounds (VOCs). VOC sources included household products, cleaning agents, glue, personal care products, building materials and vehicle emissions. High VOCs were associated with upper airways and asthma symptoms and cancer.[19]

3. **Household Air Pollution (HAP):** WHO estimates that almost 3 billion people worldwide rely on polluting fuels such as wood, coal, crop waste, animal dung or charcoal paired with inefficient stoves for cooking and heating.[20] These fuels burn inefficiently, emitting high concentrations of both gaseous and particulate pollutants within households.[21] There is now considerable evidence linking household air pollution to a broad range of cardiorespiratory,[22, 23, 24] paediatric and maternal[25] conditions, with these disease categories specifically highlighted by WHO.[26] Exposure to household air pollution is among the top ten risk factors for disease, with the highest prevalence observed in the poorest communities in low-income and middle-income countries (LMICs).[27]

   Household air pollution is associated with an increased risk of adverse health effects, with the strongest association observed for respiratory diseases such as COPD and lung cancer. There was clear geographical variation, with the overwhelming majority of burden associated with household air pollution seen in LMICs.[28] HAP is associated with increased risk for all kinds of respiratory illnesses.[29]

4. **Nitrogen Oxide:** NOx formation can occur as the result of anthropogenic action, such as burning fossil fuels in stationary sources like industrial plants or in motor vehicles.[30] Nitrogen oxides (NOx), considered as primary air pollutants, act as precursors of secondary air pollutants, such as ozone ($O_3$), nitric acid ($HNO_3$) and others.[31] NOx also participate in the formation of photochemical smog consisting of products resulting from interaction with organic

compounds and together with sulfur dioxide ($SO_2$), contribute to the formation of acid rain.[32] $NO_2$ is a very toxic gas that can trigger cell damage and inflammatory processes throughout the respiratory system, from the nose to the pulmonary alveoli. It is estimated that diesel truck engines produce five times more NOx than lighter, gasoline-powered engines, per vehicle.[33] Increased NOx is associated with increased mortality in adults and elderly.[34, 35]

**Impacts of Air Pollution on Children:**

Children are especially vulnerable to air pollution because they breathe faster and more often through their mouths, taking in more pollutants than adults. Studies have shown that air pollution can affect children's brain development during the critical early years of life and, in some cases, cause stunting. In 2019, 20% of newborn deaths were attributed to air pollution, most related to complications of low birth weight and preterm births.[36] Mitigating exposure to environmental pollutants is essential for respiratory health protection. This involves implementing policies to cut down emissions from various sources, including industrial, vehicular and other human activities, along with individual actions like using indoor air filters and limiting outdoor activities when pollution levels are high.

Global cooperation and policies, such as the Paris Agreement, aim to tackle air pollution and its contribution to climate change, highlighting the need for a concerted effort to protect human health and the environment from the effects of air pollutants.

**Measures for Reducing Adverse Affects of Air Pollution:**

1. People should keep a good living habit and regulate their daily activity according to the local air quality report. For people with chronic respiratory disease like COPD, reduction of exposure to indoor and outdoor air pollution can reduce the risk for acute exacerbation of COPD. For asthma patients, less exposure can reduce the onset of asthma. Regular treatments under the guidance of physicians are recommended.
2. Regulate daily activity according to the air quality index (AQI). People can reduce the detrimental effects of ambient air pollution by shorting the time spent on activity outdoor and the level of activity when AQI is beyond a specified level. The AQI is an index for reporting daily air quality, which has been used by the U.S. Environmental Protection Agency to provide simple information about local air quality.
3. Use of Masks: Wearing personal protective equipment (N95 mask or equivalent) might be a useful for avoiding detrimental effect of ambient air pollutants.[37] Surgical face mask and plain face mask are designed for preventing and avoiding spillage droplets spread and large particulate materials usually hundred micrometer large. But they are not of any use in preventing inhalation of fine articles like $PM_{2.5}$.

**Measures for Reducing Indoor Air Pollution:**

1. To choose furniture with less chemical emission, check the ventilation system of the house regularly, ventilate the room as opening the door and windows regularly to fresh the air so as to reduce harmful gaseous pollutants from the furniture and construction material, use clean fuels instead of biomass fuels if possible, improve cooking stoves to burn fuel more efficiently and

use a chimney woodstove to vent emissions to outside and similar interventions are feasible and recommended.[38, 39]

2. Air filtration is frequently recommended as an environmental control measure for patients with chronic respiratory disease. Particle filtration systems can supply filtered air into the room or whole-house, reducing indoor exposures to particles from outdoor air and reduce the morbidity and mortality associated with air particles.[40]

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Chapter - 12

# Air Pollution and Asthma and COPD

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**Introduction:**

Chronic Obstructive Pulmonary Disease (COPD) and asthma are two major chronic airway diseases. As per available data, in 2015, more than half a billion individuals in different parts of the word were diagnosed as asthma or COPD. Although, asthma constitutes a majority of these cases (two thirds), COPD related mortality was reported to be twice that of asthma.[1]

COPD and asthma are obstructive airway diseases, characterised by airflow limitation, chronic airway inflammation and progressive decline in lung function. Pathological changes in both these airway diseases are the result of interplay of environmental factors and immunogenetic configurations of the individual.

Since air is an integral and major component of the environment and is inhaled and exhaled in large amounts– nearly 8 to 10 litre per day by a healthy individual, its quality is bound to affect lung health, mainly in form of lung cancer, infections and airway diseases e.g. asthma and COPD. Air pollution weather it is outdoor (ambient) or indoor (house hold and work place) is a major cause of human morbidity and mortality and is the largest environmental health threat globally.[2]

In year 2019, Global Observatory on Pollution and Health at Boston College, the Indian Council of Medical Research and the Public Health Foundation of India reported that air pollution in India resulted in 1.67 million deaths, the largest pollution related deaths in any country in the world, estimated to be accounted for $36.8 billion in economic losses.[2] Roughly half of these are from respiratory diseases or their sequelae. In addition to many etiological factors, traditionally discussed, recent studies have reported the relationship between air pollution and the development and exacerbation of COPD and asthma. In this article, we attempt to briefly discuss the epidemiological evidence and pathophysiological aspects for the impact of exposure to air pollution on asthma and COPD.

**Air Pollution Major Sources and Composition:**

Environment is everything that surrounds us, living, non-living with natural forces and their interactions. Environmental pollution is any addition of erroneous or harmful substances, chemical, physical or biological agent or energies (pollutants) to the environment that changes the natural composition of the environment. The variables of environmental pollution can be air, water, soil, noise, light, other energies and changes in their natural values that can have serious consequences for ecosystems and human life. Common sources of air pollution are household combustion devices, motor vehicles, industrial activities and forest fires. There are some differences in sources

and composition of pollution in outdoor (ambient) and indoor air pollution (household and workplace), but there are always chances of overlapping of sources and pollutants.

Categorisation of air pollutants, can be done on the basis of their

i) Source: Indoor and outdoor.

ii) Nature: Gases or particles.

iii) Size: Ultrafine, fine and coarse.

Air pollutants, whether they are of indoor or outdoor origin, are a mixture of gases, liquids and solids with vast variation in size and constituents, depending upon the source of origin.

Indoor Air Pollution (IAP): Generated inside homes or buildings through occupants' activities, such as cooking (biomass, fossil fuel), smoking, use of electronic machines, use of consumer products or emission from building materials, cleaning, gardening, pets and household dust emitting pollutants like - carbon monoxide (CO), volatile organic compounds (VOCs), particulate matter (PM), aerosol, biological pollutants and many others.[3]

Outdoor air pollution: Mainly originate from incomplete burning of fossil fuels in automobiles, agricultural, industrial and energy production activities, deforestation, volcano, dust storms and wild fires.

Most of the pollutants responsible for major human health concerns include particulate matter and gaseous molecules including greenhouse gases, carbon dioxide ($CO_2$), methane ($CH_4$), nitrous oxide (NO), hydrofluorocarbons (HFCs), perfluorocarbons (PFCs), sulphur hexafluoride ($SF_6$), nitrogen trifluoride ($NF_3$) and other gases such as carbon monoxide (CO), ozone and nitrogen dioxide ($NO_2$). Air pollutants are also classified as primary or secondary. Primary pollutants include sulphur dioxide ($SO_2$), nitrogen oxides (NOx: NO and $NO_2$), organic compounds (VOCs), metals and particulate matter (PM). Most of them are emitted directly into the atmosphere by industries, thermoelectric power plants, combustion of fossil fuels used in motor vehicles and other industries. Secondary pollutants are formed by chemical reactions induced by photochemical oxidation of VOCs, catalysed by nitrogen oxides (NOx). Ultimately, in the presence of ultraviolet rays from sunlight, they give rise to production of ozone.[4] Some other secondary pollutants are also formed through a process of nucleation and condensation of gaseous pollutants ($NO_2$ and $SO_2$) and acid mists, such as NOx and secondary PM, formed by sulphates and nitrates.[5] Out of all air pollutants, airborne particulate matter (PM) is a major causative factor for premature mortality and cardiopulmonary morbidity in the form of exacerbation of asthma and COPD, ILD and lung cancer. Particulate matter (PM), most of the airborne particulate matter (PM) are not single pollutants, but are complex mixtures of many chemicals in the form of solids and aerosols composed of small droplets of liquid, dry solid fragments and solid cores with liquid coatings. There is vast variation in size, shape and chemical composition of PM and may contain inorganic ions, metallic compounds, elemental carbon, organic compounds and compounds from the earth's crust. (Table-1) Depending on the size of particles inhaled, they are deposited in different parts of the airway.[6] (Table-1)

**Air Pollution: Impact on Asthma and COPD Prevalence:**

There are evidences that exposure to air pollutants, exacerbates pre-existing airway disease, but it has not yet been definitely established that long-term pollution exposure increases the risk of new-

**Table : 1. Particulate Matter (PM) – Source, Constituents and Deposition in Lung**

| Particulate Matter {Size in mm} | Source | Constituents | Deposition In Lung |
|---|---|---|---|
| **PM** $_{10\text{-}2.5}$ {2.5–10 µm } **(Coarse)**[7]<br>Life span-min. to hrs.<br>Transit distance-1 to 10 km. | Mechanical disruption, e.g. crushing, grinding, dust from roads and other construction activities, uncovered sand, industry, ash from fossil fuel burning, pollen grain and mold spores.[7] | Ionic components: $NO_3^-$, $Cl^-$, $SO_4^-SO_2$ and $Ca^{+2}$, $NO_3^-$, $Cl^-$ and $NH_4$ +, Si, Fe and Al | Mostly deposited in upper respiratory tract and larger airways.[8] |
| **PM** $_{2.5}${2.5 or less µm} **(Fine)**<br>Life span- days to wks.<br>Transit distance 100 & 1,000 km | Vehicle exhaust, fossil fuel combustion, biomass burning, smelting, metal processing, chemical industries, burning of organic materials such as oil, wood and coal. | Comprises multiple sulfates, nitrates, carbon compounds, ammonium, hydrogen ions, and metals (Pb, Cu, Zn, Mn & Fe). | Upper and lower airways. Deposit on the surface of the deeper parts of the lungs. |
| **PM** $_{0.1}$ {0.1 or less µm } **(Ultrafine Particles - UFP)** 05<br>Smaller than 300 nm are considered as nanoparticles<br>Residence time ~1 Wk.<br>Transit distance-0.2 to 200 miles, depending upon environmental conditions[11] | Produced by dynamic formation processes e.g. nucleation, condensation and coagulation, mostly from compounds in the gaseous phase.<br>**Natural Sources:** Forest fires, volcanic eruptions, marine aerosols, local minerals and biological particles.<br>**Anthropogenic Sources:** Combustion of gas, coal or hydrocarbons, biomass burning, forest fires, waste disposal, vehicular & industrial emissions, construction activities, cigarette smoke.[8] | Carbonaceous material with small contributions of inorganic ions, sulphates, nitrates, carbon compounds, ammonium, hydrogen ions, silicon and other metals, gas phase PAH, ozone, $SO_2$, NOx, CO, methane and black corbon.[8] | Deposited in peripheral lung tissues and can penetrate alveoli, leading to systemic translocation.[9, 10] |

onset asthma or COPD. In the year 2020, in a consensus document of American Thoracic Society based on a workshop on outdoor air pollution and new onset airway disease, concluded that long-term exposure to air pollution (specially traffic-related air pollution e.g. nitrogen dioxide and black carbon) is associated with onset of childhood asthma. However, evidence is not sufficient to support its causal role in adult onset asthma or COPD.[12]

A landmark ongoing population-based prospective cohort study derived from UK Biobank, enrolling approximately half million participants reported that long term exposure to air pollution is associated with increased risk of COPD. The risk increases amongst genetically susceptible individuals, having pro-COPD lifestyle.[13]

It was also reported that nitrous oxide was positively associated with an increased risk of outpatient

visits of patients presenting as COPD, whereas, ozone, sulphur dioxide and nitrous oxides were positively associated with an increased risk of outpatient asthma visits.

It has been observed that daily increase in PM, corresponds to increase in deaths and hospitalizations for airway diseases and cardiovascular diseases.[14]

Several studies showed that air pollutants e.g. $PM_{2.5}$, $O_3$, CO, $NO_2$ and $SO_2$ were related to faster decline in lung functions and significant increase in outpatient and hospitalization rates of chronic respiratory diseases e.g. asthma and COPD.[14, 15]

Studies from US and Beijing reported that each 10 $\mu g/m^3$ increase in $PM_{2.5}$ was associated with a 1.61% (US) and 0.82% (Beijing) increase in the risk of hospitalization for patients with COPD.[16, 17]

A large population based (5.1 million aged 35 to 85 yrs.) retrospective cohort study in the city of Ontario in Canada reported that increase (interquartile-range) in fine PM more than 2.5 µm diameter ($PM_{2.5}$), $NO_2$, $O_3$and the redox-weighted average of $NO_2$ and $O_3$ (Ox) was associated with 3-7% higher incidence of COPD. On the contrary there was no convincing evidence that incidence of adult onset asthma was associated with past exposure to air pollution.[18]

Several other studies have assessed the effect of long-term exposure to air pollution and risk of COPD but did not arrive at the same conclusion. Studies from, Europe, ELAPSE study [Effects of Low-Level Air Pollution: A Study in Europe], Korea, Canada (Toronto) has reported significant association between exposure to air pollutants and COPD risk.[19, 20]

On the contrary, there are studies reporting that $PM_{2.5}$ and $PM_{10}$ were negatively associated with the risk of asthma outpatient visits. A possible reason for this may be, that the concentrations of ozone and $PM_{2.5}$ are seasonal and that asthma is affected by many other factors e.g. pollens and many meteorological factors.[14]

A cohort study from Denmark assessing the impact of 35 year's of exposure to traffic related air pollution concluded that it may contribute to the development of COPD, with possibly enhanced susceptibility amongst patients having diabetes and asthma.On the contrary, authors observed that groups having exposure of 25-years or 15-years periods did not show significant associations with COPD risk.[21]

Similarly, ESCAPE (European Study on Chronic Air Pollution Effect) study, also reported that none of the air pollutants e.g. $PM_{2.5}$, $PM_{10}$, NOx, $NO_2$, were significantly associated with the incidence of COPD.[22]

There are several reports on the impact of short term exposure of air pollution on airway diseases favouring an increase in rate of deterioration in lung functions, acute exacerbations, hospital visits and hospitalisation of asthma and COPD cases. There have been convincing evidences of causal relationship with traffic induced childhood asthma, but not in adult asthma. There are studies suggesting relationship of long term exposure to air pollutants, COPD and asthma but causal relationship is yet to be established.

**Pathophysiology of Pollution Induced Airway Diseases:**

Environmental factors in combination with immunogenetic configuration of the individuals and genetic susceptibility constitute the major risk factors for chronic airway diseases.[23]

Air pollutants may enter the human blood stream through the nose, mouth, skin, respiratory tract and the digestive tract. Airborne particulate matter (PM) especially nano particles play the leading role for premature mortality and morbidity due to respiratory diseases specially exacerbations of asthma, COPD, idiopathic pulmonary fibrosis and lung cancer. As the airway epithelium is the major site of PM deposition, it bears the critical effect of exposure to PM and other air pollutants.[6] The pseudo stratified human airway epithelium is composed of several subsets of cells, including secretory goblet and club cells (GC and CIC), ciliated cells (CC), basal cells (BC), neuroendocrine cells (NC) and recently identified ionocytes, each responsible for a specific function.[3] (Figure 1A).

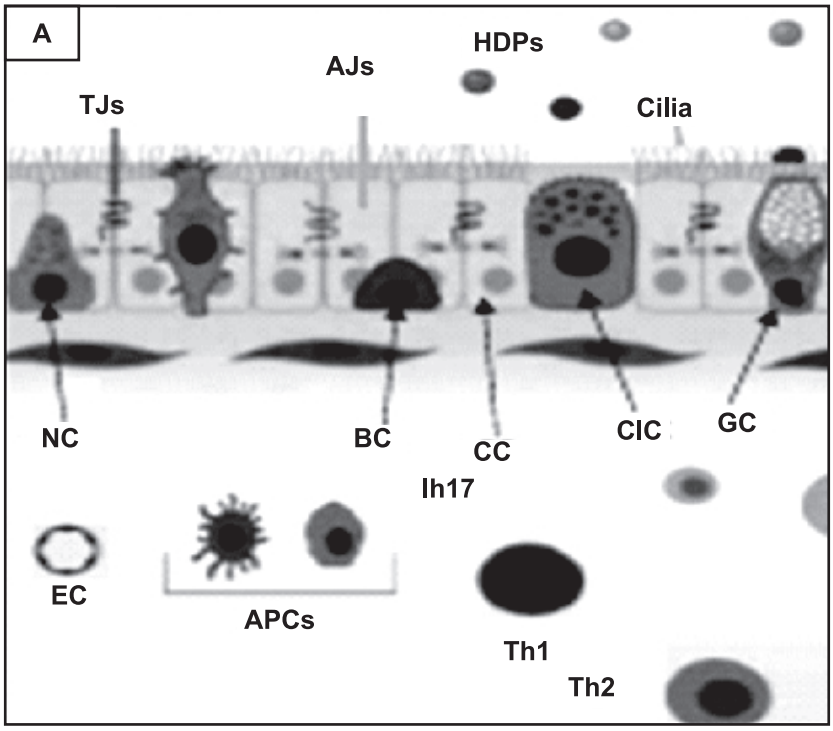



**Figure 1: Healthy Airway Epithelium**

Abbreviations : **CC:** Ciliated cell, **NC:** Neuroendocrine cell, **BC:** Basal cell, **CIC:** Club Cell, GC: Goblet Cell, **EC:** Endothelial Cell, **APC:** antigen-presenting cell, **AJ:** adherens junction, **HDP:** host defence proteins

Healthy airway epithelium is protected against pathogens by strong physical junctions between its adjacent cells and by releasing innate immune host defence proteins (HDPs).[3]

In normal circumstances airway epithelium acts as a mechanical and immunological barrier through its protective functions e.g. airway cleaning employing mucociliary machinery, metabolism of pollutants and production of antimicrobial and immune mediators, also contributing to the protection of complete gas exchange unit, including alveoli.

Normally, mucus produced by goblet cells, traps and neutralises noxious particles that can subsequently be cleared by ciliary movements of the ciliated cells. Basal cells (BC) are capable of

regenerating these secretory subsets and ciliated cells. Airway epithelial cells (AECs) protect the submucosal layer against noxious particles, allergens and respiratory pathogens, by forming, physical, mucosal and innate immune barriers.

Many hypothesis for the possible mechanisms for air pollution to cause airway diseases favoured by studies have been postulated, but face different levels of acceptance. Inhalation of air pollutants especially nanoparticulate components, generated from primary combustion promote airway epithelial barrier dysfunction, by inducing oxidative stress, pro-inflammatory responses and imbalance of systemic inflammation, autophagy, apoptosis and epigenetic modifications.[6,24]

Exposure to Airborne PM may cause (Figure-1B & C):

- Disruption of the tight junctions (TJs) and adherens junction (AJs) between the airway epithelial cells (AECs); Including disruptions of zonula occludens (ZO-1), occludin and E-cadherin.
- Mucociliary dysfunction by reduction in number and activity of cilia.
- Goblet cell metaplasia leading to increased mucus production.
- PM in the airway submucosa is presented to adaptive immune cells by antigen-presenting cell (APCs) inducing an increase in major histocompatibility complex class II (MHCII) on APCs leading to expansion of adaptive immune cells and production of inflammatory cytokines that further contribute to airway epithelial barrier dysfunction.
- Induces submucosal accumulation of neutrophils which may lead to barrier dysfunction by secretion of serine protease (SPs).

Several other studies have reported elevated level of blood biomarkers of systemic inflammation (e.g., IL-6, IL-8 and TNF-α), coagulation (e.g., fibrinogen), soluble intercellular adhesion molecule-1 (sICAM-1), DNA methylation levels were influenced by exposure to air pollutants.

Long term exposure to air pollutant especially fine particulate matter and ozone can cause airway remodelling, which can lead to induction and worsening of asthma and COPD.[12]

Exposure to air pollutants in association with extremes of temperature (high and low) may increase susceptibility of airway for infections with microorganisms present in environment, buccal cavity and other part of respiratory tract. Airway infection plays a major role in exacerbation of airway diseases and has been considered to have some role in their etiopathogenesis also.[3]

Prolonged exposure to many of the inhaled pollutants directly or indirectly adversely affect airway epithelial barrier system leading to the favouring of colonisation and invasion of respiratory pathogens and thus may contribute to the development and progression of COPD and asthma.[25]

Exposure to burning biomass fuel is an important etiological factor for COPD in India and many underdeveloped and developing countries. There is increasing evidence to suggest that COPD cases that are linked to exposure to the emissions released by burning biomass fuels show a distinct phenotype with more prominent airway disease (bronchitis) and less alveolar damage (emphysema).[26,27]

**Conclusion:**

There are convincing evidences that air pollution exposure exacerbates pre-existing airway disease, but it has not been firmly established that long-term pollution exposure increases the risk of new-onset asthma or COPD. However, long-term exposure to traffic-related air pollutants (e.g. $NO_2$ and black carbon) is associated with onset of childhood asthma, but the evidence for a causal

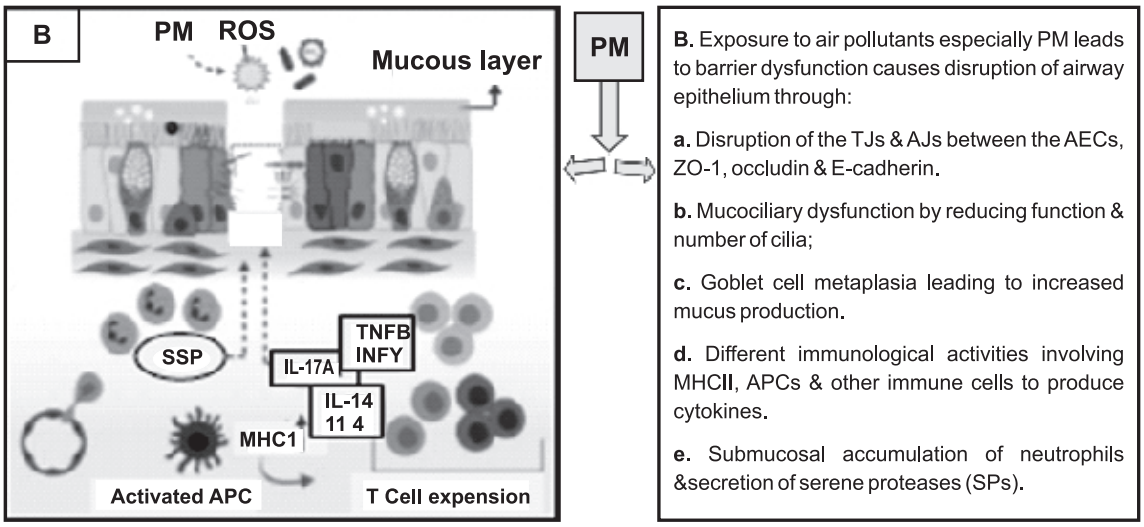
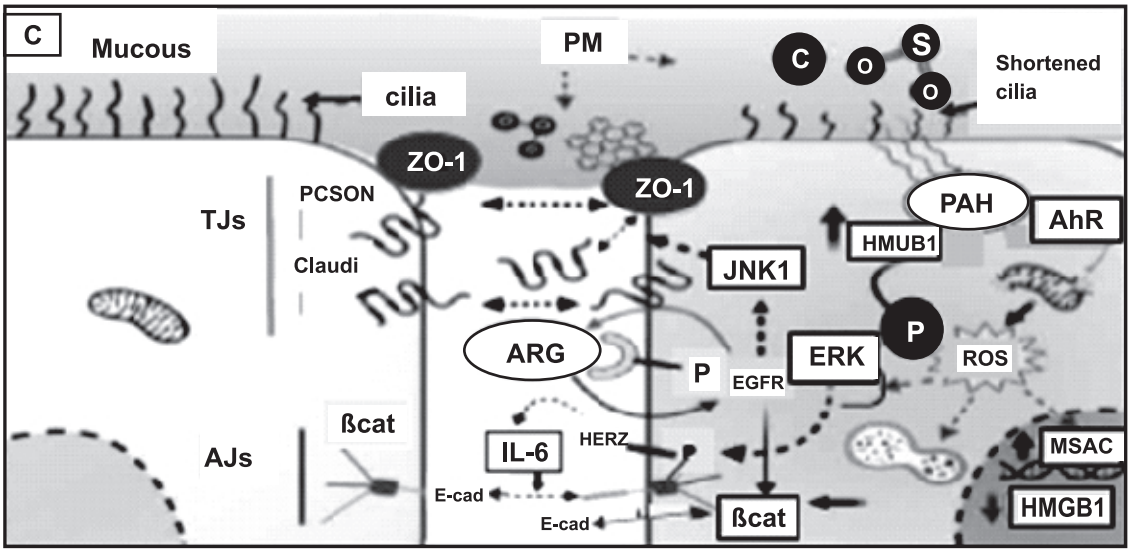



**Figure 1B & C: Dysfunction of Airway Epithelial Barrier System by Inhalation of Air Pollutants.**

**C.** Exposure to PM facilitate increase in autophagy in AECs leading to barrier dysfunction is partly triggered by interplay of AhR, ROS, EGFR & ERK or ROS mediated increase in cytoplasmic HMGB1 & epidermal growth factor receptor (ROS). Activation of EGFR causes disassembly in AJs by disrupting E-cadherin/β-catenin & increased TJs permeability by Rac1/JNK-mediated disruption in ZO-1 and occludin. Also HER2-mediated increase in IL- triggers airway barrier dysfunction.




**Abbreviations: AEC:** airway epithelial cell; **AhR:** aryl hydrocarbon receptor; **AJ:** adherens junction; **APC:** antigen-presenting cell; **AREG:** amphiregulin; β-cat: β-catenin; **E-cad:** E-cadherin; **EGFR:** epidermal growth factor receptor; **ERK:** extracellular signal-regulated kinase; **HDP:** host defence proteins and peptide; **HER2:** human epidermal receptor 2; **HMGB1:** high-mobility group box 1; **IFN:** interferon; IL: interleukin; **JNK:** c-jun N-terminal kinase; **MHCII:** major histocompatibility complex class II; **M5AC:** mucin 5AC; **OCLDN:** occludin; **PAH:** polyaromatic hydrocarbon; **PM:** particulate matter; **ROS:** reactive oxygen species; **SP:** serine protease; **Th:** T-helper cell; **TJ:** tight junction; **TNF:** tumour necrosis factor; **ZO-1:** zonula occludens-1. (Figure partially created.)

role in adult-onset asthma or COPD remains insufficient.

While discussing the patho-physiology of pollution induced airway disease many mechanisms have been discussed. Inhalation of air pollutants may induce oxidative stress, pro-inflammatory responses, an imbalance of systemic inflammation, autophagy, apoptosis and epigenetic modifications, may be as a result of dysfunction of airway epithelial barrier through disruption of the tight junctions between the airway epithelial cell, mucociliary dysfunction, goblet cell metaplasia leading to increased mucus production and induction of submucosal accumulation of neutrophils.

It is high time to act on multiple fronts to prevent the impact of air pollution all over the world on human health, ecosystem and economic growth, through increasing awareness amongst general public, profession, leadership, administrators and executers about air pollution and its global impacts.

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Chapter - 13

# Air Pollution and Cancer

*Ketan K. Mehta, Alok Modi*

**Introduction:**

Air pollution is a significant public health concern worldwide, contributing to various adverse health outcomes, including cancer. This monograph provides an extensive review of the epidemiological evidence linking air pollution exposure to cancer incidence and mortality. It examines the mechanisms by which air pollutants exert carcinogenic effects, discusses key epidemiological studies and explores the role of different pollutants in various cancer types. Additionally, it highlights the challenges in studying air pollution and cancer epidemiology and suggests potential strategies for mitigating these risks.

Air pollution is a complex mixture of gases, particulate matter and other harmful substances released into the atmosphere by natural processes and human activities. It is a major environmental health risk factor, contributing to a wide range of adverse health effects, including respiratory diseases, cardiovascular diseases and cancer. While the link between air pollution and respiratory and cardiovascular diseases is well-established, the association with cancer has gained increasing attention in recent years. Epidemiological studies have provided compelling evidence of the carcinogenic effects of various air pollutants, raising concerns about their impact on public health.

**Epidemiological Evidence:**

Numerous epidemiological studies have investigated the association between air pollution exposure and cancer incidence and mortality. These studies have utilized various study designs, including cohort studies, case-control studies and ecological studies, to assess the relationship between air pollutants and different cancer types. The findings from these studies have consistently demonstrated a positive association between air pollution exposure and cancer risk, with particular emphasis on lung cancer, but also extending to other sites such as bladder, breast and prostate cancer. On October 17 2013, the World Health Organization (WHO) announced for the first time that outdoor air pollution is carcinogenic to humans.[1] The International Agency for Research on Cancer (IARC), WHO's specialized cancer agency, officially classified outdoor air pollution and particulate matter (PM) as IARC Group 1 carcinogens.[2] This announcement acknowledges the importance and global impact of air pollution, a leading environmental factor in cancer deaths worldwide.

The global population weighted mean annual average $PM_{2.5}$ concentration was 46 $\mu g/m^3$ in 2017, which is 4-fold greater than the WHO's health-based world air-quality guideline of

10μg/$m^3$.[3] Ninety-two percent of the global population worldwide lives in areas where ambient $PM_{2.5}$ concentrations exceed.

**Common Health-Impacting Air Pollutants, Grouped by Origin:**

**Typical Sources of Air Pollutant:**

1. **Predominantly Outdoor Air Pollutants:**[4,5]

   Sulfur dioxide ($SO_2$), fuel combustion, smelters ozone ($O_3$)[6,7] generated via photochemical reactions in the atmosphere from nitrogen oxides (NOx) and volatile organic compounds (VOCs) as well as natural processes (e.g., stratosphere), arsenic (As), chromium (Cr), coal combustion fine particulate matter ($PM_{2.5}$), nickel (Ni), vanadium (V), residual oil combustion fine PM ($PM_{2.5}$).

2. **Predominantly Indoor Air Pollutants:**

   Radon, building materials (concrete, stone), ground water, asbestos, mineral, synthetic fibres, fire-retardant, acoustic, thermal, or electrical insulation, biological contaminant infections, dust mites, animal dander, allergens.

3. **Both Outdoor and Indoor Air Pollutants:**

**Outdoor:** Fossil fuel combustion, gas-to-particle conversion, biomass burning, dust storms, windblown soil, pollens, fossil fuel combustion (e.g., diesel vehicle emissions), petrochemical solvents, evaporated fuels, biogenies, fossil fuel combustion,biomass burning, wildfires, industrial emissions, leaded fuel combustion, lead processing, coal combustion, ore refining, agricultural, livestock yards incomplete combustion, chemical processing.

**Indoor:** Biomass fuel combustion, tobacco smoking, coarse PM ($PM_{2.5\text{-}10.0}$), mold spores, resuspended dust, nitrogen dioxide ($NO_2$), tobacco smoking, gas cooking stoves, volatile organic compounds (VOCs), fuel and paint vapours, combustion, adhesives, cosmetics, solvents, particleboard (formaldehyde), insulation, furnishings, tobacco smoke, carbon monoxide (CO), unvented gas heaters, lead (Pb), leaded paint wear, mercury (Hg), fungicides in paints, thermometer breakage, ritual use, pesticides, home applications of herbicides, insecticides, fungicides, etc, ammonia, metabolic activity, cleaning products, hazardous air pollutants (HAPs) (e.g., benzene, 1,3-butadiene, formaldehyde, acids), solvent use.

Large percentages of the populations of China, Bangladesh, India, Pakistan and Nigeria have exposures above the WHO's highest interim target guideline of 35 μg/$m^3$. Among the 10 largest countries by population, population-weighted ambient $PM_{2.5}$ in 2017 varied by >12-fold, from 7 μg/$m^3$ in the United States to 91 μg/$m^3$ in India. For $NO_2$, global population-weighted mean concentrations were estimated to be 1.6 parts per billion (ppb) during 1996 through 2012 and were observed to have increased by 0.9% (95% CI, 0.6%-1.1%) per year during that time. Areas with the highest population-weighted mean concentrations were high-income Asia Pacific (4.9 ppb), Western Europe (4.1 ppb) and high-income North America (3.7 ppb), although there was a decreasing trend ranging from 2.1% to 4.7% per year. Population-weighted mean concentrations in East Asia were 2.9 ppm and were increasing at the highest rate of 6.7% per year. In contrast, population-weighted mean concentrations in areas of South and Southeast Asia, Africa and

the Caribbean were ≤0.5 ppb. The global population-weighted mean $O_3$ concentration worldwide was 57 ppb in 2017, which was unchanged from 1990.[8, 9]

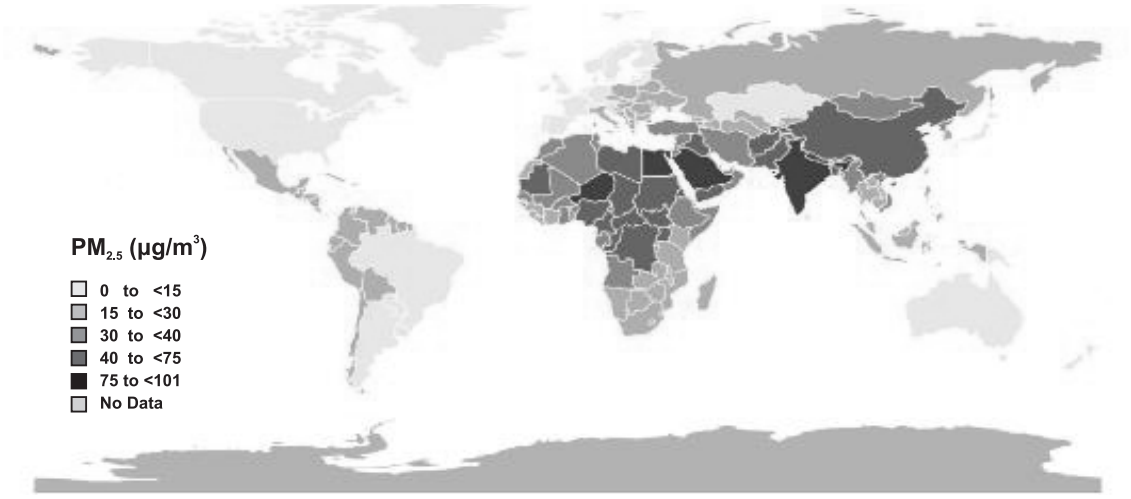


**Figure 1: Average Annual Population Weighted Fine Particulate Matter Concentrations in 2017. $PM_{2.5}$ indicates particulate matter (PM) particles ≤2.5 µm in aerodynamic diameter.**

(Source: Health Effects Institute State of Global Air 2019. Data source: Global Burden of Disease Study, 2017, Institute for Health Metrics and Evaluation (IHME) Study, 2018.)

**Mechanisms of Carcinogenicity:**

The carcinogenic effects of air pollutants are mediated through complex mechanisms involving oxidative stress, inflammation, DNA damage and alterations in gene expression. Particulate matter (PM), including both fine and ultrafine particles, can penetrate deep into the respiratory system, where they induce inflammation and oxidative stress, leading to DNA damage and mutations. Similarly, gaseous pollutants such as nitrogen dioxide ($NO_2$) and volatile organic compounds (VOCs) can react with other chemicals in the atmosphere to form carcinogenic compounds or generate reactive oxygen species (ROS) that damage DNA and promote tumour development.[10, 11, 12]

**Key Air Pollutants and Cancer Risk:**

Several air pollutants have been identified as carcinogenic or potentially carcinogenic to humans by international agencies such as the International Agency for Research on Cancer (IARC) and the U.S. Environmental Protection Agency (EPA).

**These include:**

1. **Particulate Matter (PM):** Fine particulate matter ($PM_{2.5}$) and coarse particulate matter ($PM_{10}$) have been consistently associated with increased lung cancer risk, as well as cancers of the bladder, breast and other sites.[13]
2. **Nitrogen Dioxide ($NO_2$):** Long-term exposure to $NO_2$ has been linked to elevated lung cancer risk, particularly in urban areas with high traffic-related pollution.[13]
3. **Polycyclic Aromatic Hydrocarbons (PAHs):** PAHs are formed during incomplete

combustion of organic matter and are present in diesel exhaust, tobacco smoke and other sources. They are potent carcinogens associated with lung cancer and other respiratory cancers.[13]

So, albeit the incidence of cancer is less compared to smoking but nevertheless it is there and significant.[14]

**Table 1: Common Health-Impacting Air Pollutants, Grouped by Origin**

| AIR POLLUTANT | TYPICAL SOURCES |
|---|---|
| **1. Predominantly outdoor air pollutants** | |
| Sulfur diaxide (SO2) | Fuel combustion, smelters |
| Ovone ($0_2$) | Generated via photochemical reactions in the atmosphere from nitrogen oxides ($NO_2$) and volatle organic compounds (VOCs) as well as natural processes (dg. stratasphere) |
| Arsenic (As), chromilum (Cr) | Coal combustion line particulate matter ($PM_{2.5}$) |
| Nideel (Nl), vanadium (v) | Residual oil combustion line PM ($PM_{2.5}$) |
| **2. Predominantly indoor air pollutants** | |
| Radon | Building materials (concrete, stone), ground water |
| Asbeslas, mineral, synthetic libers | Hire-retardant, acoustic, thermal or electrical insulation |
| Biological contaminant | infections, dust miles, animal dander, allergens |
| **3. Both outdoor and indoor air pollutants** | |
| Suspended PM | |
| Fine PM ($PM_{2.5}$) | Outdoor: Fossil fuel combustion, gas-to-particle conversion, biomass burning<br>Indoor: Biomass fuel combustion, tobacco smoking |
| Coaese PM ($PM_{2.5\text{-}10.0}$) | Outdoor: Dust storms, wtndblown soil, pallens<br>Indoor: Mold spotes, resuspended dust |
| Nitrogen diocide ($NO_2$) | Outdoor: Fossil fuel combustion (eg. diesel vehicle emissions)<br>Indoor: Tabacco smoking, gas cockling stoves |
| Volatile organic compounds (VOCs) | Outdoor: Petrochemical solvents, evaported fuels, biogenics<br>Indoor: fuel and paint vapors, combusion, adhesives, cosmetics, solvents, partideboard (formaldehyde). Insulation furnishings, tobacco smoke |
| Carbon monoidde (CO) | Outdoor: Fossil fuel combustion, biomass burning, wildfires<br>Indoor: Tabacco smoke, unvented gas heaters |
| Lead (Pb) | Outdoor: Industrial emissions, leaded fuel combustion, lead processing<br>Indoor: leaded paint wear |
| Mercury (Hg) | Outdoor: Coal combustion, ole refining<br>Indoor: fungicides in paints, thermometer breakage, rillual use |
| Pesticides | Outdoor: Agrkultural<br>Indoor: Home applications of herbiddes, Insecticides, lungicides, etc. |
| Ammonta | Outdoor: Livestock yards<br>Indoor: Metabolic activity clearning products |
| Hazardous air pollutants (HAPs) (eg, bevense, 1,3 -butadiene, formaldehyde, adds) | Outdoor: incomplete combustion, chemical processing<br>Indoor: Solvent use |

Adapted from: World Health Organisation (WHO) & Global Environment Monitoring System. Estimating Human Exposures to Air Pollutants. WHO Offset PublicationNo. 69, WHO: 1982: and International Agency for Research on Cancer (IARC). Outdoor Air Pollution, IARC Monographs on the Evaluation of Carcinogenic Risks to Humans. Volume 109. IARC: 2013.

To give you an idea (Figure 2):

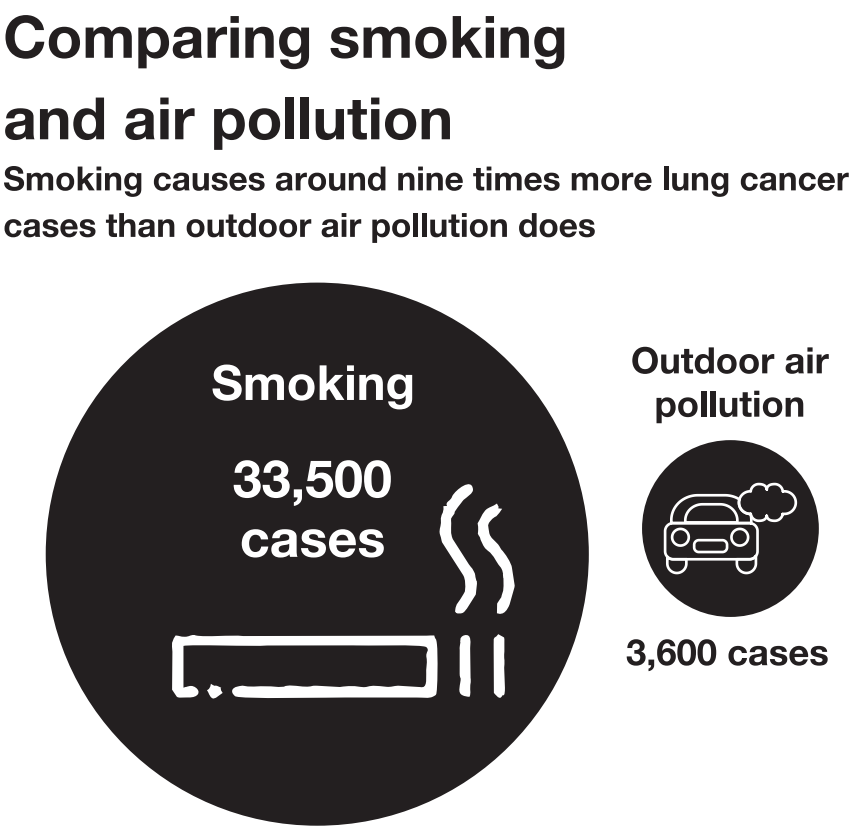


**Figure 2 : Comparing Smoking and Air Pollution.**
(Source: Brown et al, British Journal of Cancer. 2018.)

**4. Volatile Organic Compounds (VOCs):** VOCs, such as benzene, formaldehyde and 1, 3-butadiene, are emitted from various industrial processes, vehicle exhaust and household products. Prolonged exposure to VOCs has been linked to increased risk of leukemia and lymphoma, as well as breast and lung cancer.[15]

**5. Arsenic:** Arsenic, a naturally occurring element, can contaminate air and water sources through industrial activities and mining operations. Inhalation of arsenic-containing particles has been associated with lung cancer, while ingestion of arsenic contaminated water is linked to skin, bladder and lung cancer.[16, 17, 18]

A comprehensive meta-analysis of 14 studies on outdoor air pollution, primarily conducted in North America and Europe, revealed a statistically significant 9% increase in risk for lung cancer incidence or mortality per each 10 μg/m³ increase in $PM_{2.5}$ concentrations. Similarly, in 9 studies examining $PM_{10}$, there was an 8% increase in risk per 10μg/m³. Notably, lung cancer incidence and mortality were combined due to the disease's high fatality rate, making mortality a valid indicator of incidence. Although no significant heterogeneity was observed by continent, limited studies were

conducted in Asia and other regions. The findings remained consistent across exposure assessment methods, including fixed site monitoring and model-based indicators, as well as covariate adjustments for factors like cigarette smoking and sociodemographic variables.[19, 20, 21]

In a more recent meta-analysis based on 20 cohort studies, the increase in lung cancer incidence or mortality was somewhat larger (approximately 14% per 10 μg/m³ $PM_{2.5}$), with consistent results across different regions. When extrapolated to the global population-weighted mean annual average $PM_{2.5}$ concentration (46 μg/m³) relative to the WHO health-based air-quality guideline (10 μg/m³), this corresponds to an approximately 60% excess risk of lung cancer mortality.[22, 23, 24, 25]

**Challenges and Limitations:**

Despite the wealth of epidemiological evidence linking air pollution to cancer risk, several challenges and limitations exist in this field of research. These include: [26, 27, 28]

1. **Exposure Assessment:** Accurately measuring individual exposure to air pollutants over time is challenging, as it requires comprehensive monitoring data and sophisticated exposure assessment methods.
2. **Confounding Factors:** The association between air pollution and cancer risk may be confounded by other factors such as smoking, occupational exposures and socio-economic status, which need to be adequately accounted for in epidemiological studies.
3. **Heterogeneity of Effects:** The carcinogenic effects of air pollutants may vary depending on factors such as pollutant composition, concentration and co-exposure to other environmental agents, making it difficult to generalize findings across different populations and settings.
4. **Latency Periods:** Cancer has a long latency period, with tumors often developing years or even decades after exposure to carcinogens, posing challenges for studying the long-term effects of air pollution on cancer risk.

**Future Directions and Recommendations:** [29, 30]

Addressing the public health implications of air pollution requires a multi-faceted approach involving regulatory measures, public health interventions and research initiatives.

**Some key recommendations include:**

1. **Regulatory Policies:** Strengthening air quality standards and implementing emissions controls to reduce levels of carcinogenic pollutants in the environment, with a focus on transportation, industry and energy production sectors.[31]
2. **Public Health Interventions:** Promoting public awareness of the health risks associated with air pollution and encouraging behavioural changes such as reducing vehicle emissions, promoting clean energy alternatives and improving indoor air quality.
3. **Research Priorities:** Investing in longitudinal studies with long-term follow-up to better understand the cumulative effects of air pollution on cancer risk, as well as investigating potential synergistic interactions between different pollutants and genetic susceptibility factors.[32]
4. **Collaborative Efforts:** Fostering collaboration between researchers, policymakers, healthcare professionals and community stakeholders to develop evidence-based strategies for mitigating the health impacts of air pollution and reducing the burden of cancer.[32]

## Conclusion:

Air pollution is a significant environmental risk factor for cancer, with mounting evidence linking exposure to various pollutants to increased cancer incidence and mortality. Epidemiological studies have provided valuable insights into the mechanisms underlying the carcinogenic effects of air pollution and identified key pollutants of concern. Addressing the public health challenges posed by air pollution requires concerted efforts from multiple stakeholders to implement effective regulatory measures, promote sustainable practices and advance scientific research to safeguard public health and reduce the burden of cancer.

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Chapter - 14

# Air Pollution and Neurological Disorders: Is there any Relationship?

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**Introduction:**

Air pollution has emerged as a pervasive environmental challenge, drawing attention for its adverse impacts on human health. While many individuals breathe clean air daily, others are exposed to polluted air throughout their lives. According to the Global Burden of Disease report, air pollution contributes to numerous acute and chronic diseases, leading to millions of premature deaths worldwide annually.[1] The World Health Organization (WHO) reports causalities of up to 4 million people each year owing to the various types of air pollutants.[2] The ability of these pollutants to remain in the atmosphere for long durations, owing to their small size further makes their penetration and dissemination through the human bodies more likely. Fine dust is rather labeled as a first grade carcinogen by the International Agency for Research on Cancer (IARC) owing to their high metal content and their potential to cause cancers. While its effects on cardiovascular and respiratory health are well-documented, epidemiological evidence suggests a link between air pollutants and central nervous system diseases, increasing hospitalization and mortality rates. Neurological disorders encompass a broad spectrum of conditions affecting the central and peripheral nervous systems, including neurodevelopmental disorders like autism spectrum disorder (ASD) and neurodegenerative diseases such as Alzheimer's and Parkinson's disease, along with stroke, epilepsy and multiple sclerosis.[3,4] Recent epidemiological studies have highlighted associations between exposure to air pollution and an increased risk of neurological disorders. The impact of air quality on our quality of life underscores the importance of studying air pollutants and their health effects. Key air pollutants such as particulate matter (PM), nitrogen oxides (NOx), sulfur dioxide ($SO_2$), volatile organic compounds (VOCs) and heavy metals have been implicated in adverse neurological health outcomes.[4] Particulate matter, in particular, constitutes a significant fraction of air pollution and poses significant health risks due to its diverse composition and size distribution.

**Air Pollution:**

Air pollution constitutes a pressing global issue and is recognized as a primary environmental exposure contributing to morbidity and mortality. As affirmed by the Lancet Commission on Health and Pollution, it represents the foremost environmental cause of premature deaths and diseases, accounting for an estimated 16% of all fatalities and associated with a considerably wide range of diseases than previously acknowledged.[5] Air pollution encompasses a wide array of biological, physical and chemical factors that contaminate the outdoor and indoor environment, altering the natural elements of the atmosphere. Common sources of air pollution include domestic combustion appliances, automobiles, industrial plants and wildfires. Key pollutants of concern comprise particulate matter, carbon oxides, nitrogen oxides, sulfur oxides and ozone. Outdoor air pollution constitutes a significant risk factor for cardiovascular disease globally, with particulate air pollution

alone accountable for over three million annual deaths. Elevated concentrations of daily air pollution correlate with acute myocardial infarction and increased hospital admissions or fatalities due to heart failure.[6] These associations may stem from direct and indirect effects of air pollutant exposure on vascular tone, endothelial function, thrombosis and myocardial ischemia.[7] Recent epidemiological studies have revealed associations between air pollution exposure and an increased risk of neurological disorders.

**Particulate Matter:**

According to the World Health Organization, particulate matter with a diameter of approximately 2.5μm ($PM_{2.5}$) is responsible for roughly 800,000 annual deaths globally, comprising 40% of mortality attributable to outdoor air pollution. Epidemiological studies have consistently linked prolonged air pollution exposure with cardiovascular diseases culminating in death. Particulate matter, consisting of minute particles and droplets carrying acids, organic compounds, metals and dust or soil particles, constitutes a significant fraction of air pollution with profound implications for human health. Categorized based on particle size, airborne particulate matter includes coarse particles (diameter < 10 μm), fine particles (diameter < 2.5 μm) and ultrafine or nano-particles (diameter < 0.1 μm). The composition and size of particles are largely determined by their sources. $PM_{10}$ primarily emanates from soil re-suspension, construction activities and industrial emissions, while $PM_{2.5}$ is predominantly generated by the combustion of fossil fuels such as automobiles and power plants, as well as commercial and household heating using petroleum, coal or wood.[8]

Transitional metals, nitrates, sulfates, carbon and complex organic compounds are common constituents of fine particulate matter ($PM_{2.5}$). Although much is known about $PM_{2.5}$, uncertainties remain regarding the dose-response function, particularly at low exposure levels. Some studies indicate a steep slope at lower ranges of exposure, while others report variations. Various neurological disorders have been reported with different pollutants. (Table 1)

**Table: 1 Shows Relation of Air Pollutants with various Neurological Disorders.**

| Neurological Disorders | | Air Pollutants (Causative agents) |
|---|---|---|
| **Stroke** | Short Term | $PM_{2.5}$, $SO_2$, $NO_2$, $PM_{10}$ |
| | Long Term | Black Carbon, $PM_{2.5}$ |
| | ICH | $PM_{2.5}$, $PM_{10}$, CO, $NO_2$ |
| | SAH | $PM_{2.5}$, $PM_{10}$ |
| **Multiple Sclerosis** | | PM, Gas Pollutants, Heavy metals |
| **Dementia** | | $PM_{2.5}$, $PM_{10}$, UFPM |
| **Depression** | | $PM_{2.5}$, $NO_2$, $O_3$ |
| **Parkinson Disease** | | $PM_{2.5}$, $O_3$ |

**The Mechanisms of Air Pollution causing Neurotoxic Effects:** The mechanisms underlying the neurotoxic effects of air pollution are complex. Fine particulate matter ($PM_{2.5}$) and ultrafine particles can enter the bloodstream through inhalation and reach the brain, where they instigate neuro-inflammation, oxidative stress and neuronal damage. Additionally, air pollutants can disrupt the blood-brain barrier, allowing inflammatory substances and neuro-toxicants to penetrate the brain

parenchyma, exacerbating neuronal injury and dysfunction. The implications of air pollution on neurological health are significant, with implications for disease prevention, management and public health policy. Individuals residing in urban or industrialized areas with high air pollution levels face an elevated risk of developing neurological disorders or experiencing disease exacerbations. Vulnerable populations, including children, the elderly and those with preexisting neurological conditions, are particularly susceptible to the adverse effects of air pollution on the nervous system. Air pollution presents a complex interplay with the nervous system, potentially affecting it through various routes. These pollutants can reach the brain via the olfactory tract, the gastrointestinal tract/vagus nerve or the blood-brain barrier (BBB) (Figure1). Direct absorption into the brain through the olfactory bulb is the most immediate route.[9, 10] While the exact biological mechanisms linking fine dust to brain diseases are not fully understood, oxidative stress and inflammatory reactions are considered primary processes through which air pollution exerts its toxic effects on both the systemic and central nervous systems. Fine dust can directly enter the brain or indirectly through respiratory intake, leading to systemic inflammation and the release of circulating cytokines that cross the BBB. This cascade of events triggers neuro-inflammation and oxidative stress, eventually culminating in cell death. Animal studies have highlighted the role of oxidative stress in neurotoxicity induced by diesel exhaust particulates (DEP). Furthermore, DEP-induced

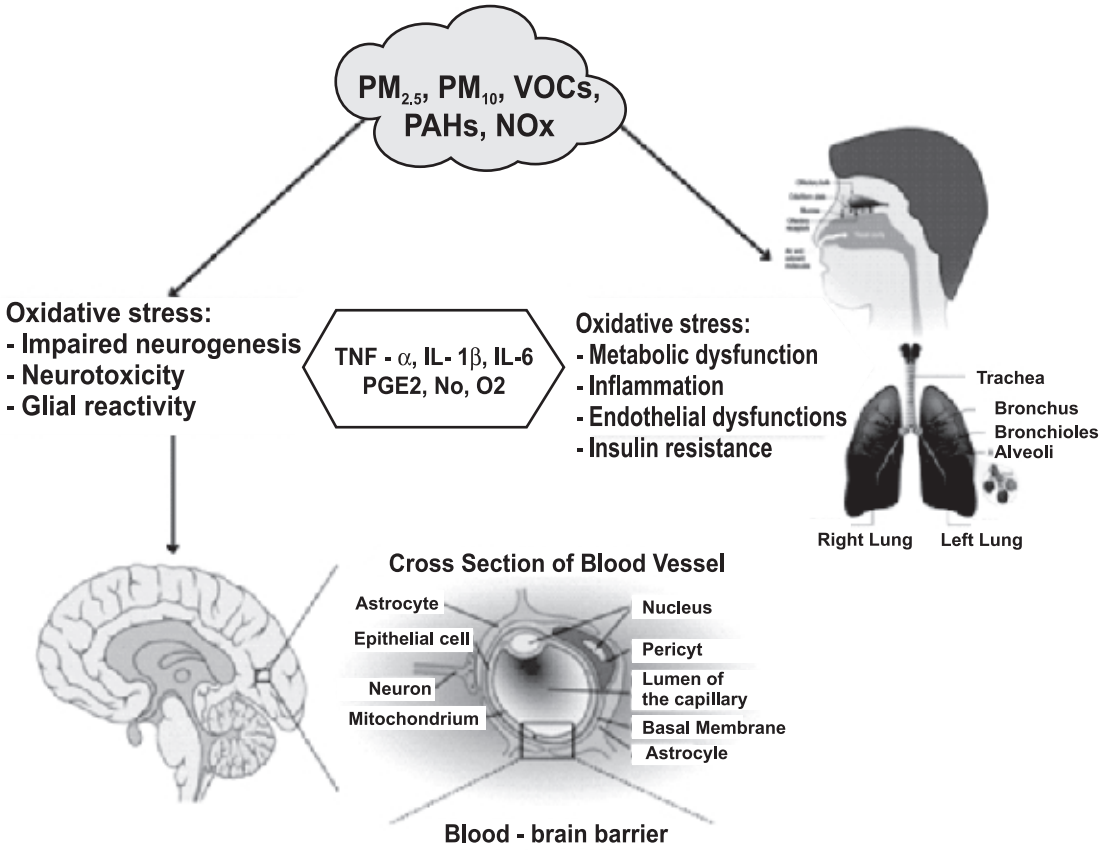


**Figure 1- Proposed Mechanisms of Air Pollution Induced Oxidative Stress on Brain.**

neurotoxicity appears to involve the inflammatory response of microglial cells, with reversible effects observed upon treatment with specific antagonists. Notably, oxidative stress induced by DEP has also been associated with neurodegenerative diseases, such as Alzheimer's and Parkinson's diseases, suggesting a broader impact on brain health.

**Air Pollution and various Neurological Disorders:**

**Air Pollution and Stroke:**

**Ischemic stroke:** Stroke stands as a paramount public health challenge, with significant global implications. In 2019 alone, there were 12.2 million incident cases of stroke, contributing to 101 million prevalent cases, 143 million stroke-related DALYs and causing 6.55 million deaths worldwide. It ranked as the second leading cause of death (11.6% of total deaths) and the third leading cause of death and disability combined (5.7% of total DALYs). Projections suggest a rise in stroke incidence, particularly in countries with aging populations. Notably, air pollution accounts for over 25% of stroke incidence and mortality, as reported by the Global Burden of Disease Study in 2013. While traditional risk factors like smoking and poor diet are known contributors to ischemic strokes, air pollution represents a modifiable risk factor independent of individual behaviour changes. High-income countries have experienced a reduction in stroke-related DALYs over the past two decades, whereas the majority of strokes (approximately 85%) occur in low and middle-income countries (LMICs), where industrialization is expected to drive a surge in air pollution levels.[11]

The relationship between air pollution and stroke incidence is well-established, particularly in highly polluted urban areas. Cardiovascular diseases (CVDs) is also receiving increased attention as a public health issue. Alongside traditional risk factors like hypertension and diabetes, epidemiological evidence suggests a correlation between $PM_{2.5}$ and CVD. $PM_{2.5}$, fine particles with an aerodynamic diameter of 2.5 microns or less, are a major component of air pollution and arise from natural and anthropogenic sources such as combustion processes and vehicle emissions. $PM_{2.5's}$ small size, large surface area and prolonged atmospheric residence time enable it to carry various chemicals, bacteria and viruses, posing health risks upon inhalation. Due to their minuscule weight, they can linger in the air for extended periods and eventually settle in the lungs' alveoli when inhaled. They are even capable of entering the bloodstream, potentially leading to adverse health effects (Figure 2).

Studies have shown a positive correlation between $PM_{2.5}$ concentration and emergency admission rates for CVD, with every 10 $\mu g/m^3$ increase associated with a 1.29% rise in risk. Short-term exposure to $PM_{2.5}$ has been linked to increased stroke hospitalization and fatality rates, emphasizing its role in cardiovascular health outcomes. Additionally, $PM_{2.5}$ exposure has been associated with reductions in hippocampal volume, indicating potential neurotoxic effects. Animal studies further demonstrate the detrimental effects of $PM_{2.5}$ exposure on vascular endothelial cells and vascular recovery following ischemia.

Fine dust (NO, $O_3$) enters the blood vessel, leading to inflammatory and oxidative stress reactions. As the expression of VEGF, VCAM and ICAM protein increases, it leads to a high probability of causing problems in the physical barrier in blood vessels, causing arterial fibrillation, more clot formation and stroke. Short-term exposure to air pollution has been linked to an increased risk of stroke and acute coronary syndromes, such as myocardial infarction. Moreover, out-of-hospital deaths from cardiac arrest show a positive association with ambient air pollution levels.[12] Fine dust constituents have been implicated in promoting thrombosis in blood vessels, thereby elevating

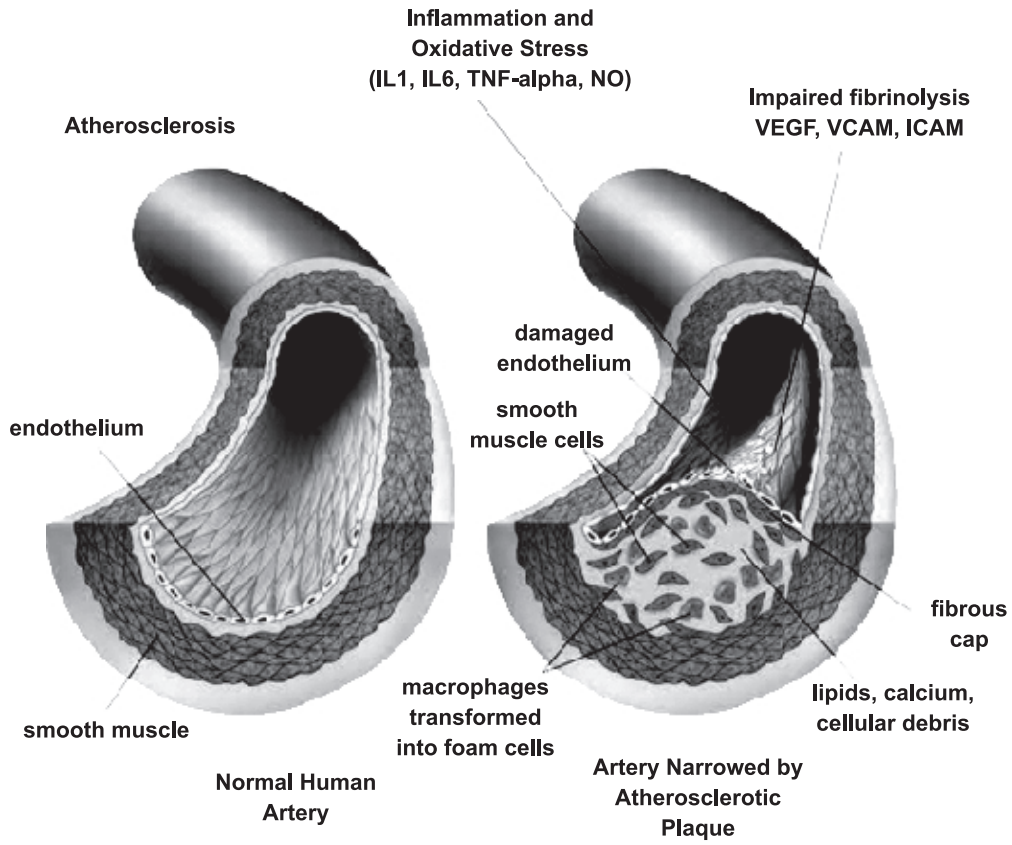


**Figure 2: Molecular Mechanism of $PM_{2.5}$ in Stroke.**

stroke rates.[13] Exposure to air pollution is associated with subclinical diseases underlying stroke, including systemic inflammation, oxidative stress, atherosclerosis, thrombosis and arrhythmia. Studies have identified $PM_{2.5}$ as a significant contributor to stroke causation, with short-term exposure to $SO_2$, $NO_2$ and $PM_{10}$ also associated with an increased risk of ischemic stroke. Furthermore, toxic components of air pollution are linked to elevated heart rate, heart block frequency and atrial fibrillation. Long-term exposure to locally emitted black carbon from traffic exhaust has been associated with increased ischemic stroke incidence. Long-term exposure to air pollution has been linked to accelerated carotid atherosclerosis, a known risk factor for stroke.[14] However, the specific mechanisms underlying the association between acute air pollution exposure and stroke remain unclear, potentially differing between ischemic and hemorrhagic strokes. Controlled exposure studies have shown adverse effects on vascular function and the sympathetic nervous system, leading to vasoconstriction, increased blood pressure and increased risk of thrombosis. Even minor increases in $PM_{2.5}$ concentrations have been associated with changes in cerebrovascular hemodynamics, including increased resistance and reduced blood flow. Additionally, air pollution may elevate the risk of atrial arrhythmias, further predisposing individuals to stroke. However, more research is needed to determine the specific subtypes of $PM_{2.5}$ that pose the greatest risk to stroke mortality (Figure 3)

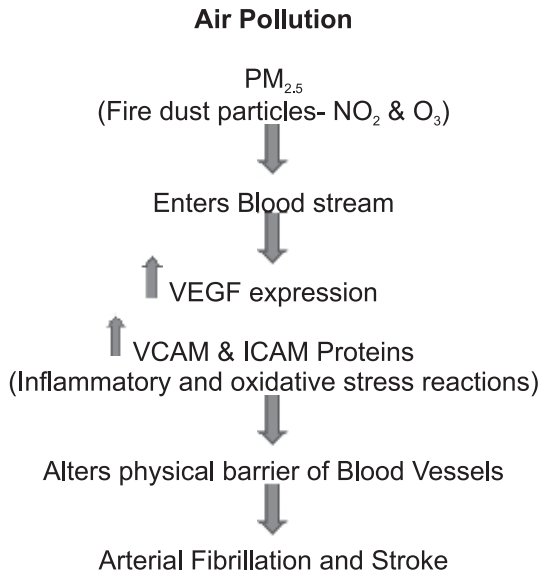


**Figure 3: Flow Chart Depicting Air Pollution Leading to Inflammation and Stroke.**

$NO_2$, a major component of air pollution, has emerged as a significant contributor to stroke incidence. Air pollution is a significant predictor of cardiovascular disease globally, responsible for over three million fatalities annually. With stroke causing five million deaths annually and emerging as a leading cause of disability, its increasing prevalence, especially in LMICs, underscores the urgent need to address environmental factors such as air pollution. Acute ischemic stroke and coronary syndrome share air pollution as a significant and modifiable risk factor, highlighting its importance as a cerebrovascular risk factor. Therefore, acknowledging air pollution as a silent killer contributing to stroke and implementing public health interventions is crucial.

Epidemiological research over the last 30 years has consistently shown that cardiovascular diseases, rather than respiratory illnesses, are the main health consequences of air pollution. While long-term exposure to air pollution has been firmly linked to an increased risk of stroke, the impact of short-term exposure is less clear, particularly concerning cerebrovascular diseases like stroke. This ambiguity is due to the inconclusive results of many studies, which may be attributed to the nature of stroke and the limited scale of these studies. The findings indicate a significant temporal association between particulate matter, gaseous pollutants and both stroke mortality and hospital admissions. However, the lag time between exposure and the onset of stroke symptoms, as well as the subsequent hospital admissions or death, requires careful interpretation. This is because, unlike other cardiac events, the timing of stroke symptoms can vary greatly, often leading to delays in hospital presentation.

**Air pollution and Intracerebral Hemorrhage (ICH):** Intracerebral hemorrhage (ICH) poses a significant health burden globally, contributing to substantial morbidity and mortality rates. Primary ICH typically arises from the spontaneous rupture of small arteries in the brain, often associated with hypertension or cerebral amyloid angiopathy, while secondary ICH may stem from vascular abnormalities or tumors. According to 2013 data, ICH had a mortality rate of 52.8 per 100,000 people and resulted in 1015.6 disability-adjusted life years per 100,000 people worldwide. Hence,

identifying modifiable risk factors and implementing public health interventions is crucial for reducing its prevalence.

There is growing evidence linking ambient air pollutants to the occurrence of ICH, with particular emphasis on particulate matter (PM) with aerodynamic diameters of 2.5 μm ($PM_{2.5}$) and 10 μm ($PM_{10}$), as well as nitrogen oxide ($NO_2$). Studies conducted in Taiwan have established a correlation between $NO_2$ levels and the prevalence of spontaneous ICH across all age groups. Moreover, seasonal fluctuations have been implicated in ICH occurrence, with $PM_{10}$ and $NO_2$ showing associations on hot days. Additionally, current-day $NO_2$ levels have been linked to hospital admissions for ICH, while carbon monoxide (CO) exposure in Edmonton, Canada, was associated with an elevated risk of ICH. Long-term exposure to $NO_2$ has been associated with an increased risk of ICH, as evidenced by a 9-year cohort study conducted in Japan in 2013. However, the long-term implications of air pollution for ICH remain poorly understood, necessitating further prospective longitudinal studies.[8]

**Air Pollution and Sub Arachnoid Hemorrhage (SAH):** Subarachnoid hemorrhage (SAH) is a subtype of stroke associated with significant morbidity and mortality worldwide. Environmental factors, including air contamination, barometric pressure and extreme climate changes, have been implicated in SAH risk. These variables can affect the blood-brain barrier, leading to SAH. Observational cohort studies have demonstrated a clear association between air pressure variation and SAH, highlighting the role of atmospheric changes in SAH pathogenesis. Changes in brain vessel dynamics due to atmospheric variations can disrupt the equilibrium of cerebral blood flow, potentially leading to vessel leakage and rupture. In addition to air pressure, temperature fluctuations, particularly extremes of temperature coupled with humidity, endothelial dysfunction induced by long-term exposure to $PM_{2.5}$ and $PM_{10}$ may also play a role in cerebral aneurysm formation, potentially contributing to SAH risk. While hypertension remains a primary risk factor for SAH, ongoing research aims to elucidate the association between air pollution and SAH, considering SAH's emergence as a medical emergency and leading cause of disability and mortality.[8]

**Air Pollution and Demyelinating Disorders:** A spectrum of central nervous system disorders may result from air pollutants owing to the ability of these harmful pollutants to cause activation of microglia causing excessive oxidative stress.[15] While the breach in the cerebral vascular-barrier is contemplated, various other biological mechanisms by which air pollution produces neurological disease still remain unexplored. Recent literature focuses on the trigger of autoimmune neurological syndromes by air pollution owing to its effects on the systemic and local inflammatory mileu.[15, 16]

**Multiple Sclerosis (MS):** MS is a chronic primary autoimmune disease of the CNS, characterized by inflammation, demyelination and degeneration. The destruction of myelin and neurological damage noted as plaque formation is the hallmark of the disease. It is also defined by the dissemination in time and space, i.e., neurological destruction occurs over a period of time and at various locations in the CNS. The prevalence is estimated to be around 2.5 million. The age range for multiple sclerosis is between 20 and 50 years and it is more prevalent in women, with a ratio of around 4:1 (F: M).[17]

While the exact pathophysiology and trigger of MS remains dubious, various environmental and genetic factors have been implicated over time. Various environmental triggers like exposure to ultraviolet rays, vitamin D deficiency, Ebstein Barr virus, stress, dysregulated gut microbiome,

smoking etc. have been implicated. The ability of the air pollutants causing the pro-inflammatory cytokine release has also been questioned.[18] The mechanism by which air pollution may contribute to multiple sclerosis (MS) involves a complex interplay of inflammatory processes and neuro-degeneration. Chronic exposure to air pollutants like particulate matter, gaseous pollutants and heavy metals can lead to an increase in pro-inflammatory markers in the brain. These markers include cyclooxygenase 2 (COX2), interleukin 1-β, inducible nitric oxide synthase (iNOS) and CD14, which can cause neuro-inflammation, neurodegeneration and breakdown of the blood-brain barrier (BBB). This breakdown allows further infiltration of harmful substances and immune cells into the brain, exacerbating the condition. Additionally, air pollutants can trigger immune-mediated interactions that impair the BBB's function, leading to more tissue damage and the accumulation of demyelinating lesions.

A. **Systemic Inflammatory Response:** Induction of pulmonary inflammation followed by or simultaneous systemic inflammation is considered to be the main trigger after the exposure to the air pollutants. The dysregulated immune response leads to production of reactive oxygen species (ROS) and nitrogen reactive species (NRS) inducing inflammatory cascades activating the neutrophils, monocytes and dendritic cells. Adaptive immune responses are further stimulated leading on to the production of auto-aggressive T cells facilitating their entry into the CNS. The activation of T cells follow, secreting pro-inflammatory cytokines and triggering the autoimmune response in the CNS. Several ex-vivo and in vitro studies have also supported the role of proinflammatory cytokines inducing upregulation of the CCR6 chemokines on the circulating CD4 + T cells inducing the production of Th17 cytokines triggering the MS process.[19]

B. **Direct Neuroinflammation:** The particulate matter owing to its ultrafine size may be directly absorbed through the olfactory bulb and may spread retrogradely as well as anterogradely in the axons and dendrites. Very fine PM may hence reach CNS through the olfactory receptor neurons or the trigeminal nerves. From the olfactory receptors, pollutants are directly transferred into the CNS through the mitral cell axons and hence to the olfactory cortex and other areas in the brain. Controlled exposures of rats to the particulate matter and various fine metal products have demonstrated their accumulation in the brain through the olfactory bulb in various in-vitro studies. Hence, these pollutants can bypass the circulatory system and directly enter the CNS. An additional pollutant mediated local or systemic inflammation may further deteriorate the olfactory mucosal barrier, leading to enhanced neuroinflammation.[18]

C. **Epigenetic Mutations:** Epigenetic changes can be induced by the pollutants, DNA methylation being the most common one. Histone modification, non coding RNA expression and mi RNA modifications have been linked with air pollution and several diseases have been thought to be an output of such dysregulated mechanisms leading on to the dysregulation of protein expression. The altered levels of various cytokine responses (e.g. IL-2, IL-6) have been linked to induction of inflammation and subsequent oxidative stress in the CNS altering the brain autoimmunity, which is thought to influence the development of varied autoimmune diseases.

**Neuromyelitis Optica Syndrome Disorders (NMOSD) and Myelin Oligodendrocyte Antibody Disorders (MOGAD) associated Syndromes:** Similar to MS, NMOSD and MOGAD are also primary immune mediated inflammatory disorders, characterised by concurrent demyelination and inflammation. Like MS, various environmental factors including pollution mediated inflammatory changes seem to play a role. Though specific studies focusing on the exact relation between air

pollution and NMOSD/ MOGAD is lacking, it is likely to cause inflammation to pathways similar as MS.[20]

**Other Neuroinflammatory Diseases and Air Pollution:** Similarly many other immune mediated inflammatory conditions like neurosarcoidosis, neuro-sjogrens, neuro-lupus etc have also been noted to show role in the development as well as exacerbation in existing diseases whilst exposed to particulate matter. Increased severity of the diseases as well as reduced quality of life has also been seen to be associated with pollutants and particulate matter.[21, 22, 23]

**Air Pollution and Dementia:**

Thus, beneath the serene facade of our skies lies a silent peril, imperiling our well-being.[24] The classification of particulate matter by aerodynamic diameter delineates coarse particles ($PM_{10}$), fine particles ($PM_{2.5}$)[25] and ultrafine particulate matter (UFPM), with particular attention to the latter due to its remarkable capacity to breach the intricate defenses safeguarding the brain. Exposure to polluted air has been correlated with accelerated brain aging, prompting concerns regarding the risk of dementia and Alzheimer's disease.[26] (Figure 4) While studies have suggested a linkage between fine particulate matter (PM < 2.5μm) and these conditions, definitive evidence and a comprehensive understanding of the underlying mechanisms remain elusive, perpetuating ongoing debate regarding air pollution's role in cognitive decline.

A consistent stream of reports has forged connections between Alzheimer's disease and exposure to ambient air particles. For instance, investigations on ApoE–/– mutant mice subjected to fine dust exposure revealed a significant reduction in dopamine cell numbers compared to control groups breathing unpolluted air, indicating a pronounced impact on nerve cells.[27] Prolonged exposure to $PM_{2.5}$ neurotoxicity has been associated with early cognitive decline, particularly affecting immediate free recall and new learning abilities, mirroring the preclinical manifestations of Alzheimer's disease. This decline has been attributed to progressive gray matter atrophy, signifying an augmented Alzheimer's risk irrespective of cerebrovascular impairment.

Biological pathways involving systemic inflammation and oxidative stress have been implicated in the nexus between air pollution and brain dysfunction. Air pollution has been shown to induce metabolic irregularities and oxidative stress within the brain, precipitating cognitive impairment and heightening the risk of dementia.

Air pollution's impact extends to disrupting the insulin signaling system, thereby increasing the risk of cognitive impairment and dementia. Genetically modified mice lacking the insulin-degrading enzyme (IDE) exhibit neural hyperinsulinemia, glucose resistance and amyloid beta (Aβ) accumulation.[28] Glucose resistance engenders memory loss and hippocampal cell atrophy, while insulin resistance diminishes glucose absorption in the cerebrum, accentuating the risk of dementia.

Exposure to fine dust, particularly $PM_{2.5}$, has been implicated in instigating cognitive impairment and neurodegeneration by perturbing mitochondrial structure and function. Inhalation of $PM_{2.5}$ disrupts aerobic tricarboxylic acid metabolism and oxidative phosphorylation within mitochondria, culminating in diminished ATP production. This precipitates hypophosphorylation of tau protein in the cortex, a hallmark of neurodegenerative conditions. Furthermore, heightened production of reactive oxygen species exacerbates cellular damage. Notably, cessation of $PM_{2.5}$ exposure offers a glimmer of hope, as partial recovery has been observed thereafter.[29] Exposure to $O_3$ has been associated with increased IL-17 expression in hippocampal neurons, leading to chronic neurodegenerative changes akin to Alzheimer's disease.[30] While long-term exposure to low doses

of $O_3$ can induce oxidative stress and irreversible neurodegeneration, some studies suggest a neuroprotective effect of $O_3$ on cognitive function, with high $O_3$ concentrations correlating with better cognitive scores.[31]

Air pollutants like $SO_2$, CO, $NO_2$ and NOx, as well as manganese, are also linked to cognitive decline in dementia:[30]

$SO_2$: Associated with synaptic dysfunction in the hippocampus, leading to cognitive decline. Inhalation can cause synaptic damage via protein kinase A (PKA) and/or protein kinase C (PKC)-mediated signaling pathways.[32] The combination of $PM_{2.5}$, $SO_2$ and nitrogen dioxide ($NO_2$) can impair spatial learning and memory and lead to abnormal expression of apoptosis-related genes (P53, Bax and Bcl-2).[33]

CO: Binds to hemoglobin, reducing oxygen delivery to the brain, exacerbating cognitive impairment. Chronic exposure linked to elevated serum carboxyhemoglobin levels and microstructural brain damage.

$NO_2$: Enters brain tissue through oxidative stress, inducing synaptic impairment, neuronal damage and cognitive deficits. Animal studies show decreased spatial learning, memory and amyloid β42 accumulation.

NOx: Implicated in Alzheimer's development, with long-term exposure associated with increased dementia risk. Population studies in Sweden and China support its role as a significant risk factor for cognitive decline.

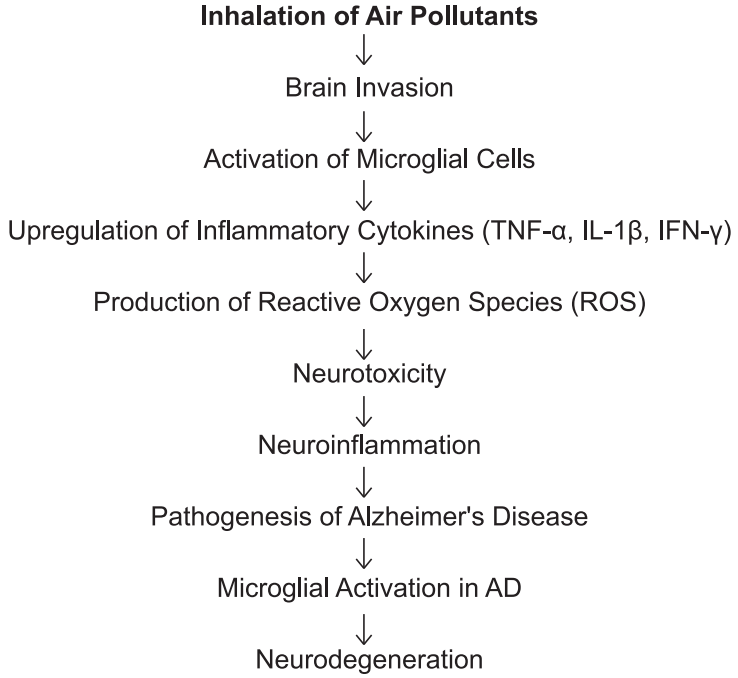


**Figure 4 : Sequential Steps Involved in the Impact of Air Pollutant Inhalation on Neuroinflammation and Alzheimer's Disease Pathogenesis.**

Manganese: Chronic exposure leads to cognitive decline, affecting attention, memory, language and executive function. Common in industrial settings, manganese contributes to dementia development.

These pollutants affect synaptic function, neuronal health and cognitive domains, contributing to dementia pathophysiology.

In (SNAC-K), a longitudinal population-based study, it was seen that higher tHcy levels worsened air pollution's impact on dementia risk, while increased methionine levels protected against it. The methionine to tHcy ratio, reflecting methylation activity, was linked to lower dementia risk from air pollution. Air pollution likely raises tHcy through inflammation, hindering homocysteine metabolism. It contributes to dementia via amyloid plaque deposition and indirectly through cardiovascular disease. Enhancing vitamin B status to lower tHcy and boost methionine levels could mitigate air pollution's dementia risk.[34]

**Air Pollution and Depression:**

The association between air pollution and depression is complex, with varied findings on the impact of different pollutants such as $PM_{2.5}$ and $NO_2$, while $O_3$ may exhibit gender-specific correlations and short-term exposure might not notably affect mood in healthy elderly populations.

**Mechanism:**[35, 36] Figure 5 flowchart explains the mechanism of air pollution leading to depression.

**Effect on Neonates and Infants:** [37]

Research into the effects of early air pollution exposure on mental health yields mixed results, prenatal exposure links to cognitive impairments in 5-year-olds, but not to increased anxiety or

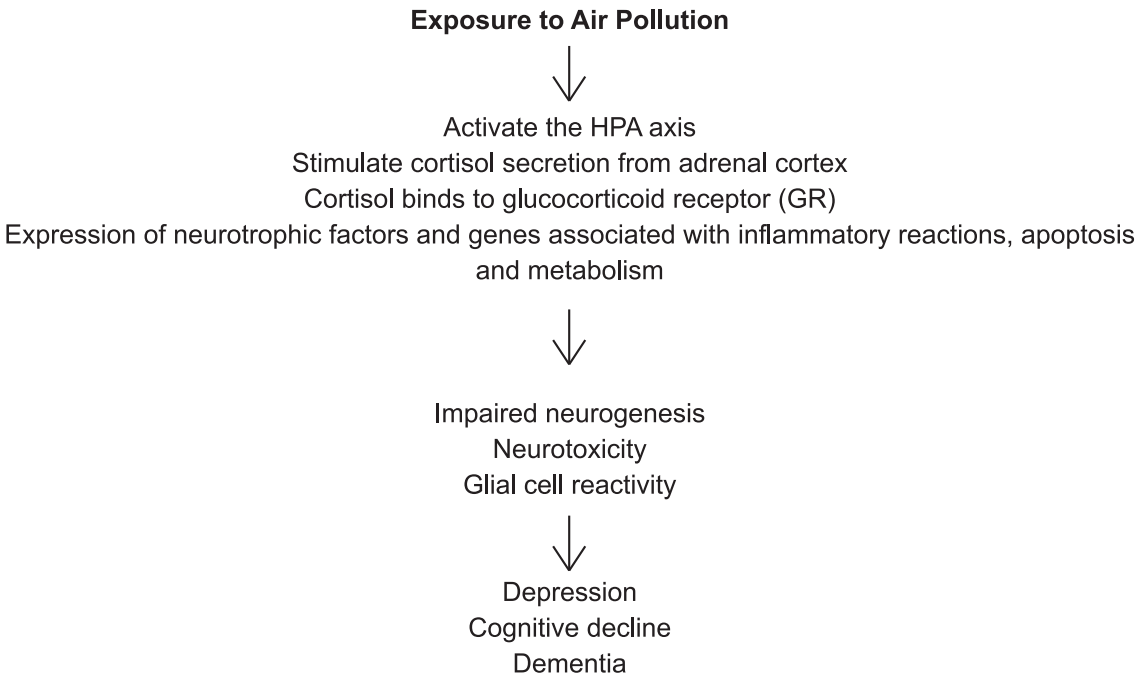


**Figure 5 : This Flowchart Illustrates the Sequential Steps and Mechanisms Through which Cortisol, Influenced by Air Pollution, Contributes to Depression.**

depressive symptoms. While certain pollutants like nitrogen dioxide and benzene show inverse associations with mental development in children, these findings lose statistical significance after adjusting for confounding factors. Moreover, exposure during pregnancy to pollutants such as $PM_{10}$, $PM_{2.5}$, nitrogen dioxide and nitrogen oxides raises the risk of unspecified mental disorders, with varying impacts influenced by different exposure pathways during infancy.

**Effect on Adolescents:** [37]

Early prevention of mental illness is imperative, given its onset typically before age.[24] Urban areas exhibit elevated rates of psychoses, possibly attributed to air quality; adolescents with heightened exposure to nitrogen dioxide and $PM_{2.5}$ demonstrate increased psychotic experiences, with nitrogen oxides elucidating 60% of variance. Associations extend to depression; while nitrogen oxides correlate with general psychopathology, $PM_{2.5}$ displays stronger connections to specific symptoms such as 'thought disorder', a characteristic of psychosis.

**Effect on Adults:** Air pollution, including $PM_{10}$, $PM_{2.5}$, diesel emissions, nitrogen dioxide and organic substances, is linked to higher risks of psychiatric disorders such as bipolar disorder, depression, schizophrenia and personality disorder in adults in studies from the USA and Denmark.[38] This pollution also correlates with increased service use for mental health issues. A recent review confirms associations of $PM_{2.5}$ and $PM_{10}$ with depression, anxiety, bipolar disorder, psychosis and suicide in adults, highlighting the necessity for more comprehensive studies to understand causality better. Further research is vital to uncover underlying mechanisms.

**Effect on Older Age Groups:** [39]

In a groundbreaking nationwide study within the Medicare cohort 16, researchers uncovered concerning links between long-term exposure to air pollution and late-life depression among older adults. Even in regions meeting air quality standards, pollutants like $PM_{2.5}$, $O_3$ and $NO_2$ were found to significantly heighten depression risk. Of particular note was the vulnerability of socioeconomically disadvantaged individuals, who showed a heightened susceptibility, especially to $NO_2$, particularly if they had cardiovascular, respiratory, metabolic or neurological comorbidities. Also, a recent systematic review emphasised the profound impact of $PM_{2.5}$ and $NO_2$ exposure on depression risk, with $O_3$ demonstrating the highest risk increase. Moreover, emerging research suggests that air pollution may trigger neuroinflammation and oxidative stress, potentially contributing to depressive symptoms, especially among socioeconomically disadvantaged populations.[40]

It highlighted the critical intersection between environmental health and mental well-being, urging policymakers and healthcare providers to prioritize pollution control measures to safeguard vulnerable populations.

**Relationship between Particulate Matter, Ozone and Parkinson's disease:**

The relationship between air pollution and Parkinson's disease (PD) is a subject of increasing concern. Research indicates that air pollution, particularly fine particulate matter and other pollutants from industrial and vehicular emissions, may be an emerging risk factor in the development of PD. A study by the Barrow Neurological Institute found a significant increase in PD risk associated with higher levels of air pollution.

**Particulate Matter and Parkinson's Disease:**

Parkinson's disease (PD) ranks as the second most prevalent neurodegenerative condition, characterized by a gradual onset and uncertain causes. It is thought to be influenced by factors

such as aging, genetic heritage and environmental elements. Research has demonstrated that short-term exposure to fine particulate matter ($PM_{2.5}$) can lead to an increase in hospital admissions and mortality from PD. Specifically, a 10 μg/m³ increase in $PM_{2.5}$ over two days was associated with a 3.23% rise in PD hospitalizations and a 0.64% increase in all-cause mortality. A longitudinal study spanning from 1999 to 2010 across 50 southeastern U.S. cities observed 10 million seniors, revealing that prolonged exposure to $PM_{2.5}$, with a yearly increment of 1 μg/m³, resulted in a 1.08 times higher risk of PD hospitalization. Additionally, animal studies have indicated that $PM_{2.5}$ exposure can lead to an increase in alpha-synuclein levels in the midbrain, suggesting potential early pathological changes in PD.[41]

**Ozone and Parkinson's Disease:** The impact of long-term exposure to ozone ($O_3$) on PD has been increasingly documented in scientific literature. Analysis of data from the 2001 Canadian Census Health and Environment Cohort, which included 3.5 million individuals, showed a positive correlation between chronic $O_3$ exposure and PD mortality. An increase of 10.1 parts per billion (PPB) in $O_3$ levels was linked to a 1.09-fold increase in the risk of death from PD. Meta-analyses have further supported the association between chronic ambient air pollution exposure and PD, underscoring $O_3$ as a significant risk factor.

**Air Pollution and its Influence on Epilepsy:**

Epilepsy, a prevalent neurological condition, is marked by erratic neuronal activity leading to spontaneous, recurrent seizures. It is a multifaceted disorder impacting over 70 million individuals globally, spanning all age groups from infants to the elderly. The exploration into how air pollutants affect epilepsy remains in its nascent stages. However, emerging studies are beginning to shed light on this critical area. For instance, research by Xu et al. from a Chinese medical center indicated a significant correlation between sulfur dioxide ($SO_2$) levels and the frequency of visits to epilepsy clinics. They observed a 3.55% surge in clinic visits for every 10 μg/m³ increase in atmospheric $SO_2$ concentration. Similarly, a comprehensive study by Cakmak et al. across Chile reported a parallel rise in epilepsy-related hospital admissions in response to elevated $SO_2$ levels. Despite the scarcity of literature on this subject, these findings underscore the necessity for more extensive research to ascertain the full extent of epilepsy's burden attributable to $SO_2$ and other air pollutants.[42]

**Conclusion:**

Addressing air pollution as a modifiable risk factor for neurological disorders is imperative for public health efforts. By understanding the mechanisms by which air pollution impacts the brain, targeted interventions can be developed to reduce exposure and mitigate its detrimental effects. Various pollutants, including atmospheric particulate matter, ozone, sulfur oxides, carbon oxides, nitrogen oxides and heavy metals, pose health risks to human populations. Living in areas with high levels of air pollution has been associated with neurodegenerative diseases, highlighting the need for environmental interventions to mitigate these health risks. As the global burden of neurological disorders continues to rise, addressing air pollution emerges as a crucial strategy for promoting neurological health and overall well-being. Improving air quality requires concerted efforts by policymakers to implement effective measures to protect citizens from the adverse health effects of air pollution. However, our understanding of this relationship remains limited, necessitating further research to obtain more accurate data.

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Chapter - 15

# Water Pollution and Non Communicable Disease: Is there any Relationship

*Jayagopal. P.B*

**Introduction:**

Water is an important factor in sustaining life. It is essential that the water we are using is safe to use and does not cause any harmful effects to the consumer. Nowadays, water bodies are contaminated with chemicals, plastics and waste products. Drinking water must be free from pathogens and contaminants. Drinking unsafe water poses a significant health risk to the individual. Water pollution is an emerging threat to global health. Water pollution will result in the occurrence of infectious diseases like cholera, diarrhoea, dysentery, hepatitis, etc., as well as non-communicable diseases like cancer, cardiovascular, renal, hepatic, respiratory, neurological and immunological disorders. Noncommunicable diseases (NCDs) are responsible for 72% of deaths globally.[1]

This is a significant problem now in low and middle-income countries. The epidemiological transition from communicable diseases to NCDs is well documented.[2] Air and water pollution is a major cause of concern. Pollution accounts for 22% of all deaths from cardiovascular disease and 26% of ischemic heart disease deaths. This is very relevant to a country like India. (Figure 1). However, pollution control has been neglected for many years. This is mainly because of the difficulty in establishing a cause and effect on health issues, which takes many years. Moreover, the control needs multiple stakeholders other than the medical department. The first initiative to make pollution a health hazard was shown by the Lancet Commission in 2017. Subsequently, the United Nations (UN) and World Bank took some initiatives.[3]

The role of water pollution in communicable diseases is well known. However, as the industrial revolution advanced, the nature of pollutants evolved. They are now implicated in the manifestation and spread of non-communicable diseases (NCDs). Water, a basic necessity for human life, is now a source of concern due to pesticides and plastic debris, especially microplastics. The quality of water and its processing, which should be a source of life, can also become a carrier for many diseases by providing a habitat for insects. This, in turn, can lead to an increase in NCDs.[4] Wastewater from industries and agriculture can create a breeding ground for toxic materials, which can then spread downstream, affecting larger areas and leading to NCDs. Chemical pollution from industries such as pharmaceutical, chemical, leather and electronic manufacturing units is a significant cause of water pollution. The effects of this pollution could be direct and take many years to manifest as a disease entity. Plastic debris and chemical pollutants are increasingly recognised as significant determinants of pollution and NCDs.

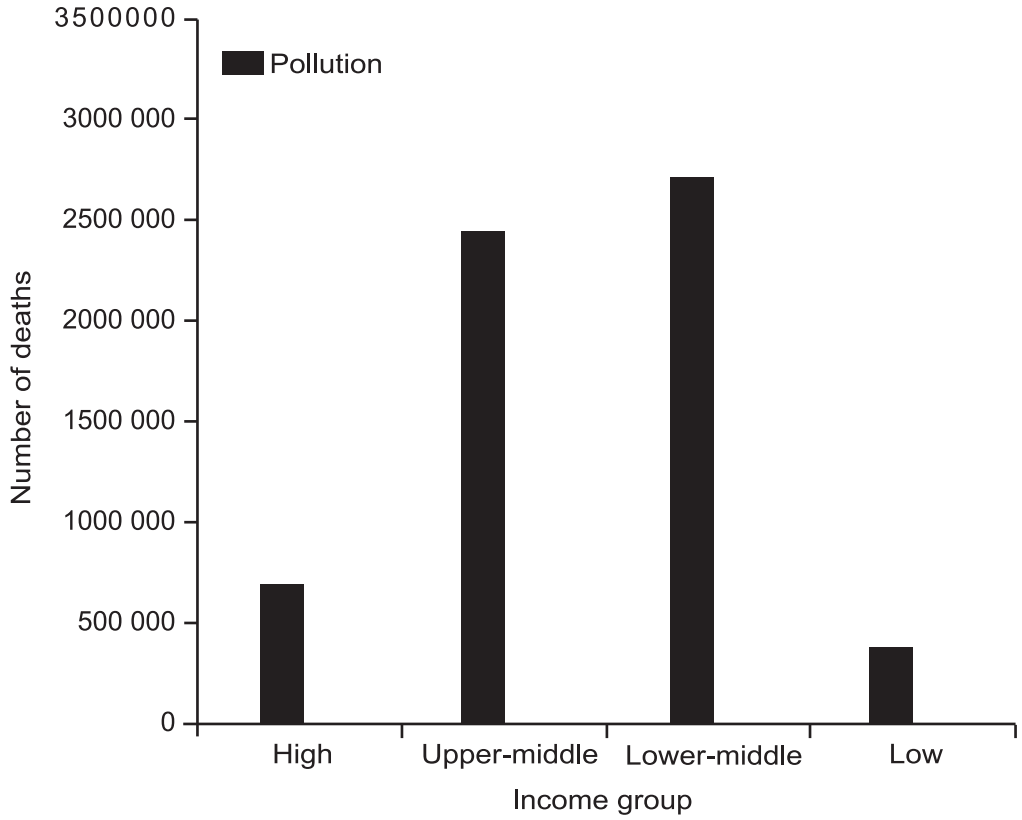


**Figure 1 : Pollution-Related Deaths Within Different Income Groups.**

Chemical contamination in the river basins affects the population through multiple pathways. The chemical pollutants and the various cocktail effects are mostly unknown. Much research is needed to understand the disability-adjusted life years (DALY). The newer documentation of DALY linked to pollutants is a welcome move. This helps to understand, prevent and manage these pollution-related issues. Unfortunately, most of the water quality standards look into the communicable disease. The micropollutants and heavy metals directly affect the aquatic system but ultimately affect humans as well. Chronic ecotoxicity and endocrine disruptions are well known. These lead to hormonal imbalances and hemorheological changes in the system.[5]

The pollutants and contaminants include a variety of agents. (Figure 2) Soil and water contamination produce many detrimental effects through a variety of mechanisms. The effects of CVS through vascular damage, endothelial dysfunction and atherosclerosis by the oxidative process are well established.[6] Pesticide exposure during pregnancy has been implicated in acute myocardial infarction, heart failure and arrhythmia.[7]

**Heavy Metals:**

These are not biodegradable and hence, bioaccumulate. These are mainly carcinogenic to the

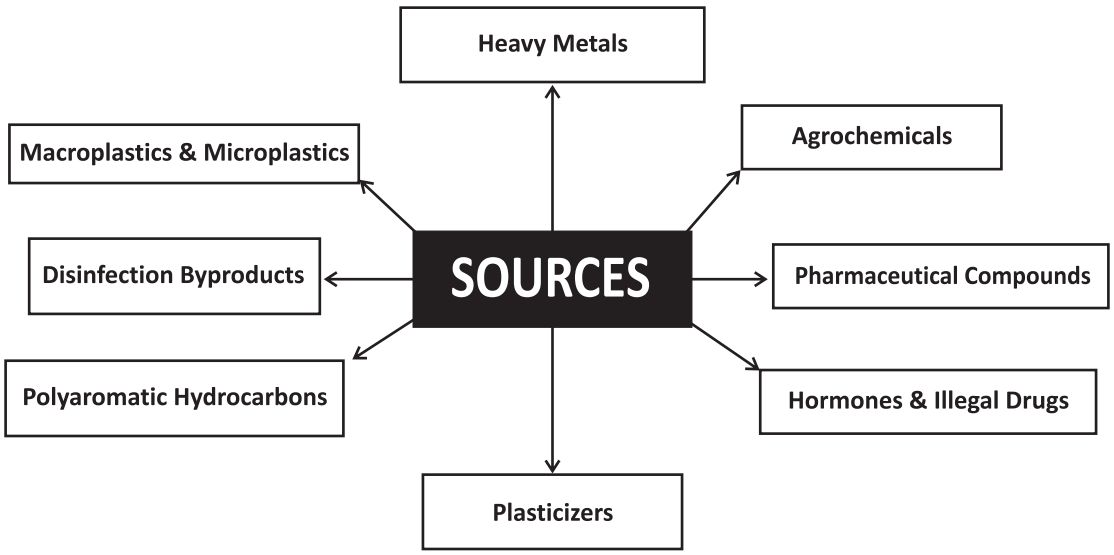


**Figure 2 : Sources of Water Pollution.**

bladder, lung, kidney and prostate. Leukaemia and neurological ailments are also known to be implicated.[8]

- Arsenic (As) is a toxic compound in the Earth's crust. The International Agency for Research on Cancer (IARC) stated that arsenic in drinking water is carcinogenic to humans.[6] Inorganic arsenic in drinking water is classified as a Group 1 carcinogen by the International Agency for Research on Cancer (IARC), constituting a significant public health issue and impacting millions worldwide. Arsenic in drinking water causes different types of cancers like urinary tract cancer, lung cancer, renal cancer, skin cancer, etc.[9] Long-term ingestion of arsenic may also cause other NCDs like diabetes, pulmonary diseases, kidney diseases, cardiovascular diseases and arsenic-induced myocardial infraction.[9]
- Chromium accumulation has a severe negative impact on human health. Skin disorders, allergies, kidney and liver failure and lung, bone, brain and gastrointestinal diseases. Also, damage to the reproductive, immunological and central nervous system has been reported.[10]
- Mercury is another type of hazardous heavy metal that contaminates water bodies. The primary source of mercury in humans is through contaminated water supply and not by inhalation. They are present naturally in the earth's crust. They are also used extensively in manufacturing batteries, lamps and thermometers, as well as in various pharmaceutical industries. Exposure to mercury results in lung and kidney damage and also leads to neurological and psychological problems.[11]
- A significant source of heavy metals is e-waste, which may cause specific adverse health effects on respiratory, intestinal, immune, endocrine and nervous systems, as well as certain types of cancers.[12, 13]

**Disinfection Byproducts (DBP):**

DBPs are mostly trihalomethane (TTHM) and haloacetic acids (HAA) implicated in cancer. Most countries are aware of this issue and their occurrence in water is stipulated in various countries. TTHMs can cause cardiac, renal and hepatic problems and damage the lungs and central nervous system. They also possess carcinogenic effects and may cause bladder and colon cancer. HAA, like DCAA and TCAA, may result in various reproductive problems and they also have carcinogenic effects.[14]

**Agrochemicals:**

Paraquat can produce melanoma, lung conditions, immune system damage and also multiorgan dysfunction syndrome. Chlorpyrifos can lead to cancer of breast, lung, brain and leukaemia. Alkylphenols are used in pesticides, are found in agricultural runoff and have a harmful estrogenic effect.[15]

Nitrate levels in our water resources have increased mainly due to agricultural activity, wastewater disposal and the oxidation of nitrogenous waste products in human and other animal excreta.[16] Certain studies suggest that there is a strong relationship between the ingestion of drinking water nitrate[17] and the occurrence of adverse health effects like colorectal cancer, bladder and breast cancer and thyroid diseases.

**Pharmaceutical Compounds:**

Pharmaceutical compounds used to treat various diseases are not correctly disposed off. After their expiry date, these medicines become highly toxic to living organisms. Hormonal compounds, analgesics, anti-inflammatory products, anti-cancer agents, antibiotics, statins and beta-blockers are the most commonly present pharmaceutical compounds.

- Analgesic and anti-inflammatory products like Ibuprofen, acetylsalicylic acid and salicylic acid result in the formation of kidney, respiratory, gastro, nervous and urinary tract problems.
- Anti-cancer compounds have carcinogenic, mutagenic and reprotoxic effects. Thus, their waste products also have similar negative impacts on human health. The primary sources of anti-cancer residues in water bodies are faecal and urinary excretory products.[18]

**Plasticizers:**

Di-2-ethylhexyl phthalate (DEHP)) is extensively used as a plasticizer in manufacturing medical devices, furniture materials, cosmetics and personal care products. Plasticizers have endocrine, testicular, ovarian, neural, hepatotoxic and cardiotoxic effects.[19]

Microplastics can enter water bodies through atmospheric deposition, degraded plastic waste, surface runoff from agricultural land, wastewater and industrial effluent. Plastics like polyurethanes, polyacrylonitriles, polyvinyl chloride, epoxy resins, styrene copolymers, etc, are detected as carcinogenic. Polyethylene terephthalate (PET) and polypropylene (PP) were the commonly seen microplastics in fresh water.[20]

**Polyaromatic Hydrocarbons (PAH):**

The incomplete combustion of organic materials like coal, oil, petrol and wood produces polycyclic

aromatic hydrocarbons (PAHs), which are environmental pollutants. Specific concentrations of PAHs can also be found in water since PAHs can leach out from soil into water or infiltrate water through industrial effluents and accidental marine spills during oil shipment. Crops like wheat, rye and lentils may synthesise or absorb PAHs via water, air or soil. Chronic exposure to PAHs may result in decreased immune function, cataracts, kidney and liver damage and respiratory problems. PAH exposure is a risk for cancer and has been linked to skin, gastrointestinal and bladder cancers. PAHs are potent as co-carcinogens due to the presence of two to four aromatic rings and their low molecular weight. PAH compounds like benz(a)anthracene, benzo(a)pyrene, benzo(b)fluoranthene, benzo(k)fluoranthene, chrysene, dibenz (ah) anthracene and indeno (1,2,3-cd) pyrene areprobable human carcinogens. Increased exposure to PAHs has also been associated with cardiovascular disease and poor foetal development.[21]

**Hormones and Illicit Drugs:**

Hormonal compounds have a negative influence on the human reproductive system. Hormonal wastes lead to the development of tumoral cells in the breast, testis and prostate. Cognitive impairment is also reported. Estrogen is the most commonly found compound in animal manures and human excretions. Hormonal compounds like ethinylestradiol, estradiol and tamoxifen are primarily found in water bodies. Ethinylestradiol may cause specific reproductive abnormalities and tamoxifen leads to endometrial cancers. Nowadays, the use of illegal drugs and their frequent unregulated discharge into water bodies are very prevalent in our society. Commonly found narcotics in water bodies are amphetamine, amphetamine-sulphate, opiates, morphine, cannabinoids and cocaine. It may cause urinary problems, syncope, depression, hypotension, atrial fibrillation, etc.[18]

**How can water pollution be prevented?**

Pollution-related NCDs are preventable. Two primary sources of contaminants pollute water: intentional and unintentional. We can prevent these intentional pollutants to a certain extent. Physical, chemical and biological methods can be used to remove contaminants from water. Our responsibility is to keep our water resources clean and safe for today and a better tomorrow. Though all these are recognised by international agencies like the United Nations, the World Health Organisation and the World Heart Federation, pollution control is not their focus. It is not on their priority list for control. Thus, it is the country-specific measures that are essential.[22]

Many proposals are feasible. One is heavy taxation on pollutants, like what has been done for tobacco control. The money collected as tax could be directly channelled for pollution control measures. We need to encourage scientific studies in this area and any measures to address climate change. We also need to enable the media to campaign against pollution and help governmental agencies work towards pollution control.

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Chapter - 16

# Water Pollution and Cardiovascular Diseases

*A K Pancholia, Subodh Banzal*

**Introduction:**

Adding some contaminants and the change of physical and chemical characteristics of water in any way to make water unfit for human consumption is defined as water pollution. It is caused by waste products of industries, domestic sewage, oil spillage, agricultural and industrial run off etc. Pollution of air, water and soil is a great and growing threat to global health. The Lancet Commission on Pollution and Health documented that pollution is the largest environmental cause of disease and premature death in the world today. Diseases caused by pollution were responsible for an estimated 9 million pre-mature deaths in 2015. It is 16% of all deaths worldwide and three times more than from AIDS, malaria and tuberculosis together.[1] (Figure 1). Additionally, pollution was

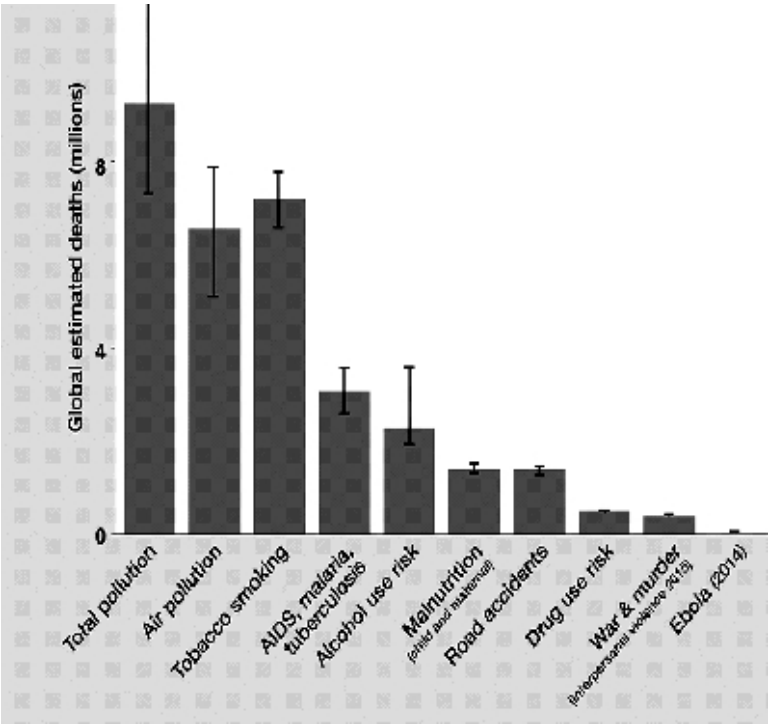


**Figure 1 : Estimated Global Deaths for Different Pollution Categories.**

(Source: Landrigan et al. Lancet 2018; 391:462–512.)

responsible in 2015 for the loss of 268 million disability-adjusted life years DALYs—254 million years of life lost and 14 million years lived with disability.[2] Despite the fact that 70% of pollution-related diseases are non-communicable diseases NCDs and more than 60% are cardiovascular diseases, interventions against pollution are barely mentioned in the Global Action Plan for the Prevention and Control of non-communicable diseases (NCDs).[1] In addition to ignoring chemical pollutants, the Global NCD Action Plan also neglects the health effects of non-chemical environmental stressors such as mental stress, noise exposure, nocturnal light pollution and climatic changes that all together may easily outcompete all genetic pre-disposition-related health-risk factors. Data from epidemiological studies suggest that environmental-risk factors are major contributors to cardiovascular disease along with other NCDs like metabolic and mental diseases.[3–6]

**Sources of Pollution:**

**Industrial Wastes:** Several industrial waste containing heavy metals and chemicals are directly disposed into the water bodies such as lakes, ponds and rivers with no proper treatment. These wastes contaminate the water bodies and make them unsuitable for human consumption. Hot water is another noted pollutant from industries.

1. Many industries use water as a coolant for the machinery and release of hot waste water into the water bodies causing thermal pollution which affect both the plant and animal life.
2. The surface run off from agricultural land is contaminated with pesticides and residues of inorganic fertilizers. (Figure 2 A).
3. Organic and inorganic compounds are richly present in the drain from urban and industrial land which contaminates both surface and ground water resources.
4. Domestic sewage is also an important source of water contamination rich in organic matter and detergents. (Figure 2B).
5. Oil spills in the oceans from oil containers, offshore drilling and exploration operations can contaminate water and damage to the marine and coastal environments. (Figure 2C).
6. Radioactive waste in water, extraction of radioactive mineral, nuclear power plants, production of military weapons or radioactive materials utilizes for medicine and research by medical institution can also contaminate the water bodies.
7. Availability of excess nutrients results in algal bloom on the surface of water resulting in the deficiency of oxygen content BOD – Biological Oxygen Demand. This in turn leads to the death of aquatic organisms. This process is known as Eutrophication.



Figure. 2 A



Figure 2 B



Figure 2 C

**Pathophysiology:** Drinking polluted water, skin contact and consumption of food grown or prepared with contaminated water are the important sources to affect health of human beings. Toxic substances such as heavy metals, metalloids or pesticides that contaminate soil frequently produce oxidative stress that is considered as a common initiating event for multiple NCDs including cardiovascular disease CVD.[7] (Figure 3).

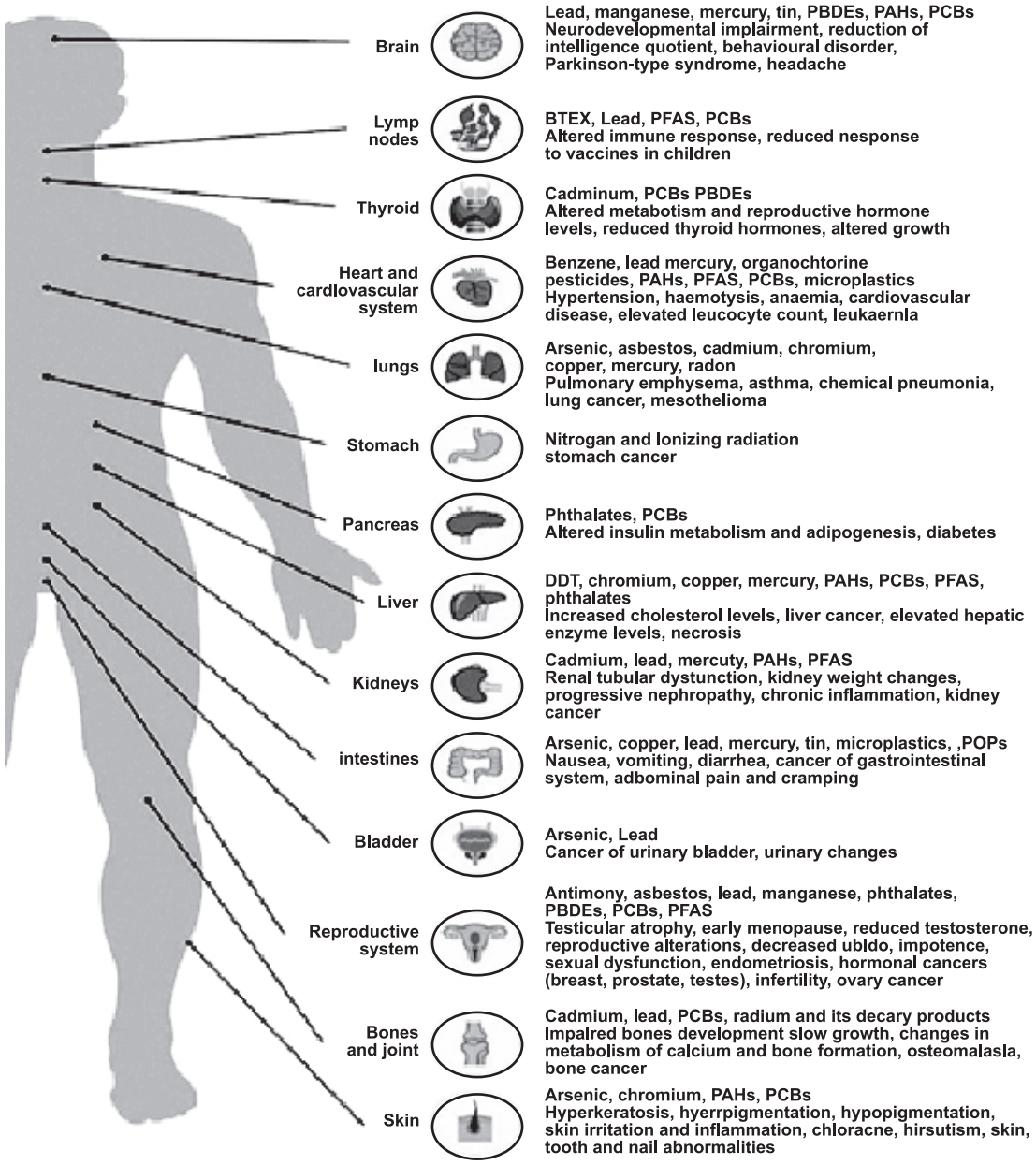


**Figure: 3 Soil and Water Pollution and Health Side Effects**

(Source: Thomas Munjel. Cardiovascular Research. July 2022 1192)

Experimental and epidemiological studies suggest that heavy metals can trigger cardiovascular diseases. [Cadmium in 31 studies[8], Lead in 12 studies[9] as well as Arsenic in[12] studies].[10] Cadmium through oxidative stress is responsible for vascular damage, endothelial dysfunction and atherosclerosis e.g. promoting Fenton reaction by replacing iron and copper in sulphur complexes,[11, 12] disruption of zinc– sulphur complexes by interference with antioxidant responses[13] and inhibition of NO-mediated vasodilation.[14] Strong evidence also exists for disruption of circadian rhythm by cadmium, which is termed 'cadmium chronotoxicity' in the literature.6 Disruption of circadian rhythm may promote cardiovascular diseases.[15,16,17]

Lead contributes to oxidative stress, inflammation, endothelial dysfunction and proliferation of vascular cells with adverse effects on heart-rate variability.[18] Overall, lead and cadmium have many similar biological effects. Chemical Soil Pollutants like polychlorinated biphenyls (PCBs), e.g. dioxins, polybrominated diphenyl ethers, perfluorocarboxylic acids, perfluorooctanesulphonate, benzene and bisphenol A (BPA) have adverse health effects. Sources of these chemicals originate from industrial processes or they can be applied to soil in pesticide formulations. These compounds through induction of oxidative stress, inflammation or epigenetic dysregulations e.g. via microRNAs are responsible for endothelial dysfunction, atherosclerosis, apoptosis, NASH, obesity and other cardiometabolic complications[19] as well as for neurodegenerative disorders. It is estimated that 25 million agricultural workers per year are affected by pesticide poisoning[20] and that pesticides used in agricultural fields are associated with an increased risk of developing several chronic diseases such as diabetes, cancer and asthma as well as a variety of shortterm problems.[21] Pesticide exposure through variable oxidative stress were reported to have increased risk of acute myocardial infarction, arrhythmia, heart failure as well as severe arterial hypertension during pregnancy.[22] There is also pre-clinical and clinical evidence for an impact of environmental organic chemicals on circadian pathways.[23]

**Conclusion:**

Cardiovascular diseases can be initiated by many pollutants that contaminate water and soil. While these pollutants differ in their chemical composition, they cause disease through shared pathophysiological pathways centred on oxidative stress and inflammation leading to a dysregulation of circadian rhythms. Oxidative stress and inflammation in response to contamination with plastic, heavy metals, pesticides and toxic agents represent major pathophysiologic mechanisms causing cardiovascular and metabolic diseases.

At last we have to implement 'Healthy Planet for All', air, water, and soil pollution have to be reduced to levels at which these are no longer considered harmful to health and thus creating a non-toxic environment

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Chapter - 17

# Soil Pollution and Non-Communicable Diseases: Is there any Relationship?

*Mangesh Tiwaskar, Agam Vora, Amit Saraf, Shilpa Tiwaskar*

**Introduction:**

The ancient Indian Vedic texts revered the earth as a sacred entity, recognizing the vital role that soil plays in sustaining all life on our planet. The Atharva Veda, one of the four canonical sacred texts of Hinduism, contains hymns that pay homage to the earth, referring to it as "Bhumi Mata or Bhumata", the mother of all beings. The Vedas teach that our physical bodies are composed of the same five elements found in nature, including the earth element, which forms the basis of our flesh, bones and tissues. Therefore, the health and vitality of the soil are intrinsically linked to our own well-being. The concept of "Prithvi Tattva" or the "Earth Element" is one of the five fundamental elements (Pancha Maha Bhutas) that are believed to constitute the entire material universe. The importance of nurturing the soil, not just for bountiful harvests, but for ensuring the physical and spiritual well-being of all beings is paramount and supreme. If we pollute and spoil our soil, the impact on the health, especially on the non-communicable diseases (NCDs) is exponentially astounding.

Soil pollution refers to the contamination of soil by various substances that can have adverse effects on human health and the environment. These pollutants can originate from various sources, including industrial activities, agricultural practices, waste disposal and urbanization. The impact of soil pollution on human health has become a growing concern in recent years, particularly in relation to the development of NCDs.

NCDs, such as cardiovascular diseases, cancers, chronic respiratory diseases and diabetes, are the leading causes of death globally. According to the World Health Organization (WHO), NCDs account for over 70% of all deaths worldwide. While the traditional risk factors for NCDs, such as unhealthy diets, physical inactivity, tobacco use and harmful use of alcohol, are well-established, emerging evidence suggests that environmental factors, including soil pollution, may play a significant role in the development and progression of these diseases.[1]

This chapter will explore the epidemiological links between soil pollution and NCDs, highlighting the potential mechanisms through which soil contaminants can contribute to the development of these diseases. Additionally, it will discuss on the role of endocrine disruptors causing increase in NCDs through soil contamination and the current state of research in this field and the challenges associated with establishing causal relationships between soil pollution and NCDs.

**Sources and Types of Soil Pollutants:** [2]

Soil pollutants can originate from a variety of sources, including:

1. **Industrial Activities:** Heavy metals (e.g., lead, cadmium and mercury), organic pollutants (e.g., polycyclic aromatic hydrocarbons, dioxins) and radioactive substances can be released into the soil through industrial processes, waste disposal and accidental spills.
2. **Agricultural Practices:** Pesticides, fertilizers and livestock waste can contaminate soil, introducing various chemicals and pathogens.
3. **Urbanization:** Urban activities, such as transportation, construction and waste disposal, can contribute to soil pollution through the release of heavy metals, organic pollutants and other contaminants.
4. **Mining Activities:** Mining operations can lead to the release of heavy metals and other toxic substances into the soil, affecting both nearby communities and downstream areas.

**The types of soil pollutants can be classified into the following categories:**

1. **Heavy Metals:** Lead, cadmium, mercury, chromium and arsenic are among the most common and hazardous heavy metals found in contaminated soils.
2. **Organic Pollutants:** This category includes polycyclic aromatic hydrocarbons (PAHs), polychlorinated biphenyls (PCBs), dioxins and pesticides, many of which are persistent and bio-accumulative.
3. **Radioactive Substances:** Radionuclides, such as uranium, radium and caesium, can contaminate soil through nuclear accidents, nuclear waste disposal or natural sources.
4. **Pathogens:** Soil can be contaminated with pathogenic microorganisms, such as bacteria, viruses and parasites, from various sources, including sewage, livestock waste and medical waste.

**Exposure Pathways and Health Effects:** [3]

Humans can be exposed to soil pollutants through various pathways, including:

1. **Ingestion:** Direct ingestion of contaminated soil, particularly in children exhibiting pica behavior (the persistent eating of non-food substances) or indirect ingestion through the consumption of contaminated food crops grown in polluted soil.
2. **Inhalation:** Inhalation of soil particles or volatile compounds released from contaminated soil, especially in areas with high levels of soil disturbance or during agricultural activities.
3. **Dermal Contact:** Exposure through direct skin contact with contaminated soil, which can lead to the absorption of pollutants through the skin.

The health effects associated with exposure to soil pollutants can vary depending on the type and concentration of the contaminant, the duration of exposure and individual susceptibility factors. Some potential health effects linked to soil pollution include: [2,4]

A. **Cardiovascular Diseases:** Exposure to certain heavy metals, such as lead and cadmium has been associated with an increased risk of cardiovascular diseases, including hypertension, coronary heart disease and stroke.[1,2]

B. **Cancers:** Several soil pollutants, including PAHs, PCBs, dioxins and certain heavy metals, are classified as carcinogenic or potentially carcinogenic by international agencies, such as the International Agency for Research on Cancer (IARC).[1,3]

C. **Respiratory Diseases:** Inhalation of soil particles and pollutants can contribute to the development or exacerbation of respiratory diseases, such as asthma, chronic obstructive pulmonary disease (COPD) and lung cancer.

D. **Neurological Effects:** Heavy metals, such as lead and mercury, can have adverse effects on the nervous system, particularly in children, leading to cognitive impairment, developmental delays and behavioural problems.[14]

E. **Endocrine Disruption:** Some soil pollutants, like certain pesticides and persistent organic pollutants (POPs), can interfere with the normal functioning of the endocrine system, potentially contributing to the development of metabolic disorders, reproductive problems and hormone-related cancers.[5]

F. **Birth Defects and Developmental Disorders:** Exposure to soil pollutants during pregnancy or early childhood can have detrimental effects on fetal and child development, leading to congenital abnormalities, growth retardation and developmental delays.

**Role of Endocrine Disruptors in Causing NCDs:** [5]

**Endocrine Disrupting Chemicals and Soil Pollution:** Endocrine disrupting chemicals (EDCs) are a class of compounds that can interfere with the normal functioning of the endocrine system, which regulates crucial processes such as growth, development, metabolism and reproduction. Many soil pollutants, including certain pesticides, industrial chemicals and persistent organic pollutants (POPs) have been identified as potential endocrine disruptors.

**Sources and Types of Endocrine Disruptors in Soil:** [5] Endocrine disrupting chemicals can enter the soil through various sources, including:

a. **Agricultural Practices:** Pesticides, such as organochlorine insecticides (e.g., DDT, dieldrin) and certain herbicides and fungicides, have been found to possess endocrine-disrupting properties.

b. **Industrial Processes:** Polychlorinated biphenyls (PCBs), bisphenol A (BPA), phthalates and dioxins are examples of industrial chemicals that can contaminate soil and disrupt endocrine function.

c. **Waste Disposal:** Improper disposal of human waste, plastics, electronic waste and other materials containing EDCs can lead to soil contamination.

d. **Sewage Sludge:** The application of sewage sludge as a fertilizer in agricultural fields can introduce various EDCs, including pharmaceuticals and personal care products, into the soil.

**Mechanisms of Endocrine Disruption and Health Effects:**

Endocrine disrupting chemicals can interfere with the endocrine system through various mechanisms, including:

1. **Mimicking or Blocking the Action of Hormones:** Some EDCs can mimic the effects of natural hormones, such as estrogen or testosterone, potentially leading to hormonal imbalances and adverse health effects.
2. **Altering Hormone Synthesis, Transport, or Metabolism:** Certain EDCs can interfere with the production, release, transport, or metabolic processes of hormones, disrupting their normal

regulation.

3. **Modifying Hormone Receptor Expression or Activity:** EDCs can alter the expression or activity of hormone receptors, affecting the way cells respond to hormonal signals.

**Epidemiological Evidence:**

Several epidemiological studies have investigated the potential associations between exposure to endocrine disrupting chemicals and the development of NCDs:

A. **Metabolic Disorders:** A prospective cohort study in the United States found a positive association between exposure to certain persistent organic pollutants (POPs), including PCBs and dioxins and an increased risk of developing type 2 diabetes.[6]

B. **Reproductive Disorders:** A case-control study in Italy reported a higher risk of endometriosis (a condition associated with infertility) among women with higher levels of exposure to certain phthalates and BPA.[7]

C. **Neurodevelopmental Effects:** A cohort study in the Netherlands observed an association between prenatal exposure to certain organochlorine pesticides and an increased risk of autism spectrum disorders in children.[8]

D. **Thyroid Dysfunction:** A cross-sectional study in Belgium found an association between exposure to certain POPs and thyroid hormone disruption, particularly in overweight and obese individuals.[9]

While these studies provide evidence for the potential role of endocrine disruptors in contributing to the development of NCDs, further research is needed to establish stronger causal links and elucidate the specific mechanisms involved.

**Epidemiological Studies and Findings:** [3]

Several epidemiological studies have been conducted to investigate the potential links between soil pollution and NCDs. These studies have employed various methodological approaches, including ecological studies, case-control studies and cohort studies.

**Ecological Studies:** Ecological studies examine the relationship between environmental exposures and disease patterns at the population level. These studies have provided valuable insights into the potential associations between soil pollution and NCDs. For example, a study conducted in China found a positive correlation between soil lead levels and the prevalence of hypertension and cardiovascular diseases in various regions of the country.[1] Similarly, a study in the United States reported an association between soil concentrations of PAHs and the incidence of certain cancers, such as lung, breast and prostate cancers.[13]

**Case-Control Studies:** Case-control studies compare individuals with a specific disease (cases) to individuals without the disease (controls) and evaluate their exposure to potential risk factors, such as soil pollution. A case-control study in Italy found a significant association between residential proximity to industrial sites with soil contamination and an increased risk of lung cancer.[4] Another study in Mexico reported higher levels of lead and cadmium in the blood of children with learning disabilities and behavioural problems compared to healthy controls, suggesting a potential link between exposure to soil pollutants and neurodevelopmental effects.[14]

**Cohort Studies:** Cohort studies follow a group of individuals over time and assess the relationship between exposure to potential risk factors and the development of diseases. A prospective cohort study in the Netherlands investigated the association between exposure to dioxins and dioxin-like compounds in soil and the risk of developing diabetes mellitus. The study found a positive association between higher levels of exposure and an increased risk of developing diabetes, particularly in obese individuals.[3] Another cohort study conducted in the United States examined the relationship between residential proximity to industrial facilities with soil contamination and the incidence of cardiovascular disease. The study reported a higher risk of cardiovascular events among individuals living closer to these facilities, suggesting a potential link between soil pollution and cardiovascular health.[16]

**Challenges and Limitations:** [10]

While epidemiological studies have provided valuable insights into the potential links between soil pollution and NCDs, several challenges and limitations exist:

1. **Exposure Assessment:** Accurately measuring and quantifying individual exposure to soil pollutants can be challenging, as it involves considering multiple exposure pathways, environmental factors and individual behaviors.
2. **Confounding Factors:** Disentangling the effects of soil pollution from other environmental and lifestyle factors that may contribute to the development of NCDs can be difficult, as many of these factors can be interrelated and potentially confounding.
3. **Long Latency Periods:** The development of many NCDs, such as cancers and chronic respiratory diseases, can have long latency periods, making it challenging to establish temporal relationships between exposure to soil pollutants and disease onset.
4. **Multiple Exposures:** Individuals are often exposed to multiple soil pollutants simultaneously, as well as other environmental contaminants, making it difficult to attribute health effects to specific pollutants or their interactions.
5. **Susceptibility Factors:** Individual susceptibility factors, such as genetic predisposition, age, gender and comorbidities, can influence the health effects of exposure to soil pollutants, further complicating the interpretation of epidemiological findings.
6. **Limited Longitudinal Studies:** While cross-sectional and case-control studies can provide valuable insights, there is need for more large-scale, longitudinal cohort studies to better understand the temporal relationships and long-term effects of soil pollution exposure.
7. **Generalisability:** Many epidemiological studies are conducted in specific geographical regions or populations, making it challenging to generalize the findings to other settings with different environmental and demographic characteristics.

Despite these challenges, epidemiological research plays a crucial role in identifying potential associations between soil pollution and NCDs and informing public health policies and interventions.

**Addressing the issue of endocrine disrupting chemicals in soil pollution requires a multifaceted approach, including:**

A). Stricter regulations and monitoring of industrial processes, agricultural practices and waste

management to minimize the release of EDCs into the environment.

B). Developing and implementing effective soil remediation techniques to remove or reduce the levels of endocrine disruptors in contaminated areas.

C). Promoting sustainable alternatives to EDC-containing products and practices, such as organic agriculture and green chemistry.

D). Raising awareness among the public, policy makers and healthcare professionals about the potential health risks associated with exposure to endocrine disruptors and the importance of preventive measures.

E). Conducting further epidemiological and toxicological research to better understand the mechanisms of endocrine disruption, identify susceptible populations and develop targeted interventions and treatment strategies.

**Future Directions and Recommendations:** [11, 15]

To advance our understanding of the epidemiological links between soil pollution and NCDs and to develop effective prevention and mitigation strategies, several future directions and recommendations can be considered:

1. **Improved Exposure Assessment Methods:** Developing and employing more accurate and comprehensive methods for assessing individual exposure to soil pollutants, taking into account multiple exposure pathways, environmental factors and individual behaviours, is crucial for strengthening epidemiological studies.
2. **Longitudinal Cohort Studies:** Conducting more large-scale, prospective cohort studies with long-term follow-up can provide valuable insights into the temporal relationships between exposure to soil pollutants and the development of NCDs, while accounting for potential confounding factors and individual susceptibility.
3. **Biomonitoring and Biomarker Research:** Integrating biomonitoring techniques and exploring potential biomarkers of exposure and early biological effects can enhance our understanding of the mechanisms through which soil pollutants contribute to the development of NCDs.
4. **Consideration of Susceptible Populations:** Focusing research efforts on populations that may be particularly vulnerable to the health effects of soil pollution, such as children, pregnant women and individuals with pre-existing health conditions, can help identify and address potential health disparities.
5. **Interdisciplinary Collaboration:** Fostering interdisciplinary collaborations among epidemiologists, toxicologists, environmental scientists and other relevant disciplines can facilitate a more comprehensive understanding of the complex interactions between soil pollution and NCDs.
6. **Risk Assessment and Risk Communication:** Conducting robust risk assessments and implementing effective risk communication strategies are essential for informing policymakers, regulatory agencies and the public about the potential health risks associated with soil pollution and the measures needed to mitigate these risks.

7. **Remediation and Prevention Strategies:** Developing and implementing effective soil remediation techniques and pollution prevention strategies, informed by epidemiological evidence and risk assessments, can help reduce exposure to soil pollutants and mitigate their potential health impacts.
8. **International Collaboration and Knowledge Sharing:** Promoting international collaboration and knowledge sharing among researchers, public health agencies and policymakers can facilitate the exchange of best practices, research findings and strategies for addressing the global challenge of soil pollution and its impact on NCDs.

**Conclusion:**

The epidemiological evidence linking soil pollution to the development and progression of non-communicable diseases is growing, highlighting the importance of addressing this environmental health issue. While challenges and limitations exist in establishing causal relationships and quantifying the magnitude of the health impacts, epidemiological studies have provided valuable insights and contributed to our understanding of the potential mechanisms and exposure pathways involved. By addressing the issue of endocrine disrupting chemicals in soil pollution, we can contribute to the broader efforts to reduce the burden of non-communicable diseases and promote a healthier environment for present and future generations.

Continued research, improved exposure assessment methods and interdisciplinary collaborations are crucial for advancing our knowledge in this field and informing effective public health policies and interventions. By addressing soil pollution and its potential health consequences, we can contribute to the global efforts.

Incorporating robust epidemiological evidence into policy decisions and implementing evidence-based strategies for soil remediation, pollution prevention and public health interventions can help mitigate the adverse effects of soil pollution on human health. Additionally, raising awareness about the potential risks associated with soil pollution and promoting sustainable practices in industries, agriculture and waste management can play a vital role in reducing the burden of soil contamination and its impact on non-communicable diseases.

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Chapter - 18

# Noise Pollution and Non-Communicable Diseases: Is there any Relationship?

*Anuj Maheshwari, Shweta Kanchan*

**Introduction:**

The present century has seen a steady increase in the prevalence of non-communicable diseases in the society by and large. Several factors are responsible for this surge, factors like lifestyle, diet, stress levels have all been highlighted as the reason behind increasing prevalence of non-communicable diseases. Another important factor, that somehow does not get the attention as the above factors is the increase in pollution levels in general and noise pollution in particular. Noise pollution which is on the rise also plays an important role in perpetuating these non-communicable disorders. Several researches have taken place to draw a relationship between noise pollution and non-communicable diseases and it has been noticed that noise pollution is directly link to diseases like hypertension, cardiovascular disorders, mental stress and others disorders. In the present discussion, we discuss the pathophysiological link of noise pollution to various non communicable disorders and what is the cause effect relationship between the two.

**Noise Pollution and Sleep Disturbance:**

It is a known fact that good quality sleep is not possible in noisy surroundings. Noise pollution leads to fragmented and non consolidated sleep. The arousal threshold of sleep also decreases when a person is exposed to noise and objective sleep indices like total sleep time, sleep stage distribution, sleep latency are disturbed due to noise pollution.[1] Sleep disturbance due to noise could have physiological consequences similar to insomnia, sleep apnea or other sleep disorders leading to non refreshing sleep. A person exposed to high levels of noise at night could have increase in sleep inertia in the morning along with excessive daytime somnolence and functional impairment. However, it is noticed that habituation to noise takes place to a certain extend after prolonged exposure. Exposure to prolonged loud noise has been shown to produce disturbance in the circadian rhythm, a desynchronization of the normal circadian clock and changes in the expression pattern of circadian associated genes.[2]

**Noise Pollution and Cardiovascular Disorders:**

Increased level of noise is associated with noise induced stress which leads to increased blood pressure along with endothelial dysfunction and oxidative stress, all this can predispose towards development of arterial hypertension. The adverse effect of noise on cardiovascular system is also linked to its association with several cardio metabolic risk factors like development of sleep disturbance, increased stress level and increased predisposition for developing type 2 diabetes.[3] Limited studies are available relating the risk of noise pollution to development of cardiovascular disorders, the presently available studies do indicate that increased level of noise pollutions leads to two possible mechanisms of increasing cardio vascular disorders, one being sleep disturbance

and the other being increased stress level.

**Noise Pollution and the Endocrine Disturbance:**

Exposure to high level of noise over long periods of time has shown to increase the level of circulatory catecholamines and cortisol levels.[4] It leads to an activation of the renin angiotensin aldosterone system (RAAS) along with the development of oxidative stress leading to a proinflammatory internal milieu. Stress hormone release leads to vasoconstriction, immune cell activation, induction of cardiovascular inflammation and oxidative stress. Complex mechanisms work at the cellular and molecular level leading to the production of oxidative free radicals and pro inflammatory markers. This increase in catecholamine and cortisol levels further adds up to the cardio metabolic stress.[5]

**Noise Exposure Psychological and Cognitive Changes:**

Cognitive and emotional responses as a result of high level of noise exposure lead to depression and annoyance which further aggravates the stress response. Chronic stress leads to the activation of sympathetic autonomic responses.[6] Noise induced stress can lead to an increase in the cerebral oxidative stress and neuro inflammation which may predispose to cognitive decline which is seen prominently in children.[7] An association between symptoms of anxiety, depression and noise pollution have also been noticed.[8]

**Conclusion:**

Noise pollution acts as cerebrovascular and cardiovascular risk factor along with pre disposing towards several metabolic diseases. The association of noise pollution with non communicable disorders needs more research especially regarding the temporal association and the intensity of noise levels with non communicable diseases. Keeping in view the adverse effects linked with noise pollution it is pertinent that strategies to mitigate the adverse effects of noise pollution need to be initiated to tackle both outdoor and indoor noise pollution effectively and prevent noise pollution related human health hazards.

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Chapter - 19

# Pollution and Sexual Health: Is there any Relationship?

*Deepak K Jumani*

**Introduction:**

Environmental air pollution exposure is a leading cause of death worldwide and with increasing industrialization and urbanization, its disease burden is expected to rise even further. The majority of air pollution exposure-associated deaths are linked to cardiovascular disease (CVD). Although ample research demonstrates a strong correlation between air pollution exposure and CVD risk, the mechanisms by which inhalation of polluted air affects cardiovascular health are not completely understood. Inhalation of environmental air pollution has been associated with endothelial dysfunction, which suggests that air pollution exposure impacts CVD health by inducing endothelial injury. Interestingly, recent studies demonstrate that air pollution exposure affects the number and function of endothelial progenitor cells (EPCs), subpopulations of bone marrow-derived proangiogenic cells that have been shown to play an essential role in maintaining cardiovascular health. In line with their beneficial function, chronically low levels of circulating EPCs and EPC dysfunction (e.g., in diabetic patients) have been associated with vascular dysfunction, poor cardiovascular health and increases in the severity of cardiovascular outcomes.

One of the most common sexual dysfunctions in males is erectile dysfunction (ED). ED and endothelial dysfunction are common in individuals with multiple cardiovascular risk factors (CRFs) and are longitudinal predictors of cardiovascular events. ED is associated with systemic endothelial cell activation/dysfunction independent from CRFs or from diffuse, unrecognized vascular damage. The pathogenesis of endothelial dysfunction and ED is intimately linked through increased expression and activation of endothelial nitric oxide (NO) synthase and the subsequent physiologic actions of NO. Reduced biologic activity of endothelium-derived NO links human atherosclerosis to ED and underscores the role of altered endothelium in the pathogenesis of both conditions. ED may be the only clinical marker of systemic endothelial damage that is associated with a documented future risk of acute cardiovascular events. ED comes three to five years before any episode of angina or myocardial infarction and is the first sign of coronary artery disease (CAD) in men.

The common noncommunicable diseases of industrializations and urbanizations are diabetes, hypertension, obesity and dyslipidaemia, all these lead to cardiovascular heart disease. The common etiopathology in all the above is endothelial dysfunction and the earliest marker of coronary artery disease is endothelial dysfunction. The key issue is reduction of Nitric Oxide (NO) which is the initiator of erectogenic mechanism as its potent vasodilator present in our endothelium. Exposure to ambient air pollution due to increased construction and increased traffic is also a

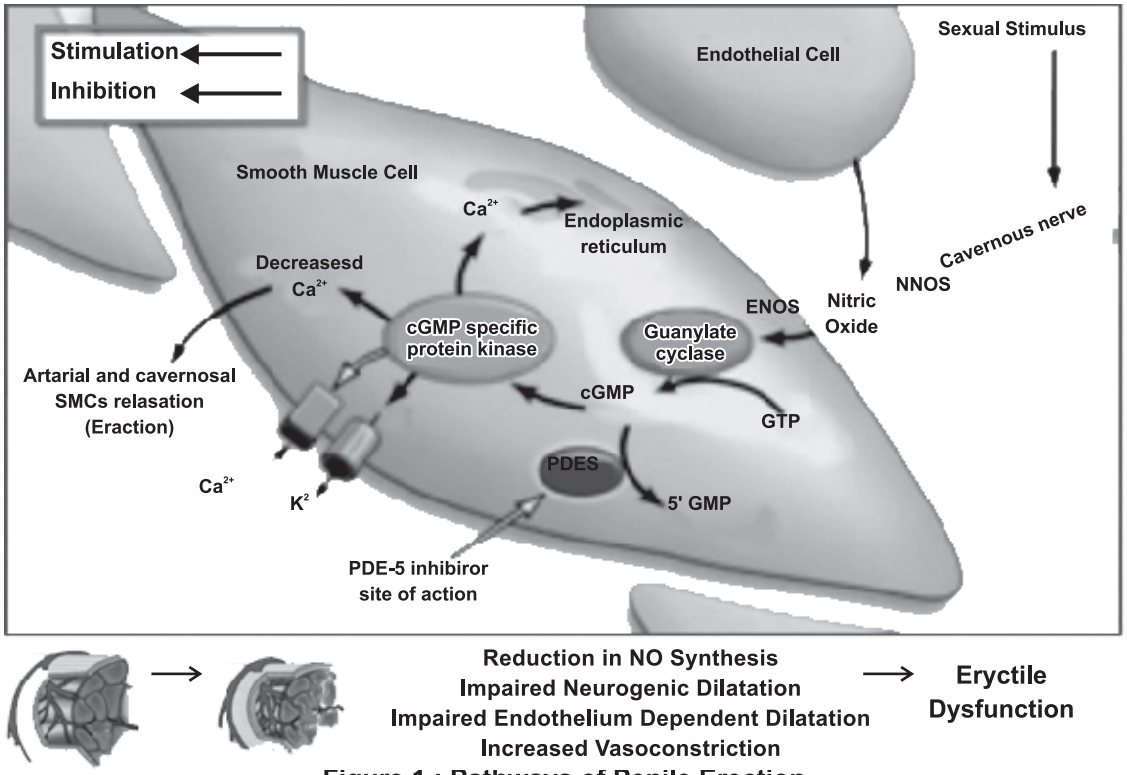



**Figure 1 : Pathways of Penile Erection**

Dilation of cavernosal arteries and smooth muscle cells (SMCs) of cavernosal spaces is mediated by the nitric oxide (NO)–cyclic guanosine monophosphate (cGMP) pathway. NO is derived from nonadrenergic, noncholinergic nerves (nNOS, NOS type I), and the endothelium (eNOS or NOS type III) of cavernosal sinuses (both calcium2+/calmodulin-dependent isoforms). NO crosses plasma membranes to enter vascular smooth muscle cells (VSMCs) and promotes the synthesis and accumulation of cGMP, which induces a cascade reaction, leading to smooth muscle relaxation by reducing intracellular calcium level. NNOS = neuronal nitric oxide. ENOS = endothelial nitric oxide.

leading cause of death worldwide and has been linked globally to 7 million premature deaths and to make things worse, the disease burden of air pollution is likely to increase further, as industrialization and urbanization are on the rise.[2] Endothelial dysfunction is a pathophysiological process caused by habitual exposure to different threat factors including poisons, vulnerable differences, diabetes, hypertension, dyslipidemia, oxidative stress and smoking, among others. These factors produce changes in the permeability of the endothelial subcaste, leading to the infiltration of low density lipoproteins (LDL) into the tunica intima subcaste of the endothelium, latterly, LDLs suffer oxidation, which enhances the process of endothelial dysfunction. As a consequence, the vascular face becomes prothrombotic displaying a pro-inflammatory cellular and humoral terrain. In addition, there's an aggravated product of adhesion proteins that leads to the reclamation of monocytes, lymphocytes and platelets, as well as changes in the towel microstructure. These physical, cellular and biochemical variations enhance the proinflammatory response, leading to habitual inflammation. In addition, signed monocytes are actuated by macrophages, which gulf oxidized LDLs. These actuated macrophages also lead to froth cells that suffer apoptosis and release cholesterol patches, further enhancing the seditious state of the

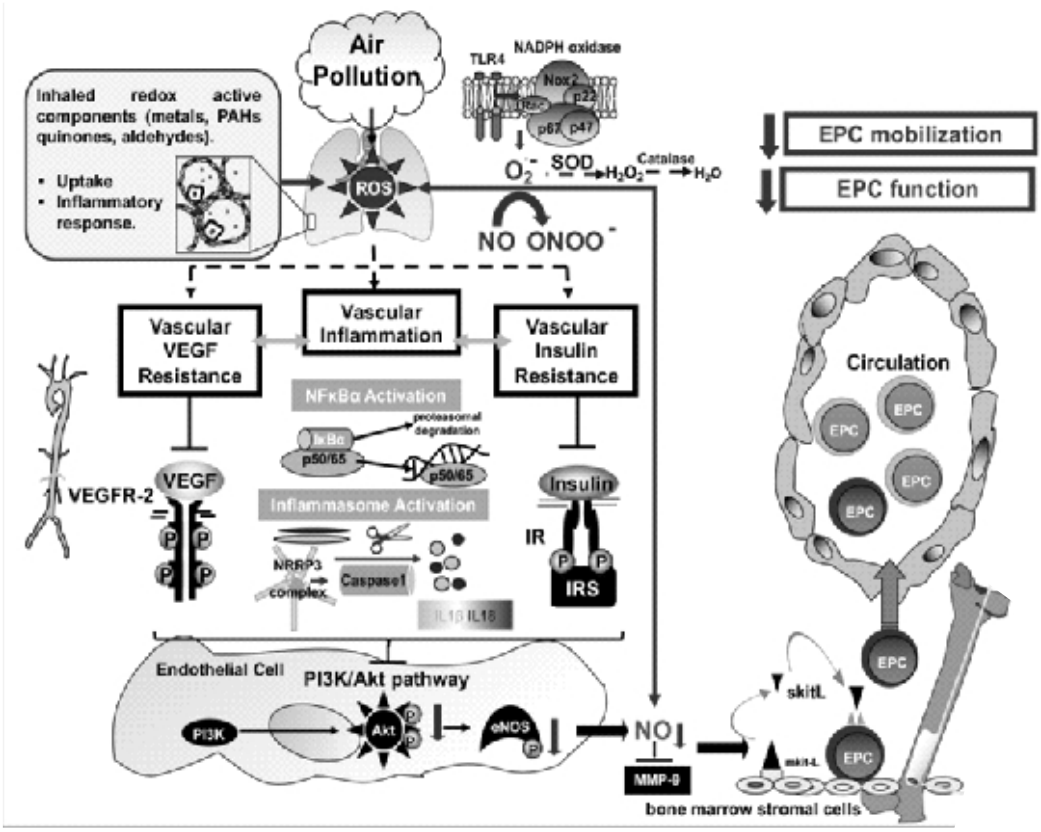
endothelium. All these mechanisms contribute to endothelial damage, converting the migration of smooth muscle cells from the tunica media to the tunica intima and creation the stashing of collagen, which stabilizes the atheroma subcaste. As a final event, endothelial dysfunction leads to loss of homeostasis with a significant reduction in vasodilator agents similar as nitric oxide (NO), a sustained seditious response, increased vascular permeability, differences in angiogenesis and increased product of adhesion proteins. For these reasons, endothelial dysfunction might be considered a marker of subclinical atherosclerosis.

**Is there a link between Environment Pollution and Sexual Dysfunction?**

Both environment pollution and sexual dysfunction decrease the EPC in the vascular endothelium and lead to increased mortality due to CAD. A study with patients of the EPCAD study[3] (circulating EPCs and cardiovascular morbidity and mortality in patients with coronary artery disease study) were assessed with regards to sexual and erectile function within the EROSS Programme (evaluation of role of sexual dysfunction in the Saarland University program). A total of 119 patients (32–86 years old) with CAD diagnosed by angiography and classified according to the level of stenosis and the number of coronary arteries affected, were enrolled in this study. ED was documented by the KEED questionnaire, while EPCs were measured in peripheral blood withdrew from the femoral artery before catheterization. The results allowed to establish a positive relationship between hypertension, diabetes and low levels of high-density lipoproteins, while age and body mass index resulted to be independent risk factors for ED. Cigarette smoke, a well-known life habit which damages the endothelial function, did not play a significant role in this study. This is likely due to the fact that the prevalence of smokers among the participants was low. Finally, a more severe ED was not significantly associated with strokes or myocardial infarction. As far as EPCs, the study showed their reduction in patients with cardiovascular risk factors, heart failure or ED, suggesting that EPCs may play an important role in atherosclerosis and CAD. In patients with ED, the number of EPCs was also significantly reduced in patients without cardiovascular risk factors. This finding suggests that EPCs may be an independent risk factor of ED. It has been demonstrated that the number of circulating EPC[4] is decreased in individuals with hypercholesterolemia, hypertension and/or diabetes. In addition, the number and the migratory activity of these cells are inversely correlated with risk factors such as hypertension, hypercholesterolemia, diabetes and metabolic syndrome. On the other hand, the number of circulating EPC is increased in hypoxia or acute myocardial infarction (AMI). In another study, patients with arterial erectile dysfunction (AED) had significantly higher blood pressure, triglycerides, homeostasis model assessment index of insulin resistance and cavernous artery acceleration time and intima-media thickness than PED (psychogenic erectile dysfunction) whereas international index of erectile function[5] score, HDL-cholesterol and cavernous artery peak systolic velocity was lower than PED. Both EPC and EMP (endothelial microparticles) were significantly higher in patients with AED as compared to patients with PED. Patients with AED showed worse metabolic parameters, cavernous artery parameters and higher EPC and EMP compared to patients with PED. This suggests that AED is an expression of endothelial dysfunction and that EPC and EMP may be considered predictors of endothelial dysfunction in patients with AED.

**Proposed Mechanism of Air Pollution-Induced Endothelial Progenitor Cell (EPC) Depletion and Dysfunction:**

Exposure to environmental air pollution triggers oxidative stress in the lungs directly by inhalation of redox-active components or by activation of immune cells (e.g., macrophages). Induction of oxidative stress [e.g., via activation of Toll-like-receptor 4 (TLR4) and NADPH oxidase] leads to induction of vascular inflammation (e.g., activation of NF-κB and inflammasome pathways stimulating the transcription and cleavage of IL-1b and IL-18) as well as vascular endothelial growth factor (VEGF)/insulin resistance. As for instance shown for exposure to concentrated ambient fine particulate matter (CAP) and acrolein, inhalation of particulate and volatile air pollution impairs the phosphorylation of Akt in the blood vessel and blunts the endothelium-specific phosphorylation of endothelial NO synthase (eNOS) in response to insulin and VEGF. Decreased eNOS activity could result in a decrease in NO bioavailability that consequently impairs EPC mobilization and function. On the other hand, air pollution exposure could, by inducing oxidative stress directly, diminish NO bioavailability, affecting EPC number and function. In addition to inducing vascular insulin resistance, exposure to CAP (9 days for 6 h/day) also impaired insulin signalling in bone marrow cells. Ficoll gradient-separated bone marrow cells aspirated from femur and tibia of both hind limbs were stimulated with 100 nM insulin for 10 min and insulin-induced Akt phosphorylation was analyzed by Western blot (mean ± SE, n = 5, normalized to control, $P < 0.05$ control vs. insulin; NS, not significant figure 2.



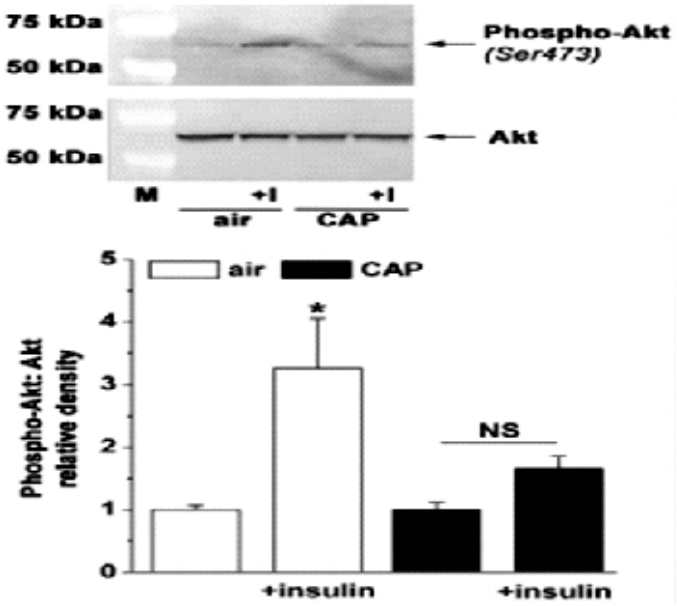
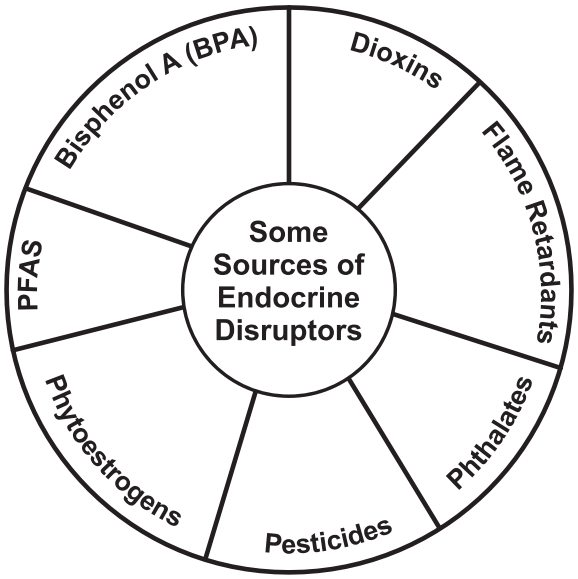



**Figure 2: Effect of Exposer to air pollution on endothelium-specific phosphorylation of endothelial NO synthase (eNOS) in response to insulin and VEGF.**

(AJP-Heart Circ Physdoi:10.1152/ajpheart.00804.2020 www.ajpheart.org Downloaded from journals.physiology.org/journal/ajpheart (114.079.178.141) on June 19, 2022.)

There are several other environmental pollutants as endocrine disruptor compounds (EDC) which also affect the endothelium. Endocrine disruptors are found in many everyday products, including some cosmetics, food and beverage packaging, toys carpets and pesticides. Some chemicals that act as flame retardants may also be endocrine disruptors. Contact with these chemicals may occur



through air, diet, skin and water. EDCs cannot be completely avoided or removed; however, you can make informed choices to reduce exposure and risk of any potential health effects. Chemicals that may disrupt your endocrine system According to the Endocrine Society, there are nearly 85,000 human-made chemicals in the world and 1,000 or more of those could be endocrine disruptors, based on their unique properties.

The following are among the most common and well-studied. Atrazine is one of the most commonly applied herbicides in the world, often used to control weeds in corn, sorghum and sugarcane crops. Bisphenol A (BPA) is used to make polycarbonate plastics and epoxy resins. It is used in manufacturing, food packaging, toys and other applications. BPA resins may be found in the lining of some canned foods and beverages. Dioxins are a byproduct of certain manufacturing processes, such as herbicide production and paper bleaching. They can be released into the air from waste burning and wildfires. Perchlorate is a colourless salt manufactured and used as an industrial chemical to make rockets, explosives and fireworks, which can be found in some groundwater. Per- and polyfluoroalkyl substances (PFAS) are a large group of chemicals used widely in industrial applications, such as firefighting foam, nonstick pans, paper and textile coatings. Phthalates are a large group of compounds used as liquid plasticizers. They are found in hundreds of products including some food packaging, cosmetics, fragrances, children's toys and medical device tubing. Cosmetics that may contain phthalates include nail polish, hair spray, aftershave lotion, cleanser and shampoo.

Recent National Institute of Environmental Health Science-supported research shows links between endocrine-disrupting chemicals and the ways in which well-being may be harmed. Exposure to certain phthalates was associated with behaviours characteristic of attention deficit hyperactivity disorder (ADHD).[5]

**Immunity:** Children exposed to high levels of PFAS had a diminished immune response to vaccines.[6] Other research found some indication of increased risks of childhood infections, particularly following exposures to PFAS metabolism.[6] Long-term exposure to arsenic can disrupt metabolism, increasing the risk of diabetes and other metabolic disorders.[7] A large-scale study on exposure to PFAS in humans and rodents showed consistent evidence of chemical-driven liver damage.[8] Other research indicated that exposure to another endocrine-disrupting chemical, triclosan, worsened fatty liver disease in mice that ate a high-fat diet.[9]

**Puberty:** Chemicals in lavender oil and tea tree oil were associated with premature breast development in girls,[10] abnormal breast development in boys.[11]

**Reproduction:** DES can alter the way genes are turned on and off in reproductive organs of mice, potentially affecting fertility and reproduction.[12] BPA substitutes have also been linked to similar reproductive issues.[13]

**Conclusion:**

Evidence from an abundant number of studies suggests that human sexual and reproductive functions have become impaired over the past half century and that there might be a relationship between environment pollution and endocrine disrupting chemicals (EDCs) which leads to sexual dysfunctions and reduced fertility. EDCs are substances present in our environment, food and consumer products. A reconciliation of the basic experimental data with observations in humans

needs to be achieved through translation in both directions, from bench to bedside and from bedside (and populations) to bench. As a Sexologist, I, suggest that The Endocrine Society actively engages in lobbying for regulation seeking to decrease human exposure to the many endocrine-disrupting agents. Scientific societies should also partner to pool their intellectual resources and to increase the ranks of experts with knowledge about EDCs who can communicate to other researchers, clinicians, community advocates and politicians.

Our chemical policies at local, state and national levels, as well as globally, need to be formulated, financed and implemented to ensure the best public health. By communicating these priorities to basic and clinical researchers, physicians, community advocates and the public at large, we are hopeful that early identification and intervention will be facilitated. But the fact remains, environment pollution is a menace to sexual health and with ever growing and dynamic development either in the infrastructure or technology the end to this seems far from reach.

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Chapter - 20

# Pollution and Gastrointestinal Diseases: Is there any Relationship?

*Rajesh Upadhyay, V S Gaurav Narayan*

**Introduction:**

There have been multiple diseases of the liver and gastrointestinal tract that have been attributed partially or completely to environmental pollutants and toxins, ranging from seemingly benign conditions like Irritable Bowel Syndrome (IBS) to grave disorders like liver and gall bladder carcinoma. Although a causal relationship has not been established in many of the studies, a direct correlation of the prevalence and mortality of multiple disorders, with the apparent level of pollutants has been demonstrated extensively. In this chapter, we shall discuss various types of pollutants and their effects on the GI tract, pancreas and the hepatobiliary system, based on current evidence.

**Air Pollutants and Gastrointestinal Effects:**

According to the United States Environmental Protection Agency (EPA), air pollutants have been categorised into six major categories- carbon monoxide, lead, nitrogen oxides (NO), ground level ozone, particulate pollution (also known as particulate matter-PM) and sulphur oxides. Amongst these, long term exposure to nitrogen dioxides and PM has been shown to be associated with an increased risk of early onset Crohn's disease.[1] Additional studies have demonstrated an increased admission rate for Inflammatory Bowel Disease (IBD) in areas with higher levels of air pollutants.[2] A study from Canada has demonstrated a higher incidence of perforating phenotype of appendicitis in patients exposed to higher levels of ozone.[3] The disadvantages of these studies are that the level of pollutants is based on regional estimates and not personal monitoring. A dysfunctional gut microbiome has been associated with multiple disorders, including IBD, metabolic syndrome, obesity and various hepatobiliary disorders. The gut microbiome is diverse, with over 100 trillion microbes in the GI tract.[4] The effect of environmental pollutants on the gut microbiome have not been extensively studied. In simulation models, Van de Wiele et al illustrated that inorganic Arsenic in the soil is converted to toxic metabolites by the gut microbiota.[5] Kish L et al demonstrated in mouse models that higher amounts of ingested pollutant particles significantly altered the gut microbial levels of Firmicutes, Bacteroidetes and Verrucomicrobia. This was confirmed to correlate with an altered production of short chain fatty acids, which are one of the essential substrates for colonocytes and epithelial immune cells.[6]

Increased gut permeability has been linked with multiple inflammatory intestinal disorders.[7] Studies based on analysis of excreted lactulose /mannitol have demonstrated that ingested particulate matter (PM) decreases the intestinal epithelial barrier and causes an inflammatory response.[8]

Hence, PM induced increased gut permeability can also induce systemic inflammation.

**The Effects of Water Pollution:**

There are multiple mechanisms of gastrointestinal disease from consuming contaminated water: toxic microelement content (phosphates, sulphates, chlorates, nitrates, perfluoroalkyl substances), the presence of Helicobacter Pylori and toxic levels of heavy metals, causing GI inflammation and immune responses.[9] It is well known that contaminated drinking water, containing pathogenic microbes can cause various GI infections. However, there are relatively lesser studies evaluating long term effects of exposure to water pollutants. In a paired cross sectional and longitudinal analysis from China, with 13,322 and 9,688 participants respectively, participants consuming purified tap water were found to have a lower incidence of hepatitis, liver cirrhosis and cancer in the longitudinal arm. This proved that long term exposure to toxins (as opposed to a single time exposure) is more likely to cause water toxins induced disorders.[10] In another study from China, a large number of gastrointestinal cancers were attributed to exposure to the polluted H river basin 15 years ago. It was found that the mortality related to liver, esophageal, colorectal and anal cancers was higher in people living in areas surrounding the H river basin, as compared to the national average. When these same surveillance areas were re-evaluated years after the river's pollution levels came down, the mortality related to the same cancers reduced significantly.[11] In India, a large portion of the population, especially people of lower socio-economic status, reside along the banks of the Ganges (Ganga) river, as they are dependent on the river for their livelihood. It is well known that a tremendous amount of industrial pollutants, agricultural effluents and untreated sewage is dumped into the river on a daily basis. High levels of nitrates, pesticides and heavy metals have been detected in the water of the Ganges. Significantly higher levels of nitrates and heavy metals (Cadmium, Chromium and Lead) have been detected in the bile aspirate of patients with gall bladder carcinoma, as compared to patients with just gall bladder stones.[12] This is a possible factor why the incidence of gall bladder cancer is much lesser in southern India, where most rivers are not perennial. Certain liver disorders, such as NAFLD, are affected by environmental factors. Shuilin Zheng et al have demonstrated positive associations between NAFLD and long term exposure to water contaminants such as microcystins (MCs), disinfection by-products (DBPs), heavy metals, dioxins and polychlorinated biphenyls (PCBs).[13] In a study from West Bengal, liver enzymes (AST, ALT, ALP and GGT) and bilirubin levels were compared between participants residing in areas with and without Arsenic contamination of drinking water. The levels of these laboratory tests were much higher in patients in the Arsenic exposed arm.[14] In a systematic review, a positive association was established between arsenic, cadmium, iron, lead, mercury and fatty liver disease. Surprisingly, for reasons that are unclear, exposure to zinc and copper showed a negative relationship with progressive fatty liver disease.[22]

**Soil Toxins:**

The major toxins found in soil are heavy metals, which are defined by metals with a density >5g/cm$^3$. These include Arsenic, Mercury, Lead, Chromium and Cadmium.[15] Heavy metals are known to cause damage to the GI mucosa by various mechanisms:

1) Disrupting the gastric mucosal barrier by decreasing mucosal thickness.
2) Generation of Reactive Oxygen Species (ROS) which alter cell growth, signal transduction and gene regulation, which ultimately results in carcinogenesis.
3) Induce expression of proinflammatory cytokines (such as IL-18) and micro RNA.[16]

Heavy metals have been classified as certain or probable carcinogens by the International Agency for Research on Cancer.[17] Many studies have demonstrated increased incidence and mortality related to gastric cancer in patients exposed to high levels of heavy metals. A meta-analysis has indicated that Chromium (Cr) exposure significantly increases the risk of gastric cancer.[18] Increased topsoil concentrations of Cr correlated with mortality in women with upper gastrointestinal (GI) tract cancer, indicating that long-term exposure to even low levels of heavy metals in topsoil could be a potential risk factor for GI cancers.[19] In a study in a region surrounding a multi-metal mine, it was demonstrated that long-term exposure to Cd and Pb enhanced the mortality risk of several cancers, including lung, esophageal and gastric cancer.[20] In a study from Turkey, a higher degree of contamination of fruits, vegetables and soil was shown to be associated with a higher rate of GI cancers.[21]

**Conclusion:**

It has been well documented in oncological literature that environmental factors play a significant role in the pathogenesis of various GI malignancies. There are various degrees of evidence to suggest that in diseases such as IBD, IBS, NAFLD and liver cirrhosis, environmental pollutants may play a role in their pathogenesis. Ameliorating the exposure to environmental toxins may be the key to preventing a large number of GI diseases, including malignancies. There are relatively few studies in India, assessing the relation between exposure to pollutants and the incidence of various GI disorders, necessitating the requirement of more such studies in our country. Preventing such diseases will require a holistic approach, including interventions from environment protection agencies and implementation of stricter government policies.

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Chapter - 21

# Pollution and Obesity: Is there any Relationship?

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**Introduction:**

Most countries have seen a decline in air quality because of fast industrialization, modernization and population expansion. Air pollution is one of the main risks to the health of the world and a major contributing factor to noncommunicable illnesses. Many detrimental health effects, including lung cancer, respiratory disorders, cardiovascular disease and strokes, have been connected to high levels of air pollution. Concurrently, obesity's rising global prevalence is a serious public health concern. Previous literature supports that exposure to air pollution may be a contributing factor in obesity. This chapter provides an overview of the epidemiological data supporting the link between obesity and exposure to different indoor and outdoor air pollutants. This chapter also discusses the possible mechanisms, that underlie the elevated risk of obesity brought on by air pollution and emphasizes the various preventive and management strategies to control air pollution-induced obesity.

**Obesity:**

Obesity is a global public health issue. It is a multifactorial chronic metabolic illness defined by an imbalance in the metabolism of energy and an excessive build-up of fat. It is the primary cause of insulin resistance and metabolic syndrome. The prevalence of obesity is rapidly increasing, both in developed and developing nations. It is one of the main causes of avoidable death worldwide.[1] Since 1975, the global obesity rate has almost tripled.[2] Globally, the prevalence of obesity is predicted to surpass 21% for women and 18% for men by 2025, while severe obesity is predicted to affect more than 6% of men and 9% of women.[3]

Numerous health issues can result from obesity. The worldwide obesity epidemic has a serious detrimental effect on people's health since obesity is linked to fatty liver disease, diabetes mellitus (DM), respiratory disorders, cardiovascular disease, reproductive issues and several malignancies.[4,5] Each year, the expenditure on medical treatment related to obesity amounts to more than $200 billion. Life expectancy can be reduced by 0.9 to 4.2 years due to obesity.[6] Lung ventilation is affected by obesity and being overweight increases the likelihood of pulmonary infections like severe corona virus disease (COVID-19), severe acute respiratory syndrome (SARS), etc.[7] Furthermore, several psychological issues, including depression and low self-esteem, as well as cognitive impairment and dementia, including Alzheimer's disease, are linked to obesity.[8] Obesity is primarily caused by environmental, behavioral and genetic factors. Diet, exercise and alcohol use are behavioral factors that contribute to obesity.[9] Concern over the effects

of air pollution on health, particularly obesity, has grown recently.

**Air Pollution:**

Air pollution is described as contamination by physical, chemical or biological agents that change the atmosphere's natural characteristics.[10] The issue of air pollution is getting worse due to rapid modernization and industrialization. Ninety-one percent of the world's population resides in areas where the average concentration of air pollutants is higher than 10 $\mu g/m^3$ for annual levels and 20 $\mu g/m^3$ for daily levels, the recommended cut offs in accordance with WHO air quality guidelines (AQG).[11] In many Asian locations, the average level of air pollution is higher than 35 $\mu g/m^3$.[11]

Air pollution comprises a variety of complex constituents, the most common of which are particulate matter ($PM_1$, $PM_{2.5}$, $PM_{10}$, etc.), nitrogen oxides (NOx), sulphur dioxide ($SO_2$), ozone ($O_3$), carbon monoxide (CO), polycyclic aromatic hydrocarbons (PAHs), volatile organic compounds (VOCs), second-hand smoke (SHS), toxic metals, aerosols and biological pollutants. Air pollution's composition affects how harmful it is to human health.[12]

PM is a category of air pollutants made up of various particle sizes and chemical compositions. PM is divided into three categories based on the size of the particles. Coarse particulate matter ($PM_{10}$, size <10 μm and PM coarse, size 2.5–10 μm) significantly damages lung function.[13] Particulate matter that is fine ($PM_{2.5}$, size <2.5 μm) stays in the atmosphere longer and passes into the lung alveoli. Smaller particles pose a greater risk than larger ones of similar composition due to the vast surface area available for biological interactions and high lung deposition proportion.[14]

NOx is made up of $NO_2$ and NO. PAHs are common organic pollutants, known to cause endocrine disruptions and carcinogenesis.[15] SHS describes the compounds that are released when tobacco is ignited and inhaled indoors. In addition, it is the most prevalent and dangerous kind of indoor air pollution and a leading global cause of mortality.[16]

Broadly speaking, there are two types of air pollution, ambient (outdoor) pollution and indoor pollution. Compounds with detrimental effects on health that are released into the atmosphere by human activity or natural processes are known as outdoor air pollutants. Due to the extensive use of biomass fuel in developing nations, the disease burden from outdoor air pollution is higher there than in developed nations.[17]

Due to the release of ammonia ($NH_3$), which is a significant factor in the synthesis of $PM_{2.5}$, agricultural emissions account for the majority of $PM_{2.5}$ emissions. Primarily, $SO_2$ and NOx are released when fossil fuels are burned to produce electricity. Road dust suspended from burning exhaust or brake wear, as well as vehicle exhaust from petrol or diesel combustion, constitute traffic-related air pollution (TRAP), which is also on the rise.[18]

The term "indoor air pollution" refers to the existence of airborne pollutants in confined spaces that pose a risk to human health. There are two main sources of indoor air pollution: indoor activity and the transfer of outdoor air pollution. A 10% daily rise in outdoor PM concentration causes an average increase in indoor PM concentration of 4.2-6.1%.[19] The concentration of outdoor pollutants, the outside weather, indoor ventilation, infiltration rates and human activity within the building all affect the levels of pollutants indoors.[20] The main causes of indoor air pollution in developing and economically disadvantaged nations are improper cooking techniques in homes

without enough ventilation. Utilizing inefficient stoves causes partial fuel combustion, which releases CO, black carbon and organic carbon compounds. These factors increase exposure duration and levels for women who cook, as well as for newborns and small children at home.[21] Furthermore, pollutants, tobacco smoke, detergents, dust, germs and allergens also contribute to indoor air pollution. In addition, harmful VOCs such as formaldehyde, alkanes and aromatic compounds are typically released by furnishings and building supplies like paint, flooring and wallpaper.[21]

**Effects of Air Pollution:** A major factor in the rising global burden of disease is air pollution. About 4.2 million deaths per year are caused by air pollution outdoors, while about 3.8 million deaths per year are caused by indoor air pollution, mostly in low- and middle-income nations. The death rate attributable to air pollution in urban areas was almost 50% higher than that of rural areas.[22] Numerous researchers have reported air pollution to cause neurological, pulmonary, cardiovascular and metabolic diseases, as well as premature births and birth deformities.[23] Hospitalization rates for respiratory disorders increase by 0.26% for every 10 $\mu g/m^3$ increase in PM coarse concentration.[24] The impact of atmospheric pollution on metabolic disorders, such as obesity and DM, is likewise becoming more significant. The detrimental impact of ambient air pollutants, especially PM, on the course of type 2 diabetes mellitus (T2DM) was demonstrated by a meta-analysis of the relationship between air pollution and diabetes.[25] Most studies revealed a positive correlation between obesity and exposure to air pollution. However, in several investigations, no meaningful relationships were found.[26] Additionally, research on animals suggests that exposure to PM may activate genes linked to the synthesis of fat in adipose tissue, resulting in larger fat cells, a greater volume of fat (visceral and total) and even weight gain.[26]

Each component of air pollution affects obesity in a different way. In children and adolescents, the risk of obesity is strongly positively correlated with $PM_1$, $PM_{2.5}$, $PM_{10}$ and $NO_2$, but not with $O_3$. In all cell models exposed to PM, whether once or repeatedly, an excess of cytosolic reactive oxygen species (ROS) results in oxidative damage. Airborne PAH exposure may cause endocrine system disruption, which would change adipocyte behavior and promote obesity.[26]

Air pollution can influence metabolic function by altering oxidative stress, adipose tissue inflammation and individual food consumption. The inhalation of air pollutants incites a cascade of physiological reactions that modify immunological, inflammatory and respiratory pathways, culminating in elevated levels of oxidative stress. Furthermore, exposure to $PM_{2.5}$ negatively impacts glucose metabolism. Exposure to air pollutants has also been associated with blood pressure elevation, decreased lung function and respiratory symptoms that can hinder one's ability to exercise and perform well. Regular physical exercise may be hampered by poor air quality, which can result in substantial weight gain and obesity. People become less inclined to engage in outdoor activities (such as jogging, walking and bicycling) as the air quality deteriorates.[26]

**Air Pollution and Obesity:**

**Epidemiology:** Numerous epidemiological studies have shown a strong correlation between exposure to environmental pollutants and the occurrence of a variety of human diseases. While cardiovascular and respiratory disorders have been the focus of previous research on human

diseases brought on by exposure to environmental pollutants, recent epidemiological studies have shown a strong correlation between air pollution exposure and obesity.[27] Healthy early years of life health play a critical role in maintaining good health later. As a result, childhood exposure to environmental factors may have a role in the development of obesity, which has its roots in early life. Determining the relationship between early-life exposure to air pollution and obesity is therefore crucial.[28]

Prenatal exposure to air pollutants is linked to an increase in infant weight and anthropometric changes from 1 to 6 months after birth. These changes may affect the infant's growth process and possibly raise the risk of childhood obesity. Empirical data suggests that exposure to air pollution at the embryonic stage may result in epigenetic changes in the placenta and fetal reprogramming.[29] In a different study, 540 expectant mothers received portable air purifiers with high-efficiency particulate air (HEPA) filters and the babies' BMI at 23.8 months was examined. The study reported that children in the intervention group had an average BMI that was 0.16 units lower than that of the children in the control group. It was concluded that there may be a higher chance of childhood obesity if pregnant women are exposed to air pollution.[30]

**Age Specific Effect:** According to a longitudinal study, there was a higher correlation between BMI and exposure to $PM_{10}$ and $NO_2$ in the first two months following delivery than there was between 2-6 months.[31] The degree to which different air pollutants and age affect the relationship between obesity and air pollution varies. Older people (≥65 years old) had a higher risk of obesity due to $PM_{10}$, $PM_{2.5}$ and $NO_2$ exposures than younger people (<65 years old), according to rural cohort studies among adults aged 18–79 years. Based on 19 studies, it was consistently shown that the younger subgroup (<18 years old) had a higher risk of obesity linked to $PM_{2.5}$ and $PM_{10}$ than adults (over 18 years old).[32] Thus, infants, adolescents (<18 years old) and the elderly (≥65 years old) may be more vulnerable to obesity linked to air pollution as compared to adults aged between 18-64 years.

**Sex Specific Effect:** It has been suggested that there are gender differences in the impact of ambient air pollution on obesity. The disparities in outcomes between men and women could be explained by the endocrine disturbing effects of air pollution and the impact of sex hormones on obesity.[33] Furthermore, the inverse sex-related results for childhood and adult obesity may be explained by the fact that hormone levels change with growth and aging. In male newborns, there was a positive correlation between $PM_{2.5}$ exposure during the first three months of pregnancy and obesity at five months, whereas in female infants, there was a negative correlation.[34] Boys were more likely to be obese in the study on PM exposure in children aged 6 to 17 years.[35] On the contrary, in a study of adults exposed to $PM_{2.5}$ from traffic pollution, the prevalence of obesity was found to be 53.6%, with a greater prevalence in women (55.0%) compared to males (48.8%).[36]

**Pathophysiological Mechanisms:** The exact mechanism that relates exposure to air pollution to obesity is still unknown. The respiratory system reacts to air pollution by stimulating inflammatory cells and releasing biological intermediates, including inflammatory cytokines and contamination-related oxidative stress molecules. This process aggravates lung inflammation and targets various organ systems via blood circulation. Additionally, $PM_{2.5}$ and ultra-fine particles (UFP) cause injury by

directly entering the bloodstream across the air-blood barrier and spreading to secondary target organs. Extrapulmonary injury is frequently associated with diseases of the nervous and endocrine systems.[27] It has been shown recently that epigenetic changes play a role in obesity in both early life and later life when exposed to air pollution, activating several downstream signal transduction pathways.[37]

**Inflammatory Mechanism:** Respiratory infections are more likely to occur in individuals exposed to high levels of $PM_{2.5}$, NOx and $NO_2$. These infections trigger an inflammatory response in the lungs.[38] In addition, air pollutants promote the recruitment of inflammatory cells and release of cytokines which lead to lung inflammation.[27] Systemic inflammation is subsequently brought on by the movement of proinflammatory cytokines and inflammatory cells into the vasculature via MyD88-dependent signaling pathways.[38] Moreover, the buildup of free fatty acid intermediates in obese people triggers proinflammatory serine kinases that promote cytokine release, which in turn induces the liver to produce CRP and create an inflammatory milieu. This process intensifies the negative effects of obesity brought on by inflammation linked to air pollution, creating a vicious cycle and cascade.[39]

**Oxidative stress:** When endogenous antioxidants cannot effectively neutralize the excess oxidants released by reactive oxygen species (ROS), oxidative stress results. The respiratory, cardiovascular, neurological and endocrine systems are all negatively impacted by oxidative stress, which develops upon exposure to air pollution.[40] Metals and organic compounds like PAHs in air pollutants function as active free radicals, which directly contribute to the higher levels of oxidants in the body.[40] The endoplasmic reticulum, phagosomes, mitochondria and cell membranes are the usual places where ROS are formed. One often-used indicator of membrane lipid peroxidation is malondialdehyde (MDA), which is a byproduct of lipids and ROS. Once released into the vascular system, the oxidized lipids trigger a systemic inflammatory response producing oxidative stress.[38]

An animal experiment revealed that the average weight of animals belonging to the unfiltered air group was higher than that of the animals belonging to the filtered air group. Additionally, the unfiltered air group's lung, liver, spleen and brain tissue had higher MDA contents than the filtered air groups. Therefore, air pollution raises levels of oxidized lipids in the blood and causes systemic oxidative stress, which ultimately results in obesity.[38] The energy metabolism is disrupted by mitochondrial oxidative injury. According to a study done on mice, exposure to PM causes mitochondrial damage mediated by oxidative stress, increased formation of reactive oxygen species (ROS) in brown adipose tissue (BAT), decreased expression of uncoupling protein 1 in BAT and increased expression of genes unique to white adipose tissue (WAT). BAT's primary function is oxidative phosphorylation, which generates uncoupled ATP and consumes energy as heat. Excess energy is stored as triglycerides in WAT. Obesity and lipid metabolic problems are caused by an imbalance between BAT and WAT.[41] All cell types exposed to the highest dose of $PM_{2.5}$ show notable alterations in mitochondrial ROS production, oxidative phosphorylation and ATP synthesis. Furthermore, the generation of ROS may promote the buildup of lipids, suppression of insulin and modifications to the mitochondria, resulting in a vicious loop that exacerbates the oxidative imbalance.[42]

**Metabolic Mechanism:** Air pollution may also cause obesity due to its endocrine-disrupting effects. In addition to storing fat, adipose tissue also maintains endocrine homeostasis.[41] Adipose tissue secretes substances known as adipokines, which include inflammatory cytokines, leptin and adiponectin. Leptin levels are altered by air pollution. In Mexico, hyperleptinemia was noted in healthy kids who lived in areas with elevated levels of $PM_{2.5}$ and $O_3$.[43] Leptin's ability to reduce appetite and boost energy expenditure is compromised in obesity-related leptin resistance, which is characterized by elevated leptin levels and decreased leptin sensitivity.[44] Adiponectin lowers fat and glucose levels to prevent metabolic diseases. Air pollution-induced reduction in adiponectin levels may interfere with glucose and lipid metabolism, leading to abnormal fat deposition.[44] Air pollution also contributes to obesity by altering lipid metabolism due to which dyslipidemia and abnormal fat deposition occur. Mice exposed to $PM_{2.5}$ had a worsening lipid profile, serum total cholesterol (TC) levels increased by 16%, triglycerides (TGs) by 86%, low-density lipoprotein (LDL) by 24% and high-density lipoprotein (HDL) by 21%. Additionally, the average body weight of exposed mice was higher than that of the unexposed group.[38] A study conducted on youths between the ages of 17 and 22 years found that an increase in long-term $NO_2$ exposure was associated with an increase in TC and LDL cholesterol levels. Furthermore, increased $O_3$ exposure has been linked to elevated TG and very low-density lipoprotein (VLDL) cholesterol, lowered HDL cholesterol and elevated liver fat.[45]

In addition, a connection between PM and T2DM is also reported, which includes an elevated risk of diabetes, insulin resistance and increased diabetes-associated mortality. Research revealed that a 10 $\mu g/m^3$ rise in $PM_{2.5}$ exposure was linked to a 7%–11% higher chance of acquiring T2DM and an approximate 19% higher risk of diabetes-related death.[46] The proposed mechanisms linking ambient air pollution to diabetes involve the development of chronic inflammation and oxidative stress, which can result in lipid deposition, insulin resistance and endothelial dysfunction.[47] When a high-fat diet is combined with $PM_{2.5}$ exposure, the result is an increase in postprandial glucose and insulin resistance, a reduction in the tyrosine phosphorylation of insulin receptor substrate (IRS-1) in the liver and a pro-inflammatory state.[48] Additional mechanisms that have been linked to the association between $PM_{2.5}$ and T2DM include elevated levels of innate immune cells and macrophages in visceral adipose tissue, an increase in BAT, oxidative stress within BAT and the down regulation of pathways that modulate insulin sensitivity in adipose tissues.[49] In addition to the inflammatory pathways, $PM_{2.5}$ can influence insulin resistance by inducing dysregulation in the autonomic nervous system, which leads to subsequent cardiovascular disorders.[50]

**Gut Microbiota:** Studies have shown a connection between obesity and the gut microbiota. One of the potential mechanisms by which air pollution leads to obesity is altering the location, function, type and relative abundance of the gut bacteria.[51] The gut flora of slim and obese people has different compositions. A study conducted on mice found that when the microbiota of obese mice is transplanted to germ-free recipients, the mice accumulate more fat than the mice that got transplants from lean donors.[52] The host's overall energy balance is altered by microbes, which obtain energy from undigested food ingredients and transform it into nutrients the host can absorb.[53] The gut flora regulates fatty acid absorption, oxidation and storage in addition to possibly

influencing host gene expression. Short-chain fatty acids (SCFAs) are derived from plant-based polysaccharides, mainly cellulose, by bacterial fermentation in the large intestine.[53] SCFAs have an anti-inflammatory function in the intestinal mucosa; however, exposure to air pollution may decrease SCFA synthesis and increase inflammation.[51,53]

Obesity is associated with the degradation of the gut mucosa and the ensuing chronic systemic inflammation. Toll-like receptors are activated by air pollutants, which permeate blood vessels and cause inflammation.[51] Furthermore, due to insufficient SCFA production, the intestinal mucosa's permeability increases, permitting intestinal germs to penetrate and enter the bloodstream. Invading bacteria secrete pathogen-associated molecular patterns (PAMPs), such as the cell wall component lipopolysaccharide (LPS), which bind to immune and adipocyte-expressed pattern recognition receptors (PRRs). This process causes the production of proinflammatory cytokines, which ultimately results in a state of low-level, chronic inflammation.[53]

**Epigenetic Mechanism:** Histone modifications, non-coding RNAs and DNA methylation are the main epigenetic processes.[37] Air pollution can cause epigenetic modification. Indoor and outdoor air pollutants such as PM, $O_3$, NOx and PAHs are reported to alter DNA methylation levels of genes linked to inflammation and immunological response, oxidative stress, signal transduction and cell cycle regulation.[13, 54] An important factor in the development of obesity is epigenetic alteration. According to recent research, there are epigenetic overlaps between genes associated with air pollution and metabolic syndrome components, such as obesity.[54]

Exposure to PM and $NO_2$ has been shown to impact the methylation state of the protein kinase C zeta gene (PRKCZ) and the Nucleoredoxin (NXN) genes, which are linked to obesity.[54] Moreover, epigenetic changes resulting from environmental exposures during pregnancy and the early years of life are connected to disorders in adulthood and transgenerational inheritance.[13] It has been demonstrated that exposure to air pollution alters the placenta's histone acetylation and DNA methylation patterns. These processes can lead to alterations in placental function, fetal intrauterine reprogramming and heightened lifelong health risks.[13] Because epigenetic alterations have long-term effects, it is imperative to minimize early life and prenatal exposure to air pollution.

**Prevention:**

The prevention and control of obesity is the aim of investigating the relationship between air pollution and obesity. Adverse air pollution components must be eliminated by implementing environmental scientific prevention methods and controlling air quality standards in accordance with national policies and WHO guidelines. A sensible urban planning strategy is crucial.[55] Therefore, a greater coverage of urban vegetation may help lower childhood obesity. Modern industrial systems should be upgraded, clean energy should be used and transportation should be optimized by the government.[10]

Personal safety must not be disregarded. To lessen exposure to air pollution, people can use air purifiers indoors and wear masks outdoors. Paying attention to one's nutrition may also guard against obesity and the negative consequences of air pollution. New perspectives on the management and prevention of obesity are offered by the hypothesis of gut flora. Studies have demonstrated that prebiotics decrease obesity by promoting adipose tissue lipolysis. Fecal

microbiological transplantation boosts the number of bacteroidetes and reduces obesity.[56] The harmful effects of indoor air pollution on obese children may be reduced by the administration of vitamin D to those with high $PM_{2.5}$ exposure. Conjugated linoleic acid (CLA) is a natural fatty acid found in diet and has significant anti-obesity properties. Omega-3 fatty acids in fish oil can partially shield the body against $PM_{2.5}$-induced harm.[57] Supplementing with B-complex vitamins and carotenoids may mitigate the negative impact of air pollution on body weight.

## Conclusions:

There is substantial evidence linking air pollution to the likelihood of being overweight or obese at various stages of life. To address the global burden of obesity, multilevel public health and policy measures are required. There are few detailed studies that are specific to air pollution and obesity risk. It is necessary to conduct additional studies on the precise composition of PM, the duration of the sensitive exposure period and the threshold dose range in addition to examining the efficacy of targeted therapies and obesity prevention methods.

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Chapter - 22

# Pollution and Rheumatological Diseases: Is there any Relationship?

*Chandra Bhushan Prasad, Aman Sharma*

**Introduction:**

Rheumatological diseases are complex set of chronic disorders which are characterized by the dysregulated and uncontrolled activation of the immune system, resulting in increased systemic inflammation and immune-mediated tissue damage.[1] It contains broad spectrum of diseases such as rheumatoid arthritis, juvenile idiopathic arthritis, psoriatic arthritis, ankylosing spondylitis, systemic lupus erythematosus, systemic sclerosis, idiopathic inflammatory myositis, systemic vasculitis and various other connective tissue diseases. Epidemiological studies have shown that the incidence and prevalence of rheumatological diseases are increasing steadily over the last few decades with its prevalence in the general population ranging from 9.8% to 33.2%.[2] The reason for such increase in trend is not fully known, which underlines the understanding of etiopathogenesis of such diseases.

While the aetiology of these diseases remains multifactorial, emerging evidence suggests a potential link between environmental factors, in particular, environmental pollution as a leading cause in development and exacerbation of rheumatological conditions in a genetically predisposed individual.[3, 4, 5] Identifying such a modifiable risk factor for disease development and prognosis is important to reduce the substantial impact and burden of these chronic diseases in society. Thus, this chapter aims to explore the relation between rheumatological diseases and pollution, examining the mechanisms involved and to set up appropriate public health prevention strategies.

**Environmental Pollution and its Mechanism in Causing Rheumatological Diseases:**

**Source of Environmental Pollution:** Environmental pollution encompasses various contaminants, which includes air pollution, water pollution and chemical exposure. Air pollution have been suggested as important environmental risk factor in the development of many rheumatological diseases.[5] Environmental air pollution composed of various solid, liquid and gases components affecting the biological systems. It is derived from various sources which includes; fossil fuel burning in industries, vehicular exhaust, forest fires, stationary fuel burners and solid fuel combustion. The main component of air pollution are particulate matters (PM), a complex mixture of chemical elements such as heavy metal, carbonaceous materials, persistent organic pollutants, volatile compounds and polycyclic aromatic hydrocarbons and a miscellany of gases (e.g. carbon monoxide [CO], nitrogen dioxide [$NO_2$], ozone [$O_3$] and sulphur dioxide [$SO_2$]).

PM can be classified according to the nature of particles, that is, biological, chemical, mineral and metal. However, based on its size PM is classified into four groups: $PM_{10}$ ($\leq$10 µm in aerodynamic

diameter), $PM_{2.5}$ (<2.5µm; fine particles), coarse PM (particulate matter ranging from 2.5µm to 10µm) and ultrafine PM (<0.1µm).Chronic exposure to concentrations of $PM_{10}$ above 30µg/$m^3$ and $PM_{2.5}$ above 20 µg/$m^3$ has been associated with a 12% and 13% higher risk of developing an autoimmune diseases (ADs), respectively (adjusted OR [aOR] 1.12, 95% CI 1.05 to 1.20 and aOR 1.13, 95% CI 1.06 to 1.20).[6] Research suggests that exposure to these pollutants may contribute to pathogenesis of rheumatological diseases through several mechanisms.

**Mechanism Linking Air Pollution and Rheumatological Diseases:**

Mechanism linking exposure to air pollution and development of rheumatological diseases mainly include, inflammation both local and systemic, increased oxidative stress, epigenetic modification and finally the immune dysregulation in which lung may act as the early initiation site for autoimmunity.[3] Environmental air pollutants which act as an immunological adjuvant causes local pulmonary inflammation which participates in the pathogenesis of ADs through the following two mechanisms. Firstly, it results in direct citrullination of the proteins, which stimulates the secretion of anti-citrullination peptide antibodies (ACPAs) which has a pathogenic, diagnostic and prognostic significance in rheumatoid arthritis[7] and secondly, through induction of inducible bronchus associated lymphoid tissue (iBALT) which acts as a site of antigen presentationand plays an important role in the transformation of innate immune responses into adaptive immune responses resulting in T and B cell activation, production of proinflammatory cytokines and B cell differentiation into autoantibody producing plasma cells.[8]

Also, interaction of PMs with alveolar macrophages leads to the release of Th1-type cytokines (IL-12 and interferon gamma) that generate an intense local inflammation. $PM_{2.5}$ exposure has been associated with an increased production of interleukin (IL)-1, IL-6 and tumour necrosis factor.[9] Furthermore, PM frequently contains microbial components (e.g. Lipopolysaccharides) which can activate the NLPR3 inflammasome, resulting in an increased production of proinflammatory cytokines that contribute to the local and systemic inflammation.[10] Oxidative stress generated by PMs induce dendritic cells to migrate to the local lymph nodes, cause cell necrosis and apoptosis and contribute to the release and activation of neutrophil extracellular traps, which is accompanied by increased IL-17 and IL-23 serum levels.[11]

Moreover, air pollutants may induce epigenetic changes like DNA methylation, histone modification and microRNA expression leading to aberrant immune responses and inflammatory signaling contributes to ADs. Short-term exposure to $PM_{2.5}$ may induce decreased methylation at CpG loci of the corresponding inflammation-related genes, consequently involved in the inflammatory response and thus, contributes in the development of ADs.[12]

**Evidence for an Association between Air Pollution Exposure and the Development of Rheumatological Diseases:**

**Rheumatoid Arthritis:** Several large epidemiological studies have reported the associations between the incidence of rheumatoid arthritis (RA) and ambient air pollution. Incidence of RA is higher in urban areas as compared to rural areas, which suggest possible pathogenic role of air pollution in these urban cities.[13] In the Nurses' Health Study (NHS) in the United States, after adjustment for multiple confounders, an elevated risk of RA [hazard ratio (HR), 1.31; 95% CI,

0.98–1.74] was observed in women living within 50 m of a road, compared with those women living 200 m or farther away.[14] In the Swedish Epidemiological Investigation of RA (EIRA) case-control study, no evidence of an increased risk of RA with $PM_{10}$ was observed. However, an increased risk for RA was seen with increases in $NO_2$ and $SO_2$ with stronger associations for individuals with less than university education and with ACPA-negative phenotype, but the results were not statistically significant.[15] Two studies from Taiwan, the first one is a longitudinal and nationwide study, observed an increased risk of RA in residents exposed to $PM_{2.5}$ and $NO_2$ and second one is a retrospective cohort study, showed that newly diagnosed RA patients were positively associated with exposure to CO, $NO_2$, $O_3$ and $SO_2$.[16, 17] A systematic review and meta-analyses study analyzing the association between outdoor air pollution and the development of RA revealed a significant association between RA and $O_3$ and between RA and residence ≤ 50 m from a traffic road compared to residence farther away. The meta-analysis did not show significant associations between exposure to $PM_{10}$, CO, $NO_2$ and RA and even showed an inverse relationship between $PM_{2.5}$ exposure and RA and between $PM_{10}$ exposure and seropositive RA, but these contradictory results were attributed to methodological errors such as the fact that studies were developed in areas with a low variability of air pollutants, which may have hindered detection of risks limited to higher exposure levels.[18]

PMs generate free reactive oxygen species resulting in oxidative stress causing activation of nuclear factor kappaB (NF-kB), which stimulates the production of proinflammatory cytokine including TNF-α and IL6, ultimately leading to joint inflammation. In addition, it stimulate chronic lung and systemic inflammation, which promotes citrullinated products and ACPA production and ultimately cause joint inflammation and erosion.[19] Furthermore, air pollution may further aggravate RA through hypovitaminosis D. Air pollutants such as $O_3$ can absorb UVB in the atmosphere, thereby reducing the effectiveness of sun exposure on the synthesis of vitamin D in the skin and could thus increase RA incidence.[20]

Therefore, air pollution can induce protein citrullination, ACPAs production, more extensive iBALT formation and stimulate aryl hydrocarbon receptor (AHR) pathway to participate in the etiopathogenesis and development of RA.

**Systemic Autoimmune Rheumatic Diseases (SARDs):** All of the studies on associations between fine particulate ($PM_{2.5}$) air pollution exposure and the development of SARDs (systemic lupus erythematosus, primary Sjogren's syndrome, scleroderma, polymyositis, dermatomyositis or undifferentiated connective tissue disease) come from population-based data from two Canadian provinces, Alberta (1993–2007) and Quebec (1989–2011), they suggested that fine particulate air pollution ($PM_{2.5}$) was associated with an increased risk of SARDs.[21]

It is well known that several major components of $PM_{2.5}$, including trace elements and polycyclic aromatic hydrocarbons, are associated with the prevalence of SLE.[22] A Taiwanese cohort study reported that the exposure to increased traffic-related air pollutants (CO and $NO_2$) and $PM_{2.5}$ positively associated with the increased risk of SLE.[23]

Systemic sclerosis (SSc) has been linked with a variety of chemicals like epoxy resins, vinyl chloride, hair dyes and many more. A meta-analysis showed significant association between epoxy resins and SSc (OR 2.97, 95% CI 2.31–3.83, $p < 0.001$). However, hair dyes and vinyl chloride did

not show significant results.[24]

**Juvenile Idiopathic Arthritis:** A case-crossover study analysing associations of regional ambient $PM_{2.5}$ concentrations with onset date of 338 Juvenile idiopathic arthritis (JIA) cases living on Utah's Wasatch Front showed that increased concentrations of $PM_{2.5}$ and stagnant air conditions in the preceding 14 days were associated with significantly elevated risk of JIA onset in preschool aged children (RR 1.60, 95% CI 1.00-2.54) but not older children. Elevated risk was larger in males and in systemic onset JIA.[25] A case-control study from São Paolo, Brazil, comprising mothers of 21 JIA and 40 control subjects, matched by age and sex, completed a questionnaire that assessed demographic data and environmental inhalation exposure during pregnancy and estimated daily concentrations of $PM_{10}$, $SO_2$, $NO_2$, ozone and CO in the pre-gestational and gestational periods. In this they found that mother's exposure to tobacco smoking had a significant effect on increasing JIA incidence, while exposure to long-distance industrial activities or gas stations could be a protective factor for this inflammatory chronic disease.[26]

**Vasculitis:** In a U.K. study, no evidence for spatial clustering, $PM_{10}$ exposure and ANCA-associated vasculitis was found.[27] Similarly, in a North American study, no link between $PM_{2.5}$ and Kawasaki disease was found, after controlling for time trends, seasonality, month and weekday.[28]

**Public Health Preventive Strategies:**

In terms of potential impact, prevention of rheumatological diseases has a great potential of public health benefit, given the burden of these conditions in terms of disability and lost productivity. However, in spite of their impact, prevention of rheumatological diseases has not been a priority in most countries, possibly because these conditions are not immediately lethal. However, if rheumatological diseases are evaluated in aggregate, their overall impact on public health should make addressing preventive strategies a top priority for authorities. The potential link between pollution and rheumatological diseases has significant public health implication, highlighting the need for targeted interventions to reduce environmental exposure and mitigate disease risk. Strategies to Address Environmental Pollution and protect vulnerable population may include the following;

**Air Quality Regulations:** Implementing stricter air quality standards and emissions controls, can help in reducing the exposure to pollutants such as PM, $NO_2$ and $SO_2$, thereby lowering the risk of rheumatological diseases and other adverse health outcomes.

**Pollution Monitoring:** Continuous monitoring of environmental pollution levels is essential for identifying high-risk areas and population, it helps in formulating public health intervention strategies and assessing the effectiveness of pollution control measures over time.

**Occupational Safety Measures:** Implementing workplace regulations and occupational health programs can help minimize exposure to hazardous substances such as heavy metals, solvents and pesticides, thereby reducing the risk of occupational-related rheumatological diseases among the workers.

**Community Education:** Organising public health campaigns and community outreach programs help in raising awareness about the potential health effects of pollution and provide guidance on reducing exposure through lifestyle modification, indoor air quality improvements and

environmental stewardship.

**Conclusions:**

In conclusion, emerging evidence suggests a complex interplay between air pollutant exposure and the risk of developing autoimmune rheumatological diseases. Exposure to air pollution results in both, initiation and exacerbation of rheumatological diseases through multiple pathogenetic mechanisms which has a great impact on world's population. Therefore, it is important to develop public health policies to reduce exposure to air pollution and to further study molecular and cellular pathways involved in autoimmune rheumatological diseases.

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Chapter - 23

# Pollution and Psychiatric Disorders : Is there any Relationship?

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**Introduction:**

Simply stating, pollution is understood as addition of harmful materials in the environment. Accordingly, the harmful substances are called as pollutants. Different types of pollution include air pollution, water pollution, land/soil pollution and noise pollution. Based on specific type of pollutants, pollution is understood as noise pollution, light pollution, plastic pollution, radioactive pollution, thermal pollution, etc. In terms of various sources, pollution can be understood as an outcome of natural events (such as forest fires, eruption of volcano's) or as an outcome of human activities. Air pollution is defined anything which 'modifies the natural characteristics of the atmosphere'. It includes gaseous air pollutants, nitrogen oxide (NOx), nitrogen dioxide ($NO_2$), sulphur dioxide ($SO_2$), carbon monoxide (CO) and ground-level ozone ($O_3$) and particulate matter (PM). PM refers to a mixture of microscopic solid particles and liquid droplets in air which when inhaled can lead to deleterious health consequences. It is expressed in terms of $PM_{10}$ (coarse particles diameters<=10 micrometers) and $PM_{2.5}$ (fine particles diameters <2.5 micrometers).[1] On the other hand, noise pollution, refers to unwanted sounds in the environment. Water pollution is understood as introduction of toxic pollutants into various water bodies such as lakes, rivers and seas. Land/soil pollution is understood as the degradation of quality of soil due to addition of chemicals to the soil. The air and noise are very much relevant in urban settings where various modes of transport (traffic), civil construction works serve as sources of air and noise pollution. As per the World Health Organization (WHO) air quality recommendations, 99% of the world's population resides in places where the air quality is much below the standards. It's more relevant in rapidly urbanizing areas in the low-and middle-income countries (LAMIC). [2,3]

The association of pollution with various physical health conditions is known for long and the evidence for such association is robust. As per the WHO, exposure to household air pollution (arising due to use kerosene, burning of wood, animal dung and wastage of crops, coal) is associated with development of various non-communicable diseases such as stroke, chronic obstructive pulmonary diseases (COPD), ischemic health disease and lung cancer.[2] As per the WHO, household air pollution led to about 3.2 million deaths in 2020, that included death of 237,000 children aged < 5 years. It is further estimated that ambient and household air pollution together account for 6.7 million premature deaths every year.[2] Similarly, noise pollution has been shown to be commonly associated with hearing loss. Other health consequences of noise pollution include hypertension and cardiac ailments.[4] Water pollution is associated with various infectious ailments

(such as diarrhoea, cholera, typhoid, polio, hepatitis-A, etc), cancers and skin diseases.[5]

In recent times, pollution has also been recognized as an important risk factor for poor mental well-being and various mental disorders. This chapter attempts to provide an overview of the adverse effect of pollution on the mental health.

**Neurobiological Mechanisms of Negative Consequences of Pollution:**

**Air Pollution:** Zundel et al[6] outlined a conceptual model understanding the association of air pollution with psychiatric disorders. According to this model, neuro-inflammation and oxidative stress have been recognized as major mechanisms resulting in changes at the neurostructural (caused due to decreased in brain-derived neurotrophic factor; activation of hypothalamic-pituitary-adrenal stress response- HPA axis) and neurofunctional domains (decreasing serotonin levels) involving multiple brain regions like hippocampus, prefrontal cortex (PFC) and amygdala. The neurofunctional changes are mostly due to decrease in serotonin levels caused by the neuroinflammation by inducing the activation of the indoleamine 2, 3-dioxygenase that accelerates tryptophan degradation from which serotonin is synthesized. Epigenetic modifications involving clock genes cause disruption of circadian rhythm predisposing to sleep disturbances, which is a risk factor for many psychiatric disorders.[6, 7] The impact on brain by the PM is determined by the aerodynamic properties (depends on size and composition) and these take various pathways to induce inflammation. One is through the transmission through the nasal epithelium, second is the accumulation in the respiratory tract. Both of which can lead to activation of inflammatory cytokines. Lastly, these induce inflammation through the olfactory bulb to the brain.[8] The inflammatory cytokines released into blood streams cross the blood-brain-barrier (BBB) activating microglia to cause neuronal injury either by acute or chronic neurotoxicity induced by oxidative stress.[6,8]

**Noise Pollution:** Noise/stress model posits that noise impacts health via the direct pathway (exposure to high decibel (dB) levels i.e., >100 dB, causing direct ear organ damage/sleep issues) and the indirect pathway (chronic exposure to lower decibel levels- 50 to70 dB causing annoyance, sleep and communication issues). This is followed by activation of HPA axis and sympathetic nervous system resulting in cascading of pro-inflammatory cytokines, cortisol resistance which leads to maintenance of fear and stress response in amygdala, PFC, hippocampus, insula and the anterior cingulate cortex (dACC). The over activity in the above brain regions is associated with a breach in BBB (caused by neuroinflammation by activated immune cells) that results in influx of proinflammatory cytokines which ultimately leads to oxidative stress (release of reactive oxygen species). Oxidative stress further impairs neuronal synaptic signalling functions (dopamine, norepinephrine and serotonin). These proposals are supported by animal model studies. Noise exposure during night also results in impairment of circadian rhythms.[9]

**Negative Impact of Pollution on Mental Health:**

The impact of pollution on mental health has been evaluated in different ways including the impact of the overall environment, air pollution, noise pollution, etc. Air or noise pollution may not contribute in isolation, to the risk of a mental illness but these interact with multiple related risk factors or adversities with a host of causal pathways. The basic premise is that individual factors interacts with the social and environmental factors (natural or built environment) and bring about a change

(positive or negative) in the psychological health of the individuals.[10]

The association of pollution and mental health has mainly been evaluated for air pollution and various mental illnesses. The impact has been evaluated across the life span (Table-1). However, it is important to note that there are many limitations in studying the association of pollution and various psychiatric disorders. The factors that play a confounding role include socio-economic factors and geographic factors (temperature, humidity). This underscores the need for multilevel modelling studies in the future to strengthen the evidence base.

**Association of Air Pollution with Psychiatry-Related Disorders:** (Table-1)

Air pollution has been studied extensively in relation to many psychiatric disorders.[11] Both outdoor (ambient) and indoor air pollution have been implicated. Indoor environments include one's house, schools, work environment, hospitals and malls. Indoor air quality is determined by multiple factors like the built environment (proper ventilation, spacious structures) and the activities occurring inside which includes fireplaces, cooking and air dampness. This when associated with poor socioeconomic status and overcrowding is associated with poor physical as well as mental health.[8] Outdoor air pollution is most widely researched. The impact of air pollution on mental health has been evaluated across the lifespan starting from antenatal exposure.

**Table-1: Mental Health Consequences of Air Pollution**

**Antenatal Exposure/ Pregnancy and in Children:**

- Increased risk of postpartum depression.[46]
- Increase in the risk of attention deficit hyperkinetic disorder & autism in offsprings.[13,15,16]
- Increased nonspecific mental problems.[45]
- Cognitive deficits in offsprings.[44]
- Higher internalizing symptoms and behavior.[6]
- Increase in depressive and anxiety symptoms.[24]
- Increase in emergency department utilization due to adjustment disorder and suicidality.[17]

**Adults:**

- Increased risk of depression in long term (>6 months exposure)[19-23] and short term exposure.[20]
- Increased risk of incident anxiety.[22, 29, 30]
- Increased risk of hospital admissions for anxiety related issues.[28]
- Increased risk of mortality due to suicide.[33]
- Increased risk of psychotic experiences.[35]
- Increased mental health care utilization by those with psychotic disorders.[36]

**Elderly:**

- Increased risk of cognitive decline.[1, 37-40]
- Increased risk of depression.[47]
- Increased number of visits to community mental health teams for dementia.[48]

**Exposure to Air Pollution during Antenatal Period and Childhood:** $PM_{2.5}$ exposure in pregnancy results in preterm birth, low birth weight which are risk factors for neurodevelopmental disorders like autism and ADHD. Such exposure from indoor air pollution was found to be associated with increased risk of autism[12] more particularly in first two trimesters.[13] $PM_{2.5}$ exposure during pregnancy has also been reported to predispose to heightened risk of ADHD.[14,15] However, a longitudinal study that involved adolescent aged 10-12 years failed to support the association between $PM_{2.5}$ exposure and ADHD/autism.[16]

In terms of impact of air pollution on children, a study from United States that evaluated children demonstrated that even a small short-term increase in $PM_{2.5}$ of 10μg/$m^3$ is associated with a significant increase in number of children presenting to the emergency with adjustment disorder and suicidality.[17] Other studies have shown association of air pollution with higher internalizing symptoms, depression and anxiety.[6]

**Exposure to Air pollution and Pregnancy:** Air pollution confers greater risk of mental illness among pregnant women by predisposing them to pregnancy related complications like maternal hypertension, placental abruption, low birth weight, preterm delivery and respiratory related disorders.[18] All these can lead to neurodevelopmental outcomes like ASD and ADHD as highlighted earlier and post-partum depression in mothers. The combined effect of prenatal exposure and postnatal complications could also possibly result in cognitive deficits in the offspring. Similar results have been observed in animal models.[19] Exposure to $PM_{10}$, $PM_{2.5}$, nitrogen dioxide and nitrogen oxides during pregnancy have been shown to be associated with a 29-74% increased risk of nonspecific mental problems complicating pregnancy.[20] Also, the risk of onset of postpartum depression has been associated with exposure to $PM_{2.5}$ modifies the glutamate system and $NO_2$.[21]

**Exposure to Air pollution during Adulthood and Mental Disorders:** The relationship with air pollution and mood disorders remains the most investigated area.[1,22] Recent meta-analyses conducted have found an increased risk of depression, especially among those individuals exposed to $PM_{2.5}$, $NO_2$ in long-term >6 months exposure [23,24] and $PM_{2.5/10}$, $NO_2$, $SO_2$, $O_3$, CO in the short term.[23] A few population based prospective cohort studies with a long term follow up have revealed that long term exposure to multiple air pollutants $PM_{2.5}$, $PM_{2.5\text{-}10}$, $NO_2$ and NOx also increased the risk of incident depression[25–27] and anxiety.[25] The risk increased were associated with steeper slopes at lower concentrations and plateauing trends at higher exposure.[25] This finding is corroborated by the UK biobank data one among the largest cohorts, except for coarse PM i.e. $PM_{10}$.[28] The risk of depression was higher in those with additive effects of higher genetic risk and higher air pollution.[28–30] In terms of anxiety disorders, $SO_2$ exposure pungent smelling, $NO_2$, $PM_{2.5}$ have most been studied related to anxiety disorders. Short-term $NO_2$ & $SO_2$[31] as well as long term air pollution $PM_{2.5}$, $PM_{2.5\text{-}10}$, $NO_2$ and $NO_2$[5] exposure could either trigger the onset or exacerbate symptoms of anxiety disorders leading to increased hospital admissions.[31] However, a recent meta-analysis did not find support for long term exposures including $PM_{10}$, CO, $O_3$, $SO_2$, $NO_2$ and increase in anxiety disorders.[24] Those with short term, higher exposure to $SO_2$ present more often to emergency services with anxiety symptoms. Recently, few studies have found positive association

between $PM_{2.5}$ exposure and anxiety disorders.[32–34] It is important to note that majority of the meta-analytic evidence has reported inconsistent results and significant methodological heterogeneity between studies and this precludes any conclusive evidence.[6, 22, 35]. Short term exposures to $PM_{2.5}$, $PM_{10}$ up to 100 μg/$m^3$, $NO_2$ and $NO_2$ have been found to have associations with suicide. This could possibly be mediated through depressive symptoms and increased aggression/anxiety.[1,7,22] Even day-to day increase in $PM_{2.5}$, $O_3$, $NO_2$ were associated with mortality from suicide.[36] Only one recent study did not find such association between air pollution and suicide.[13] Air pollution has also been linked to increase incidence of psychosis. Individuals who are exposed to high levels of $NO_2$ and NOx annually have increased odds of adolescent psychotic experiences. Around 60% of the association of psychosis with urban city urban residence assessed by population density was attributed to air pollutants.[37] Additionally, $PM_{10}$ has been shown to be associated with a 33% increased risk of psychotic experiences.[38] Among those with recently diagnosed psychotic disorders, increased exposure to $NO_2$, NOx and $PM_{2.5}$ has been shown to be associated with higher mental health care utilization. [39]

**Exposure to Air pollution and Mental Disorders in Elderly:** The Taiwan Longitudinal Study on aging found NOx and CO to be associated with increased the risk of depression in older adults.[40] Also, $CO_2$ has been shown to be associated with impaired cognitive performance.[41] Exposure to air pollution has also been shown to increase the number of visits to community mental health teams for dementia air pollution.[42] Air pollution has also been linked to increased risk of cognitive decline. Most evidence on cognitive decline has been increasingly linked to $PM_{2.5}$ levels, which served as a pre cursor for dementia.[1, 43, 44] Recent Chinese longitudinal studies among middle-aged and elderly adults found that ambient particulate matter $PM_1$, $PM_{2.5}$, $PM_{10}$ decreased the cognitive functions significantly especially in females even after adjusting for various confounding factors e.g. educational status, alcohol use, chronic diseases and depression.[45, 46] Also, despite exposure to low levels of $PM_{2.5}$ and $NO_2$ individuals were significantly poorer on certain executive functions like semantic fluency test and black carbon for the digit symbol substitution test.[47] However, a few studies have reported no such association [48].

**Association of Noise Pollution with Psychiatry-Related Disorders:** (Table-2)

In contrast, to air pollution, data on association of mental disorders and noise pollution is limited. Limited and inconsistent data is present on either prenatal/ child exposure to noise pollution and conduct/ behavioral problems and inattentive/hyperactivity symptoms to draw any meaningful conclusions.[9] A recent population-based cohort study from Spain, among children aged 7-10 years found that exposure to road traffic noise was associated with deficits in working memory and attention over a period of 1 year at school but not at home.[49] Data on depression and anxiety is inconsistent with respect to road traffic noise. On the other hand, with aircraft noise exposure, consistent association has been reported.[9, 50–52] Traffic road related, night-time exposure and railway noise has been linked with increased risks of suicide in adults.[53, 54] The short-term noise exposure has also been shown to be associated with increased hospital admissions, anxiety and dementia.[55] Also, the cognitive functions are hampered in depressed individuals compared to those without depression due to traffic noise.[56]

**Table-2: Mental Health Consequences of Noise Pollution**

- Road traffic noise is associated with deficits in working memory and attention.[49]
- Aircraft noise is associated with increased risks of depression and anxiety. [9, 50-52]
- Night-time exposure and railway noise has been shown to be associated with increased risks of suicide in adults. [53, 54]
- Short-term exposure to noise increased hospital admissions, anxiety and dementia. [55]
- Exposure to higher traffic noise is associated with higher cognitive deficits in depressed patients. [56]

**Association of Water Pollution with Psychiatry-Related Disorders:**

Literature with respect to water pollution and psychiatric disorders is limited, hence definitive conclusions cannot be drawn. A recent systematic review and meta-analysis suggests that exposure to water pollution in adolescents poses major risk of many psychiatric disorders like psychosis, depression, generalised anxiety disorders and impulse control disorders.[57] Few studies have assessed the prenatal and early childhood exposure of tetrachloroethylene in water and found that it predisposes to developing substance use disorders, bipolar disorder, schizophrenia later in life.[58, 59] With regards to depression, results are mixed.[58, 60] The presence of heavy metals like lead (Pb), arsenic (As), cadmium (Cd) and manganese (Mn) have been shown to be associated with elevated risk of autism spectrum disorders,[61] schizophrenia, depression and anxiety disorders, [62, 63] and dementia. [64, 65]

**Association of Soil Pollution with Psychiatry-Related Disorders:**

Scant literature is available with respect to soil pollution and psychiatric disorders.[22] However, the presence of heavy metals like Pb and As, increases the risk of psychiatric illness in general when they consume them from vegetables grown in soil soil-to-plant transfer.[66]

**Conclusion:**

Air pollution especially $PM_{2.5}$ and noise pollution exposure, are significant environmental health risks, can potentially cause harmful consequences on mental health in the short and long term across the individual's lifespan. Air pollution, in particular, impacts on mental health over the lifespan right from pregnancy, through childhood, adulthood and old age. However, most of the evidence is in the form of association studies. Based on the available evidence, there is a need to have a comprehensive approach in various developmental stages and understand the psychopathology. It is high time that all the stakeholders, the government and all the individuals in society understood its impact and initiated appropriate strategies to address pollution, particularly in urban settings and contribute towards mitigating the risk of psychiatric disorders.

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Chapter - 24

# Pollution and Gynaecological Diseases: Is there any Relationship?

*Lajya Devi Goyal, Kirti Lata*

**Introduction:**

The relationship between environmental pollution and human health related problems has been studied extensively and has shown the increasing trends in the past two decades. The size of particulate matter is directly linked to the health-related problems. Particles of size <10 micrometers are inhalable and pose the greatest health problems like respiratory, cardiovascular diseases and increased carcinogenicity. According to the World Health Organization (WHO), approximately 92% of people are residing in areas where quality of air exceeds the recommended limit for annual mean of particulate matter (PM) with a diameter of <2.5 micrometers ($PM_{2.5}$), affecting both developed and developing countries.[1] In 2015, $PM_{2.5}$ was ranked as the fifth greatest mortality risk factor.[2] From particulate matter to chemical toxins, various pollutants have been implicated in disrupting hormonal balance, DNA integrity and immune function, thereby increasing the risk of gynaecological disorders and reproductive health problems. Although, the effect of pollution (air, water and soil) has been extensively studied on cardiorespiratory and cancer aspects but there is paucity of literature on impact of pollution on gynaecological conditions. This chapter highlights the profound impact of pollution on both gynaecological disorders and reproductive health. The evidence presented underscores the urgency of addressing environmental pollutants as significant contributors to the rising incidence of gynaecological diseases and pregnancy related issues. Moreover, the detrimental effects of air and water pollution on gynaecological, reproductive health and pregnancy related issues are well-documented, with pollutants exacerbating inflammation, oxidative stress, DNA disruption and endothelial dysfunction. This leads to a heightened risk of infertility, congenital malformations, endometriosis and gynaecological malignancies etc.

**Impact of Pollution on Gynaecological Diseases:**

**Infertility:** Worldwide, approximately 2% women in reproductive age group are infertile. According to WHO, female factor causes infertility in 37%, male factors in 8% and both partners in 35% and in remaining, cause remains unknown. Acute exposure to PM has shown negative effect on fertility, during the onset of the secretory phase and at the time of the embryo implantation. Studies have suggested the role of air pollution in diminished ovarian reserve and the proposed mechanism being the oxidative stress and aryl hydrocarbon receptor induction.[3, 4] A study done in Beijing, on 84 mice has concluded that exposure to $PM_{2.5}$ led to decreased anti mullerian hormone (AMH) in adult female mice and decreased follicular pool was observed in offspring of mice where there was maternal exposure to polycyclic aromatic hydrocarbons.[3, 4] A systemic review by Conforti

et al. showed that exposure to $PM_{2.5}$, $PM_{2.5–10}$ and $SO_2$ can decrease the conception rate.[5] Air pollution also hampers the male fertility and the level of pollution is associated with low sperm concentration and volume as well as total sperm motility and morphology.

**Polycystic Ovarian Syndrome (PCOS):** It is a metabolic disorder which is impacted by genetic, metabolic and environmental factors. Exposure to air pollutants like $SO_2$, NOx, NO, $NO_2$ and $PM_{2.5}$ are linked to its development.

The likely proposed mechanism include oxidative stress, inflammation, autonomic dysfunction and mitochondrial and DNA damage. Literature also reported that pro-inflammatory stimulus up regulates the ovarian theca cells to produce more androgens, which further contribute to the development of PCOS. Secondly, pollutants cause insulin resistance leading to androgen excess and hence promoting PCOS development. Pollutant Bisphenol A also interferes with testosterone synthesis, increasing androgen level leading to PCOS development.[6]

**Endometriosis:** Endometriosis is a complex chronic disease affecting women of reproductive age group. It is associated with severe menstrual pain, coital pain, heavy menstrual bleeding and infertility. Though its aetiology is still unclear, various factors including genetic, endocrinal and ecological have been implicated in its development and progression. Pollutants like $PM_{2.5}$ and polyaromatic hydrocarbons have been associated with chronic inflammation and disruption of hormonal balance altering the growth pattern of endometrial tissue which is the main pathology in endometriosis. Water and food contaminated with industrial waste chemical, dioxins and polychlorinated biphenyls {PCB} can accumulate in the body leading to hormonal dysregulation which can potentially initiate the development of endometriosis.[7]

Heavy metals like mercury and lead in water lead to disruption of endocrine balance which is implicated in exacerbation of the endometriosis.[8]

Soil pollution has also an impact on endometriosis. Endocrine disrupting chemicals (EDCs) are exogenous substances interfering with any aspect of hormone action.[9] Pathogenesis of endometriosis is affected by EDCs. They gain entry in the body with eatables and using cosmetics creams via dermal absorption. These compounds have pro-oxidative effects and may potentially lead to endometriosis.[10] Oxidative stress damages ovarian germ cells and disrupts formation of follicle further complicating the fertility in a patient of endometriosis. (Figure 1)

| **Endometriosis** | | | |
|---|---|---|---|
| **Air Pollution:** $PM_{2.5}$, PAH | **Soil Pollution:** Pesticides, Bisphenol A, PCBs | **Occupational Exposure:** Lead, Cadmium, Mercury, Parabens | **Water Pollution:** Heavy metals, PCBs, Dioxins |

**Figure 1. Association of Endometriosis with Pollutants**

**Gynaecological Cancers:** Gynaecological cancers are the leading cause of mortality in women worldwide. These cancers account for approximately 40% all cancers and 30% of all cancer related deaths in women globally. Risk of gynaecological cancers increases with exposure to pollutants like $PM_{2.5}$, which further increases with increased exposure to the particles. These pollutants induce oxidative stress reaction in cervical cells, destroying their DNA mimicking HPV induced damage. $PM_{2.5}$ contain polycyclic aromatic hydrocarbons and its derived compounds which activate some carcinogens and affect the metabolism of steroidal hormones, hence increasing the growth of cancer cells leading to breast, ovarian, uterine and cervical tumours, as well as dysregulation of reproductive function.[11]

**Impact on Pregnancy and Related Problems:**

**Miscarriage and Still Birth:** There is sufficient evidence from the literature supporting that both short term and long term exposure to air pollution especially the fine particles, $SO_2$, $NO_2$ and $O_3$ increases the risk of spontaneous abortions. Grippo et al. conducted a comprehensive study suggesting that $PM_{10}$ during the entire gestational period and carbon monoxide (CO) during first trimester were associated with spontaneous abortion. Association of $PM_{2.5}$, $PM_{10}$ and CO during the third trimester was also found with stillbirth.[12]

**Congenital Malformations:** Embryonic development between 3-10 weeks of gestational age is the critical time when the organogenesis occurs. Any exposure to teratogenic agents can have deleterious effects on the developing embryo leading to various congenital malformations. Exposure to $PM_{2.5}$ in periconceptional period is associated with increased risk of congenital malformations. Preconceptional exposure, one month prior, has been associated with increased risk of abdominal wall defects and hypospadias. Increased consumption of fluoride in early gestation can lead to iron deficiency anaemia and fetal outcomes like abortions, intra-uterine fetal demise and congenital disorders.[13] Presence of heavy metals like lead and other elements like nitrates, nitrites and fluoride are well studied. Drinking water containing lead is associated with neural tube defects.[14] Emission of lead by ceramic factories has a positive association with cardiovascular and facial deformities (clefts) and anomalies of musculoskeletal system[15] as depicted in Figure 2.

**Preterm Labour and Low Birth Weight:** Complication arising from preterm labour are the leading cause of neonatal and under five mortality, contributing for approximately 900, 000 deaths in 2019 (WHO). Approximately, 13 million babies are born preterm every year globally. Aetiology is multi factorial i.e. infections, chronic diseases like hypertension, diabetes, polyhydramnios, multiple pregnancy etc but many times no cause is identified. Pregnant females exposed to pollutants ($PM_{2.5}$ and $PM_{10}$) in air are at a higher risk of having preterm delivery. Though pathophysiology is unclear, studies have shown that exposure to these pollutants during the first trimester is considerably associated with very preterm births (28-32 weeks), while early term births (37-38 weeks) were observed by exposure in the second half of pregnancy, especially in the third trimester.

Air pollution adversely affects the growth and development of fetus in utero. $PM_{10}$ and $SO_2$ are significantly linked to low birth weight. Exposure to $PM_{10}$ increases oxidative stress and $SO_2$ changes the blood viscosity by causing increase in coagulation factors16 due to which placental

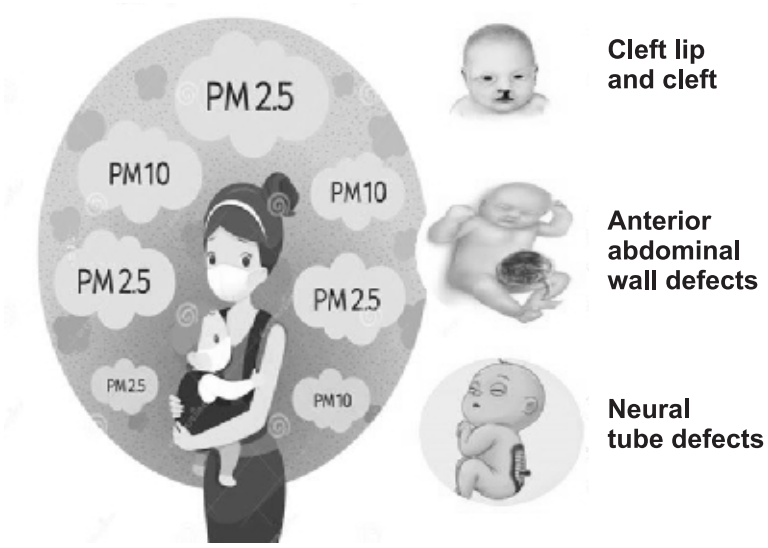


**Figure 2: Association of Pollution and Congenital Malformations**

function and placental oxygenation are reduced, leading to low birth weight.

**Pre-eclampsia:** Pre-eclampsia is a life threatening condition related to 2-8% of pregnancy related complications. Etiopathogenesis is not fully understood yet and oxidative stress, hypoxia, endothelial damage and placental ischemia have been implicated. The exposure to particulate matter ($PM_{2.5}$, $PM_{10}$, $NO_2$, $O_3$ and $SO_2$) are risk factors for preeclampsia. Though exact mechanism is not understood, these pollutants might lead to an oxygen-deficient environment, which induces trophoblastic proliferation and oxidative stress which inhibit the invasion of trophoblasts[17] preventing vascular recasting of uterine spiral arterioles leading to shallow placental implantation, explaining the pathogenesis of pre eclampsia.[18]

**Gestational Diabetes Mellitus (GDM):** One in 10 pregnancies is affected with diabetes worldwide. About 5 million women are affected with GDM annually in India. The current prevalence is 10-14.3% which is higher than western countries. Increasing prevalence due to changing lifestyle, obesity, older age at pregnancy is seen. The association between ambient air pollution and GDM is well supported by literature. Air pollution contributes to the development of glucose intolerance, insulin resistance, endothelial dysfunction and elevated inflammatory mediators (TNF α, PGE2, CRP, IL-1β and endothelin-1). This increased level of inflammatory mediators interrupts and inhibits insulin signaling and transaction causing diabetes in pregnant female.[19] In pregnancy, there is alteration in carbohydrate metabolism under the influence of hormones like estrogen, progesterone and human placental lactogen which further contribute to its development.

**Conclusion:**

The author concludes that further research is required on the impact of various types of pollutants on gynaecological diseases. Addressing the detrimental effect of pollution on pregnancy related complications and gynaecological diseases, comprehensive strategies to mitigate pollution, coupled with public health interventions and advocacy efforts are essential in safeguarding women's health and reducing the burden of these preventable diseases.

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Chapter - 25

# Pollution and Obstetrics: Is there any Relationship?

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**Introduction:**

Urban daily exposures to chemical mixtures originating from air pollution have a profound effect on health, especially during vulnerable periods of development such as intrauterine life.[1] Pregnancy exposome has been emerging as a focal point in developmental origins of diseases, because of its ability to influence the epigenome and thus to affect gene activity and expression, modifying the likelihood of maternal comorbidities and perinatal outcomes risk.[2] The exposome, defined as the totality of environmental exposure of an individual over the lifespan, is proposed to complement the genome information.[2] The exposome includes the general external environment factors, for example, environmental pollution, climate and sociodemographic factors and is highly variable and dynamic.[2] According to the World Health Organization (WHO), air pollution (indoor and outdoor) "represents the single largest environmental risk to health globally".[3] Moreover, exposure to air pollutants is emerging as a key factor to determine the susceptibility of an adverse pregnancy outcome.[3]

Fetal development is a critical window as during this period, the embryos depend on the health, nutrition, activities and emotional status of the mother, which can modify the fetal exposome.[2] According to Barker's theory, embryonic development determines the physiological and metabolic responses that the individual will have into adulthood, in a process known as fetal programming. Thus, any stimulus or insult during embryonic development will result in developmental adaptations that produce permanent structural, physiological and metabolic changes that predispose to cardiovascular, metabolic and endocrine disease in adult life.[4] Epidemiological data associates air pollution exposure during pregnancy with adverse outcomes such as preterm birth (<37 weeks of gestation), low birth weight (< 2500 g at birth), miscarriage, preeclampsia and hypertensive disorders of pregnancy.[5]

Although the mechanisms responsible for the adverse pregnancy outcomes related to air pollution are not elucidated, recent experimental evidence indicates that the placenta is a direct target tissue for air pollution.[6] It is suggested that oxidative stress, endocrine disruption, inflammatory response and DNA damage are the main contributors.[7]

**Air Pollution:**

Air pollution is defined as environmental contamination by toxic chemical compounds, gases and particles that could modify the natural characteristics of the atmosphere with potential adverse health effects.[8] Air pollution encompasses a mixture of different pollutants including particulate

matter (PM) which are defined according to their aerodynamic diameter (μm) as ultrafine particles $PM_{0.1}$, fine particles $PM_{2.5}$, coarse particles $PM_{10}$ and gaseous components like ozone ($O_3$), carbon monoxide (CO), sulfur dioxide ($SO_2$), nitrogen dioxide ($NO_2$), carbon dioxide ($CO_2$), black carbon (BC), diesel exhaust fumes, a wide variety of toxic chemicals such as polycyclic aromatic hydrocarbons (PAHs) and volatile and semi-volatile organic compounds (VOCs).[9] Air pollution is a dynamic phenomenon where both outdoor and indoor pollutants interact and affect air quality.[2,5]

The particulate matter often derives from different sources and has different chemical compositions. $PM_{10}$ commonly includes pollen debris, dust from landfills or construction sites, industrial sources, wildfires, brush or waste burning, wind-blown dust from open lands and microbial fragments.[10] $PM_{0.1}$ and $PM_{2.5}$ can be inhaled deeply into the lungs and enter the bloodstream, increasing the potential risk for cardiovascular diseases, lung cancer and adverse pregnancy outcomes.[11] PAHs are comprised of two or more fused benzene rings in different arrangements (linear, clustered and angular) highly lipophilic with relatively low solubility in water, that are stable and resistant to hydrolysis. In the atmosphere, most PAHs present on $PM_{2.5}$ have low volatility (particle-phase), are linked to mutagenic, teratogenic and carcinogenic properties.[12] PAH can accumulate in the placenta[13] inhibiting trophoblast cells differentiation and proliferation, disrupting the endocrine placental function, disturbing the redox balance[14] and forming DNA adducts .

**Air Pollution Exposure during Pregnancy:**

Outdoor air pollution exposure during pregnancy has been linked to fetal development problems, preterm birth and pregnancy complications, including pregnancy-induced hypertensive disorders.[15]

A cohort study with 34,705 singleton births delivered at Pittsburgh, between 1999 and 2002, reports the association between preeclampsia, gestational hypertension and preterm delivery with increased exposure to an ambient source of PAHs ($PM_{2.5}$) during the first trimester of pregnancy.[16] $PM_{10}$ has been associated with fetal overgrowth, with preeclampsia, particularly during humid periods (autumn/winter seasons)[17], conversely $PM_{10}$ has also been associated with small for gestational age (a birth weight of less than 10th percentile for gestational age) in twins born between 32 and 36 weeks, but not associated in term twins.[18] Suggesting that $PM_{10}$ increases the risk of abnormal fetal growth. Additionally, it has been reported that exposure to $PM_{10}$ during the first trimester can alter the fetal heart response rate without evidence of acidemia or fetal asphyxia.[19] Regarding other compounds, several studies have concluded that outdoor $SO_2$ exposure during the third trimester was associated with early-term births (birth between 37 and 38 weeks).[19] While the associations for $NO_2$, NO, CO and $O_3$ were inconclusive in some cases, in other cases $NO_2$ was linked to preterm birth, even among pregnant women living in an area with relatively low average air pollution concentrations and consistently associated with term low birth weight.[20] On the other hand, a systematic review of 84 studies found that most types of particulate matter (PM) were associated with low birth weight, but these associations had many inconsistencies in terms of PM sources and the characteristics of the built environment, proximity to traffic and green spaces near the residence of the pregnant women.[21]

A recent study analyzed the records of almost 6,00,000 pregnant patients and demonstrated a

positive association between preterm birth and $PM_{10}$, $PM_{2.5}$, $SO_2$, $NO_2$ and CO, where $NO_2$ was the largest pollutant contributor while the third trimester was identified as the most sensitive exposure window.[22] Meanwhile, a recent report showed a positive association between three-month mean residential $NO_2$ concentrations and maternal hair cortisol as a biomarker for longer-term biological stress during pregnancy.[23] Another meta-analysis that included more than 60 studies found that exposure to $PM_{2.5}$, $PM_{10}$ and $O_3$ during pregnancy correlates with the risk of preterm birth at 32-35 weeks, 28-31 weeks and before 28 weeks.[24] Exposure to $PM_{2.5}$ pollution during pregnancy is significantly associated with preeclampsia and hypertensive disorders of pregnancy.[25] Preeclampsia is a pregnancy pathology associated with placental dysfunction and defined by a new onset of hypertension with or without proteinuria after 20 weeks of gestation.[26] A recent meta-analysis performed with data up to March 2020, summarized 9 cohort studies and concluded that maternal exposure to $PM_{2.5}$ during the third trimester of pregnancy elevates the risk of preeclampsia.[27] Some epidemiological studies, use the distributed lag linear model, which is a statistical analysis model that distributes the effect of a single exposure event over a specific time period, in order to estimate the lag effect between exposure to ambient air pollutants and a health outcome.[28] During pregnancy, several studies have analyzed the lag effect of different air pollutants exposure and its association with the risk of adverse pregnancy outcomes for example, a study reported a significant association between preconceptional air pollution exposure ($PM_{2.5}$, $PM_{10}$ and $O_3$) during the cold season and the termination of pregnancy.[29] A recent study applied distributed lag nonlinear model to investigate the association between early pregnancy to mid pregnancy exposures to $PM_{2.5}$, $PM_{10}$ and $NO_2$ and lower birth weight.[30] Another study found that the acute and lag effects of high levels of $PM_{2.5}$, $PM_{10}$, $NO_2$ and $SO_2$ exposure and the calculated fertilization time was associated with spontaneous abortion preterm birth.[31] The identification of critical windows of susceptibility in which exposure to air pollutants may alter pregnancy outcome is key to improve environmental health interventions and prevent vulnerable populations, currently remains inconsistent across studies. Further research is needed to investigate the most likely window of exposure, as well as to estimate the lag and acute effect of exposure to air pollutants during pregnancy.[32]

**Maternal Physiological Adaptation during Pregnancy and Particulate Matter Exposure:**

Normal pregnancy implies profound cardiovascular changes necessary to meet the increased demands of the growing fetoplacental unit.[33] These changes occur very early in pregnancy. Exposure to $PM_{2.5}$ in this period could have a detrimental effect on cardiovascular adaptations during pregnancy leading to the development of hypertensive disorders.[34] It has been shown that the smaller particles are more harmful than the larger particles inducing adverse health effects, as the deposition rate is strongly influenced by particle size.[35] Fine particles ($PM_{2.5}$) are stable in the atmosphere with a residence time of 7 to 30 days. Recent work showed an association between the $PM_{2.5}$ exposure during the first trimester and the development of hypertensive disorders of pregnancy[36] and maternal thyroid dysfunction.[31] Since pregnancy is associated with maternal respiratory adaptations, mainly related to significantly increasing tidal volume, pregnant women could inhale more polluted air.[37] The acute or chronic exposure to $PM_{2.5}$ causes activation of

inflammatory responses together with structural damage to the alveoli, which facilitates the passage of $PM_{2.5}$ into the systemic circulation.[38]

**Fetal and Maternal Vascular Alteration by Particulate Matter Exposure:**

The most prominent mechanisms associated with $PM_{2.5}$ health effects are oxidative stress and inflammation termed as "oxi-inflammation".[40] $PM_{2.5}$ triggers the secretion of inflammatory interleukins such as IL-6 and IL-1β, increasing the inflammatory response.[41] A breakdown of intercellular junctions and increased adhesion molecules are characteristic events of inflammation and endothelial dysfunction, which are observed in pregnancy pathologies such as gestational diabetes, preeclampsia and obesity.[42] On the other hand, the endothelial damage related to $PM_{2.5}$ exposure involves endothelial-mesenchymal transition (EndMT), triggered by the activation of the transforming growth factor-β (TGF-β) pathway, linked to high levels of reactive oxygen species (ROS) and PAHs.[42] Furthermore, exposure to $PM_{2.5}$ causes a reduction in the bioavailability of NO in the vessel wall, impairing the endothelial-dependent vasorelaxation.[42] Another mechanism that could explain the endothelial dysfunction induced by $PM_{2.5}$ exposure, is the interleukin 22/interleukin 22 receptor (IL22/IL-22R) pathway.[43] IL-22 is a cytokine that plays pro- and anti-inflammatory functions, the interaction of IL-22 with its receptor can induce the production of adhesion molecules, endothelial activation and the secretion of numerous proinflammatory mediators.[44] Increased IL-22 has been observed in the blood of pregnant women with preeclampsia and premature rupture of membranes (Figure1).[45]

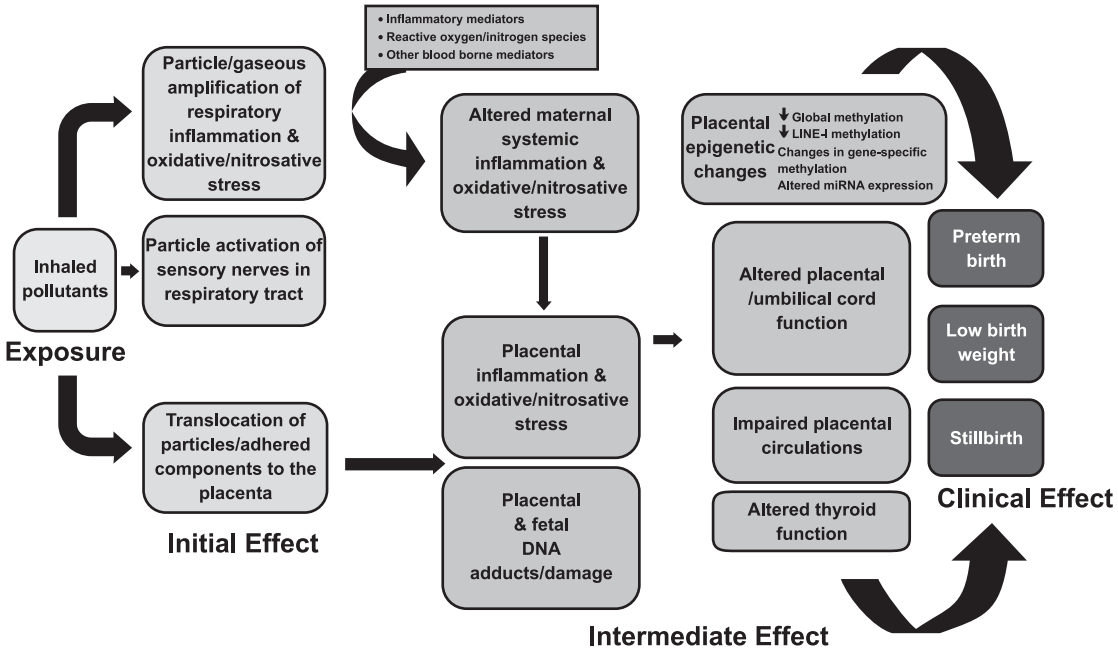


**Figure 1: Maternal and fetal Alteration by Inhaled Pollutants**

Experimental evidence indicates that the placenta is a target tissue following maternal exposure to ambient air pollutants during pregnancy. Progression of effects from left to right: light grey = exposure; intermediate grey = initial effect; dark grey = intermediate effects; darkest grey = clinical effect.

**Placental Tissue and Particulate Matter Exposure:**

Black carbon particles from air pollution can translocate from the maternal lungs into the maternal circulation reaching the placenta. The $PM_{2.5}$ exposure during the first and second trimesters of gestation has been positively associated with the amount of 3-nitrotyrosine (3-NTp) in the placental tissue from 330 mother-newborn pair cohorts.[39] 3-NTp is a well-known biomarker of both nitrosative and oxidative stress and inflammation.[46]

It has been reported that the accumulation of PAHs in the placenta from healthy pregnancies decreases the presence of PAHs in fetal blood, suggesting that under normal conditions the placenta acts as a reservoir decreasing the transfer of PAHs from the mother to the fetus.[14] While, in placental tissues from pregnancies associated with hypertensive disorders, diabetes or preterm delivery, PAHs concentration decreases together with an increase of PAHs in fetal blood.[14]

The exact concentration of $PM_{2.5}$ that reaches the placenta of a woman exposed to air pollution is unknown. It is not valid to convert from the unit used in most experimental studies (µg/ml or ng/ml) to the unit reported by air quality sensors (µg/$m^3$). However, one study indicates that levels of 5000 ng/ml (5 µg/ml) could correspond to 25 µg/$m^3$.[39] The same study indicates that 10,000 ng/ml (10 ug/ml) could correspond to levels that can be observed in a more polluted city with $PM_{2.5}$ concentrations of 50 µg/$m^3$.[39] The reference value for 24 h exposure to $PM_{2.5}$ established by WHO global air quality guidelines is 15 ug/$m^3$.[1]

**Mitigation Strategies:**

The most obvious way to avoid the deleterious effect of air pollution is not to be exposed to it. However, this is not practical since everyone must breathe the available air. We need to reduce the air pollution in our cities, but unfortunately is a long-term process that demands a government commitment, along with education and other strategies related to reduce the sources of pollution. Thus, individual and public strategies focused to reduce the harmful effects of the available polluted air are needed (Figure 2).

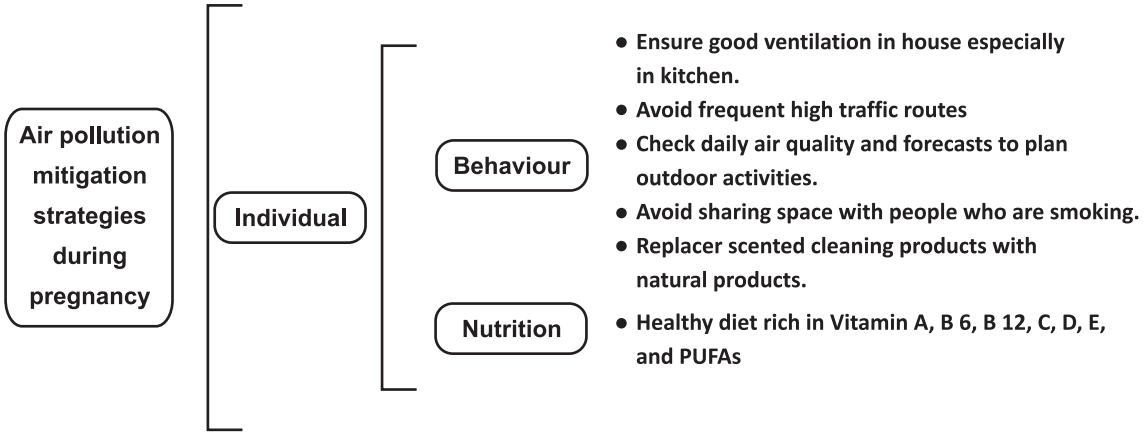


**Figure 2: Air Pollution Mitigation Strategies during Pregnancy**

**Behavioral Actions:** Reducing exposure to air pollution during pregnancy is a key opportunity to provide better health to the child. A primary prevention measure that can be given to the mother at prenatal care, ensure good ventilation to reduce the exposure to indoor air pollution. One of the biggest sources of pollution in homes is the use of the kitchen. To reduce or to eliminate air pollution in the kitchen, the American Lung Association recommends using the exhaust fan and ensuring ventilation in the kitchen.[47] Another recommendation made by the same association is to get rid of fragrant and scented products such as air fresheners and cleaners, replacing them with natural products such as vinegar, peroxide and baking soda, or non-toxic brands. Another individual measure is to check daily air quality levels and to perform outdoor activities when pollution levels are lower. It is also recommended that pregnant women avoid sharing space with people who are smoking.

**Nutrition:** Since the imbalance in oxidant production is one of the prominent mechanisms leading to cellular damage linked to air pollution, the addition of antioxidants from nutrition/supplements represents an opportunity to mitigate the air pollution effects.[48] According to FDA antioxidants are substances that, following absorption from the gastrointestinal tract, participate in physiological, biochemical or cellular processes that inactivate or prevent free radical-initiated chemical reactions.[49] The common antioxidants from diet or supplementation are DL-alpha-tocopherol acetate (vitamin E), ascorbic acid (vitamin C), beta-carotene (vitamin A), omega-3 polyunsaturated fatty acids (omega-3) and selenium, that have been reported to be involved in the deactivation of free radicals.[50]

Mitigation strategies should include advice to pregnant women on ways to reduce exposure to indoor and outdoor pollution and the importance of this issue during pregnancy. Greater efforts and interaction between different disciplines are needed to develop effective prevention and risk assessment strategies that can significantly reduce adverse effects of air pollution during pregnancy.

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Chapter - 26

# Pollution and Renal Diseases: Is there any Relationship?

*Sanjiv Jasuja*

**Introduction:**

Kidney diseases encompass a diverse range of conditions that affect the structure and function of the kidneys, vital organs responsible for filtering waste products, regulating fluid and electrolyte balance and producing hormones essential for overall health.[1] Often referred to as a "silent killer," kidney diseases are frequently difficult to detect in their early stages but can progress to fatal kidney failure.[2] Roughly 850 million individuals globally are believed to suffer from kidney ailments, including chronic kidney disease (CKD), acute kidney injury (AKI) and kidney failure, necessitating kidney replacement therapy (KRT) such as dialysis or kidney transplantation for survival.[3] The prevalence and incidence of kidney diseases differ depending on the region, with elevated rates noted in low- and middle-income nations, where access to healthcare services and preventative measures might be restricted.[3] Around 10% of adults worldwide are affected by various kidney diseases including acute kidney injury (AKI), chronic kidney disease (CKD), glomerulonephritis, polycystic kidney disease (PKD) and urinary tract infections (UTIs), among others. The global mortality of kidney diseases is estimated to be around 5-10 million annually. However, due to the scarcity of epidemiological information, insufficient awareness and often inadequate access to laboratory facilities, the actual impact of kidney disease remains underestimated. It is conceivable that annually, kidney disease contributes to at least as many deaths as cancer, diabetes or respiratory diseases do.[3] Kidney disease indirectly affects global morbidity and mortality by heightening the risks associated with at least five other leading causes of death: cardiovascular diseases, diabetes, hypertension, human immunodeficiency virus (HIV) infection and malaria.[3]

Various risk factors and determinants contribute to the prevalence of renal diseases, encompassing both non-modifiable elements like age and genetics, as well as modifiable factors such as hypertension, diabetes, obesity, smoking, unhealthy dietary habits and environmental exposures.[1,2] Recently, pollution has been attributed as a potential cause for the increase in the global burden of kidney diseases.[4–17]

Pollution, defined as the introduction of harmful or undesirable substances into the environment, can manifest in different forms, including air pollution (emission of pollutants into the atmosphere), water pollution (contamination of water bodies with chemicals, toxins, or waste), soil pollution (contamination of land with pollutants) and noise pollution (excessive or disruptive noise levels).[15,16] The Global Burden of Disease (GBD) study estimates that pollution was responsible for 9 million deaths worldwide in 2019.[16] Patients suffering from kidney disease may be particularly vulnerable

to the impacts of pollutants, given their inherent fragility and the presence of multiple coexisting health conditions. Until now, the role of pollution and pollutants has not received wide attention in the prevention, diagnosis or treatment of kidney diseases. In this chapter, we explore the current evidence linking different types of pollution to kidney disease and its associated health complications. (Table 1 to 4).

**Table 1: Impact of Particulate Matter (PM) and Gaseous Pollutants on Kidney Function and Disease.**

| Type of Pollutant | Source of Exposure | Effect on Kidney | References |
|---|---|---|---|
| **Particulate Matter (PM)** | | | |
| $PM_{2.5}$ | Air | Increase in incidence of CKD, ESKD, decline in GFR, membranous nephropathy, albuminuria, glomerulonephritis, kidney rejection post-transplant, increased mortality and cardiovascular events among patients undergoing haemodialysis. | 4, 5, 7, 8, 11-13 |
| $PM_{10}$ | Air | Increase in incidence of CKD, ESKD, decline in GFR. | 5 |
| **Gases** | | | |
| Nitrogen Dioxide ($NO_2$) | Air | Acute kidney injury (AKI), CKD-related hospital visits, increased incidence of CKD and ESKD with a decline in eGFR. | 5, 14, 20 |
| Ozone | Air | Renal injury, kidney dysfunction (limited evidence). | 17 |

**Table 2: Influence of Heavy Metal Pollutants on Kidney Function and Disease**

| Type of Pollutant | Source of Exposure | Effect on Kidney | References |
|---|---|---|---|
| **Heavy Metals** | | | |
| Cadmium | Water, Soil, Air | Linked to kidney injury, chronic kidney disease (CKD), proximal tubular and glomerular damage, oxidative stress. | 21-26 |
| Lead | Water, Soil, Air | Associated with CKD, increased serum creatinine, nephrolithiasis, proximal tubular cell injury, glomerular dysfunction. | 27-28 |
| Mercury | Water (Seafood) | Linked to renal dysfunction, proximal tubule necrosis, membranous nephropathy | 9, 29 |
| Arsenic | Water, Soil | Limited evidence of association with kidney disease. | 30 |
| Copper | Water, Soil | Proximal tubule necrosis due to oxidative stress. | 31 |
| Nickel | Water, Soil | Induces inflammatory response, tubular apoptosis, renal dysfunction. | 9, 32 |
| Uranium | Water | Triggers oxidative stress, mitochondrial dysfunction, nephrotoxicity. | 33 |
| Lithium | Soil, Water | Linked to nephrogenic diabetes insipidus, CKD, tubulointerstitial nephritis, and renal cysts (limited evidence between exposure to lithium as pollutants and kidney disease). | 50 |

**Table 3: Effects of Pesticides, Herbicides and Biologic Contaminants on Kidney Function and Disease.**

| Type of Pollutant | Source of Exposure | Effect on Kidney | References |
|---|---|---|---|
| **Pesticides or Insecticides** | | | |
| Methyl Parathion, Permethrin, Hexachlorocyclo-Hexane, Endosulfan, DDT | Water, Soil | Linked to CKD, ESKD, increased risk of diabetes indirectly affecting kidney function | 34, 39-40 |
| **Herbicides** | | | |
| Alachlor, Atrazine, Butylate Glyphosat, Metolachlor, Paraquat, Pendimethalin, Dicamba | Water, Soil | Linked to CKD, kidney dysfunction, ESKD, glomerular lesions, tubular necrosis, increased risk of diabetes indirectly affecting kidney function | 35-38 |
| **Biologic Contaminants** | | | |
| Leptospira | Water | Linked with CKD | 45 |
| Schistosoma | Water | Linked with CKD | 45 |
| Aristolochia | Water | Water Chronic tubulointerstitial nephritis, Balkan endemic nephropathy | 46 |
| Ochratoxin A | Water, Soil | Kidney injury, upper urothelial carcinoma, Balkan endemic nephropathy | 47 |

**Table 4: Role of Industrial Chemical Pollutants in Kidney Function and Disease.**

| Type of Pollutant | Source of Exposure | Effect on Kidney | References |
|---|---|---|---|
| **Industrial Chemicals** | | | |
| Trichloroethylene Tetrachloroethylene | Water | Both linked to renal toxicity and renal carcinoma, limited association with CKD. | 41, 43 |
| Melamine | Water | Kidney stone formation, renal dysfunction and impaired renal growth in children. | 42 |
| Perfluorooctanoic acid Perfluorooctane sulfonate | Water | Linked with increased risk of CKD and low eGFR. | 44 |
| Phthalates | Water | High molecular weight phthalates linked to increase in albuminuria and systolic blood pressure in children. | 41 |
| Biphenol A | Water, Air | Inverse relationship between high serum Biophenol A and renal function in pre-dialysis CKD, Induces albuminuria, Increased risk of hypertension, diabetes and cardiovascular disease. | 41 |
| Dioxins and Furans | Water | Moderate to high level exposure linked to decline in eGFR, Increase is serum uric acid, hyperuricaemia. | 41 |
| Polycyclic aromatic hydrocarbons | Air, Water | High exposure associated with elevated CRP levels, Balkan endemic nephropathy, renal parenchymal disease and urological malignancies. | 41 |

## Air Pollution:

Air pollution consists of particulate and gaseous primary pollutants like nitrogen oxides (NOx), sulfur dioxide and carbon monoxide, emitted directly into the atmosphere. It also includes secondary pollutants such as ozone and volatile and semi-volatile organic aerosols, such as benzene, toluene, xylene, 1, 3-butadiene and polycyclic aromatic hydrocarbons. The components and concentration of air pollution vary based on location, time and weather conditions.[9, 10]

Air pollution encompasses ambient (outdoor) and household (indoor) pollution. The primary source of ambient air pollution is fossil fuel combustion, household air pollution primarily stems from the combustion of biomass fuels such as wood, coal, straw, dung and charcoal in household cook stoves, incense, candles, aerosol sprays and volatile cleaning products. Inadequately ventilated buildings exacerbate household air pollution issues.

**Particulate Matter (PM):** Particulate pollutants are typically classified as $PM_{10}$ (particles with a diameter less than 10 μm), $PM_{2.5}$ (particles with a diameter less than 2.5 μm), or ultrafine particles (UFPs, with a diameter less than 0.1 μm). In 2015, exposure to $PM_{2.5}$ contributed to 4.2 million deaths globally, constituting 7.6% of total deaths worldwide out of which 60% occurred in South and East Asia.[9] Previous studies have shown that both short-term (days) as well as long-term (months/years) exposure to $PM_{2.5}$ triggers oxidative stress, inflammation, cell autophagy and apoptosis at the cellular level and additionally causes acute thrombus formation and vascular dysfunction, possibly leading to cardiovascular dysfunction.[7, 8] However, the specific mechanisms of how $PM_{2.5}$ particles affect the kidney remain less understood. Recently research using inert gold nanoparticles as a model for $PM_{2.5}$ showed that these particles, upon inhalation, can be detected in urine within minutes, suggesting that $PM_{2.5}$ may directly or indirectly injure kidney tissue by passing through the glomerulus.[18]

Various studies have attributed $PM_{2.5}$ as a risk factor for the development of chronic kidney disease (CKD) and its progression to end-stage kidney disease (ESKD), as well as a contributory factor to the morbidity and mortality in individuals already diagnosed with kidney disease. Recently, Rasking et al conducted a systematic review of 40 epidemiological studies that examined the association between $PM_{2.5}$ and kidney dysfunction.[4] These studies assessed kidney function using clinical parameters such as glomerular filtration rate (GFR), albuminuria and glomerulonephritis. One of the studies conducted in China between 2004 and 2014 on 71,151 native kidney biopsy samples collected nationwide, revealed that long-term exposure to high levels of $PM_{2.5}$ was associated with an increased risk of membranous nephropathy in regions with $PM_{2.5}$ levels exceeding 70 $\mu g/m^3$, suggesting that individuals with prolonged exposure to $PM_{2.5}$ are more susceptible to developing membranous nephropathy compared to other kidney diseases.[11] In another study, conducted among US veterans, a linear relationship was observed between $PM_{2.5}$ concentration and incident CKD and its progression to ESKD.[19] $PM_{2.5}$ particles have also been associated with increased urine albumin and a decline in GFR[13] and kidney rejection post-transplant, graft failure and all-cause death.[6]

$PM_{2.5}$ has been linked to increased risks of mortality and cardiovascular events among patients

undergoing haemodialysis. In a retrospective cohort study, Xi et al observed a 4% rise in daily mortality for each 10-µg/$m^3$ increment in $PM_{2.5}$ from wildfires and a 7% increase in death within 30 days following exposure.[12] The same researchers also showed that both short-term and long-term exposure to ambient $PM_{2.5}$ was linked to an increased risk of new cardiovascular disease events and mortality in individuals undergoing haemodialysis, the risk was particularly pronounced in older patients compared to younger individuals.[7,8]

Other than $PM_{2.5}$, increased concentration of $PM_{10}$ has also been linked to increased risk of CKD incidence, decline in eGFR and ESKD.[5]

**Nitrogen Dioxide:** Nitrogen dioxide ($NO_2$) is a gas pollutant produced when fossil fuels such as wood, coal, oil, natural gas (methane) or diesel are burned at elevated temperatures and contribute to both ambient and household pollution.[15,16] Exposure to $NO_2$ has been associated with potential kidney dysfunction. While a study in China demonstrated that increased ambient levels of $NO_2$ are associated with an elevated risk of hospital-acquired AKI[20], another study showed that short-term $NO_2$ exposure significantly increased the risk of CKD-related hospital visits.[14] Bowe et al also observed that ambient concentrations of $NO_2$ can be associated with increased incidence of CKD and ESKD, with a 30% or more decline in eGFR.[5]

**Ozone:** Ozone is a product of the interaction between ultraviolet light and oxides of nitrogen and volatile hydrocarbons. Short-term inhalation of ozone provokes an inflammatory and metabolic response in the lungs and extrapulmonary organs, such as the kidneys. Ground-level ozone, a component of smog, can induce oxidative stress and inflammation, contributing to renal injury and worsening kidney function. Limited evidence also suggests a potential association between tropospheric or ground-level ozone and kidney disease[17] although further research is needed to elucidate this relationship.

**Water Pollution:**

Water pollution has been implicated as a potential risk factor for kidney disease, although the relationship is complex and multifactorial. Water pollution can introduce nephrotoxic contaminants such as heavy metals (e.g., lead, mercury, cadmium) and chemical pollutants (industrial chemicals, pesticides and pharmaceutical residues) into drinking water sources. Chronic exposure to these contaminants can damage kidney tissues and impair renal function.

**Heavy Metals:** Heavy metals are regarded as one of the most significant hazards to human health due to their enduring presence in the environment and their ability to be absorbed into the human body via ingestion, inhalation and even skin contact. Heavy metals such as arsenic, cadmium, lead, mercury and uranium are the most studied nephrotoxins found in water.[21,22]

Cadmium: Cadmium, a toxic metal, is released into the environment through various activities such as mining, metal refining, fertilizer production, fossil fuel combustion and waste disposal. Although drinking water contributes minimally to overall cadmium exposure for most people, it can be significant near industries emitting cadmium.[21] Historical incidents, like the "itai-itai" disease outbreak in Japan, underscore the severe health effects of cadmium toxicity, including bone pain and kidney dysfunction.[23] Research has linked cadmium exposure, measured through blood or

urine levels, with kidney injury and chronic kidney disease (CKD).[21, 22, 24] Cadmium accumulates in the body over the years, particularly in the kidneys, targeting the proximal tubules and glomeruli.[21,22] Cadmium-induced nephropathy damages kidneys through mechanisms such as oxidative stress, DNA damage inhibition and apoptosis, with chronic exposure leading to irreversible kidney injury.[25] In Asian countries where rice consumption is high, cadmium accumulation in rice is a major concern, associated with renal dysfunction.[26] Urinary cadmium levels of 4–10 µg/g creatinine are linked to increased microalbuminuria, indicating kidney damage.[24]

Lead: Lead contamination in drinking water primarily originates from plumbing materials followed by runoff from smelters, mining, battery production and recycling processes. Blood lead levels are a concern due to their toxic nature, stability and prolonged half-life in bones.[27] Chronic lead exposure has been linked to CKD, increased serum creatinine, prevalence of anaemia among ESKD patients and nephrolithiasis.[27,28] Lead poisoning can cause injury to proximal tubular cells, glomerular dysfunction and interstitial fibrosis possibly resulting in albuminuria and decreased eGFR. Lead exposure also results in mitochondrial dysfunction and oxidative stress contributing to kidney damage.[28]

Mercury: Human exposure to mercury, particularly methylmercury, primarily occurs through consuming contaminated fish, shellfish and marine mammals from polluted fresh or seawater. While chronic mercury exposure has been associated with renal dysfunction, there's limited epidemiological evidence linking methylmercury specifically to CKD.[29] Mercury toxicity primarily affects the nervous system (Minamata disease), but nephrotoxicity has also been reported, with proximal tubules being the most sensitive sites. Acute mercury exposure can cause tubular epithelial cell necrosis and low-molecular-weight proteinuria. Chronic mercury exposure can also damage glomeruli, leading to membranous nephropathy.[29] Withdrawal from mercury exposure often results in complete remission in affected individuals. The pathogenic mechanisms of mercury-induced glomerular disease involve autoimmune dysfunction, characterized by the activation of T cell-dependent polyclonal B cells, production of autoantibodies and formation of immune complex deposits in the kidneys.[9] Additionally, research has suggested a potential role of NELL-1, a protein involved in bone formation, in the pathogenesis of membranous nephropathy associated with mercury exposure.[29] Identifying potential biomarkers and understanding the role of mercury in autoimmune renal diseases is essential for developing effective prevention and treatment strategies.

Arsenic: Exposure to inorganic arsenic from mining, metal smelting, pesticide production, wood preservation and medicines risks human health. Although studies on arsenic-induced nephrotoxicity are limited, one study noted an increased risk of kidney disease among individuals exposed to arsenic-contaminated drinking water in Michigan, USA.[30]

Copper: Copper, an essential trace element, can become toxic with excessive intake due to its redox-active properties, leading to oxidative stress and cellular damage in organs where copper accumulates. Copper nephrotoxicity typically manifests as proximal tubule necrosis induced by oxidative stress, facilitated by copper's ability to generate highly reactive hydroxyl radicals.[31]

Nickel: Nickel exposure through industrial and commercial use of nickel-containing compounds

can result in genotoxic, immunotoxic, mutagenic and carcinogenic effects in humans.[9] The kidney serves as the primary organ for nickel accumulation and excretion. Excessive nickel exposure triggers an inflammatory response via activation of nuclear factor-κB (NF-κB) and induces tubular apoptosis through the phosphoinositide 3-kinase (PI3K)–RAC serine/threonine-protein kinase (AKT) pathway.[32]

Uranium: Uranium is another heavy metal pollutant associated with molecular markers of renal dysfunction. Depleted uranium (DU) has been shown to induce oxidative stress and disrupt the balance of antioxidant defences within renal cellsby modulating the ETHE1/Nrf2 pathway. This disturbance ultimately results in mitochondrial dysfunction, culminating in nephrotoxicity.[33]

**Chemical Pollutants:** Pesticides, herbicides, solvents and other industrial chemicals can contaminate water sources and risk kidney health. These chemicals may disrupt renal function, impairing filtration and detoxification processes.

Pesticides/Herbicides: Numerous pesticides and herbicides have been linked to CKD or ESKD through epidemiological investigations. These include herbicides like alachlor, atrazine, butylate, glyphosate, metolachlor, paraquat and pendimethalin, along with insecticides such as methyl parathion and permethrin.[34–37] Notably, paraquat, a commonly used herbicide, has been demonstrated in animal studies to induce glomerular lesions and renal tubular necrosis.[36] In a large prospective study involving individuals engaged in pesticide application in the USA, exposure to six pesticides—five herbicides (paraquat, alachlor, atrazine, metolachlor and pendimethalin) and one insecticide (permethrin)—was linked to an increased risk of ESKD.[35] Interestingly, even the spouses of those applying paraquat, who do not have direct contact with the pesticides, showed an elevated risk of ESRD.[34] Chronic exposure to ultra-low doses of glyphosate has been demonstrated to induce kidney damage in established animal toxicity models.[38] Furthermore, the accumulation of organochlorine pesticides such as hexachlorocyclohexane and endosulfan is associated with deficiencies in the activity of glutathione S-transferases GSTθ1 and GSTμ1, leading to kidney dysfunction.[39] Dicamba, another herbicide, has been linked to reduced eGFR.[37] At the same time, the organochlorine insecticide dichlorodiphenyltrichloroethane (DDT) and its primary metabolite have been associated with insulin resistance and an increased risk of diabetes, which could indirectly affect kidney function.[40]

**Industrial Chemicals:** Several cross-sectional studies have established a connection between exposure to industrial chemicals, such as phthalates, bisphenol A (BPA) and perfluoroalkyl acids, chemicals and a heightened risk of kidney disease.[41] The 2009 melamine contamination crisis in China underscores the devastating impact of exposure to chemical pollutants, with over 300,000 infants and children affected by consuming melamine-contaminated milk-based formulas, leading to kidney stone formation, renal dysfunction and impaired renal growth.[42]

Trichloroethylene and tetrachloroethylene, widely employed as industrial degreasers and in dry cleaning, have also been found to exhibit nephrotoxic effects.[41,43] Furthermore, per and polyfluoroalkyl substances (PFAS), a group of persistent manmade chemicals, are directly associated with an increased risk of CKD in some cases, others have found an inverse correlation with GFR. Additionally, PFAS exposure has been implicated in various conditions like obesity,

diabetes mellitus, hyperlipidaemia and cardiovascular diseases, all of which are both direct and indirect risk factors for kidney disease.[44] However, the precise nature of the relationship between PFAS exposure and CKD remains unclear.

**Biologic Contaminants:** Biologic contaminants, alongside chemical pollutants in drinking water, contribute to CKD. Bacteria like Leptospira and parasitic worms from the genus schistosoma have been linked to CKD.[45] Aristolochic acids, potent nephrotoxins produced by the aristolochia plant, are implicated in Balkan endemic nephropathy, a tubulointerstitial disease prevalent in south-eastern Europe, often leading to urinary tract cancers. The pathogenic mechanisms of aristolochic acid-induced nephropathy involve autophagy activation, mitochondrial and endoplasmic reticulum stress and DNA damage leading to specific mutations in the TP53 gene.[46] Ochratoxin A (OTA), a common mycotoxin in food, has established nephrotoxic and carcinogenic effects. Exposure to OTA can result in acute kidney injury and upper urothelial carcinoma. OTA is also linked to Balkan endemic nephropathy and chronic interstitial nephropathy in certain regions, exerting its toxicity through mechanisms such as protein synthesis inhibition, lipoperoxidation and modulation of the mitogen-activated protein kinase (MAPK) cascade.[47]

**Soil Pollution:**

Soil pollutants have been implicated in renal disease.These pollutants, akin to those found in water, encompass heavy metals like cadmium, lead and mercury, as well as pesticides and industrial chemicals, which have been implicated in the onset or worsening of renal disorders. These soil pollutants can potentially affect water sources and agricultural produce, thereby contributing to the development or exacerbation of kidney disease over time.[9] A recent study in Sri Lanka sought to investigate whether contaminated water and agricultural soil were contributing factors to the occurrence of unexplained or unclear causes of CKD in certain areas. The findings revealed that the paddy soil in these regions exhibited moderate pollution levels with toxic metals and metalloids such as arsenic, lead, copper, nickel, chromium, zinc and cadmium, potentially attributed to fertilizer applications.[48] Lithium, often used in batteries and various industrial applications, can contribute to soil pollution if not properly disposed off. It is also used in the treatment of bipolar disorder and is known to affect kidney function. Long-term use of lithium can lead to the development of kidney disease, particularly nephrogenic diabetes insipidus (NDI), a condition where the kidneys are unable to concentrate urine effectively.[49] Additionally, lithium use has been associated with other renal complications such as chronic kidney disease (CKD), tubulointerstitial nephritis and renal cysts.[50]

**Conclusion:**

Environmental pollutants, including particulate matter, heavy metals and industrial and agricultural chemicals, pose significant risks for kidney disease, particularly in developing countries with prevalent pollution. While the causes and mechanisms of chronic kidney disease of unknown aetiology (CKDu) are not fully understood, it is estimated that about 10-13% of CKD cases in the USA are linked to air pollution. Given the more severe air quality in many developing nations, environmental pollution likely plays a substantial role in CKDu. Raising awareness among policymakers, industries and the public about the health risks posed by environmental pollutants is crucial. Strategies for environmental protection, such as enforcing air quality standards, controlling

emissions from vehicles and industries, promoting greener energy and transportation and prioritizing research into the effects of pollutants, could be adapted for developing countries.

Most evidence linking environmental pollution to kidney disease comes from cross-sectional studies, highlighting the need for longitudinal studies with precise measurements of environmental exposures to establish causality. Understanding the toxic effects of pollutants and establishing dose-response relationships for various exposure levels are essential. Research on the specific mechanisms by which pollutants induce kidney disease is lacking, as is the exploration of the interaction between environmental pollutants and genetic factors. High-quality population-based studies are needed to inform regulatory strategies and mitigate environmental health risks.

To address existing gaps, regulatory agencies should adopt international toxicity thresholds for pollutants, governments should consider funding an international repository of data on environmental pollutants and researchers should integrate novel study designs with biomarker data. Ultimately, the goal is to inform individual and public health policies to mitigate the risks associated with environmental pollutants and reduce the burden of kidney disease.

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Chapter - 27

# Pollution and Dermatological Disorders: Is there any Relationship?

*Sunil K. Gupta, Jaspriya Sandhu, Navneet Kaur*

**Introduction:**

The increasing levels of air pollution are increasingly being investigated for their role in a number of chronic conditions. The Air Quality Index (AQI) in many prominent cities has been noted to be one of the worst in the world.[1] Not just air, micro plastics in food and water cause inflammation at tissue level and are now bellied to be an important cause of cardiovascular morbidity.[2] It is estimated that 9 million deaths per year i.e. one in six deaths is related to pollution; thus it is a huge determinant of human health.[3] Skin, due to its sheer surface area and site is one of the organs which may be most affected by environmental pollutants as well as physical agents.

**Environmental Pollutants:**

a. **Particulate Matter (PM):** Fine particles suspended in the air, including dust, dirt, soot and smoke, can penetrate the skin's surface, leading to inflammation and oxidative stress. Particulate matter 2.5 ($PM_{2.5}$), Ultra-fine PM <0.1 are increasingly seen due to air pollution or even in cigarette smoking lead to inflammation and premature ageing, like pigment spots as well as wrinkles.
b. **Ground Level Ozone ($O_3$):** Ground-level ozone, formed by the reaction of sunlight with pollutants like nitrogen oxides and volatile organic compounds, can cause skin irritation, inflammation and premature ageing.
c. **Nitrogen Oxides (NOx) and Sulfur Dioxide ($SO_2$):** These pollutants can react with sunlight to produce reactive oxygen species (ROS), leading to oxidative damage and skin aging.
d. **Aryl Hydrocarbons:** The aryl hydrocarbon receptor (AhR) is expressed in all epidermal and dermal cells and is essential for skin integrity and skin immunity. These chemicals, released from vehicle exhaust and industrial emissions, can adhere to the skin and cause DNA damage, inflammation and pigmentation changes.
e. **UV Radiation:** Increasing exposure causes premature ageing, pigmentary alterations as well carcinogenesis. This is due to the deleterious effects of the ozone depletion leading to increasing UV radiation reaching the earth's surface.
f. **Micro-plastics:** These have already demonstrated a negative impact on skin health, with previous research demonstrating their ability to cause skin irritation, inflammation and disruption of natural skin functions. [4]

**Mechanism of Injury from Pollution:**

a. **Route of Entry:** The pollutants gain entrance into the skin by direct exposure/absorption via hair follicles/inhalation/ingestion and subsequent circulation via plasma to dermal tissue. The

transepidermal route can be divided into the shorter, transcellular (hydrophilic compounds) as well as longer intercellular routes (lipophilic compounds). Absorption through hair follicles and /or sweat ducts is the shortest route.

b. **Oxidative Stress:** Air pollutants enter the skin via nanoparticles and generate quinones that produce reactive oxygen species (ROS). This increase in the amount of ROS and free radicals within the cell and its mitochondria overcomes the skin's innate antioxidant defenses, including depletion of enzymatic (glutathione peroxidase, glutathione reductase, superoxide dismutase and catalase) and nonenzymatic (vitamin E, vitamin C and glutathione) antioxidant capacities. ROS also stimulate the release of proinflammatory mediators, which results in the accumulation of neutrophils and other phagocytic cells that further generate free radicals, thereby resulting in a vicious cycle of inflammation and metabolic impairments.[5]

**Symptoms/Signs of Pollution-related Skin Damage:**

a. **Premature Aging:** Exposure to pollutants can accelerate the aging process by promoting the breakdown of collagen and elastin fibers, leading to wrinkles, fine lines and sagging skin.
b. **Irritation:** Air pollutants can disrupt the skin barrier function, causing dryness, redness, itching and irritation.
c. **Inflammation:** Pollutants trigger inflammation in the skin, contributing to conditions such as eczema, psoriasis and acne.
d. **Pigmentary Changes:** Exposure to certain pollutants, such as PAHs, can cause age spots or hyperpigmentation (Melasma) or uneven skin tone.
e. **Impaired Wound Healing:** Particulate matter may affect angiogenesis due to inflammation and prevent normal healing in healthy as well as persons with diabetes.[6]

**Effect on Pre-existing Dermatoses:**

a. **Atopic Eczema:** Apart from westernised diet and decreasing infection rates in developing countries, the epidemic of atopic diseases, may be attributed to the rising levels of pollution which lead to epidermal barrier dysfunction. There is increasing evidence that areas with high $PM_{2.5}$ (among other pollutants) lead to increasing severity/flare of atopic eczema.[7]
b. **Acne:** Acne is known to be affected by pollution, areas with high pollution have reported to have more women with inflammatory acne versus comedonal acne.[8]
c. **Melasma:** Pigmentary alterations are a known consequence of UV exposure (enhanced by pollutants depleting the protective ozone layer) as well as the direct effects of PM leading to increasing ROS triggering metalloproteinases to cause pigment changes.[9]
d. **Psoriasis:** Increasing levels of pollution may lead to psoriasis exacerbations. In a recent study, exposures to particulate matter (PM) smaller than 2.5 μm ($PM_{2.5}$), PM smaller than 10 μm ($PM_{10}$), $NO_2$ and $SO_2$ were found to be significantly associated with increased daily psoriasis outpatient visits.[10]
e. **Skin Cancer:** Chronic exposure of the skin to PAHs and/or UVR may activate the AhR transcription factor and promote downstream epidermal targets, contributing to skin cancerogenesis.[11]

**Protective Measures:**

a. **Cleansing:** Regular cleansing of the skin helps remove pollutants and impurities accumulated throughout the day. Use gentle cleansers suitable for your skin type.

b. **Moisturising:** Proper hydration helps maintain the skin barrier function and reduces the risk of irritation. Use moisturisers containing antioxidants to combat oxidative stress.
c. **Sun Protection:** Sunscreen is essential to protect the skin from UV radiation, which can interact with air pollutants to cause more significant damage. Choose broad-spectrum sunscreens with SPF 30 or higher.
d. **Antioxidant Skincare:** Incorporating antioxidant-rich skincare products, such as vitamin C serums or niacinamide creams, can help neutralize free radicals generated by air pollution.
e. **Barrier Protection:** Consider using physical barriers like hats, scarves and clothing to shield the skin from direct contact with pollutants, especially in highly polluted environments.

**Environmental Awareness:**

a. **Public Health Initiatives:** Governments and health organisations play a crucial role in implementing policies to reduce air pollution levels and mitigate its impact on public health.
b. **Sustainable Practices:** Encouraging eco-friendly transportation, renewable energy sources and reduced industrial emissions can help improve air quality and protect the skin and overall health.
c. **Education and Awareness:** Educating the public about the link between air pollution and skin health promotes proactive measures to minimise exposure and protect against its adverse effects.

**Conclusion:**

Air pollution poses a significant threat to skin health, leading to various dermatological concerns ranging from premature aging to skin irritation and inflammation. Adopting protective measures and advocating for environmental sustainability are essential steps in safeguarding skin health amidst increasing pollution levels.

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Chapter - 28

# Pollution and ENT Disorders: Is there any Relationship?

*Vaibhav Saini*

**Introduction:**

Advancements in technology and urbanization have proved detrimental to global health. Pollution and its impact on humans has emerged as an essential aspect debated on international forums. The pollutants in the environment have devastatingly severe consequences on the survival of humanity. The association of ENT diseases with pollution has been vastly studied in recent years. Emergence of new onset diseases in young population supports cumulative impact of pollutants on health. ENT comprises three vital aspects in human body that come in direct contact with the environment: Ear, Nose and Throat (ENT) and are responsible for hearing, respiration and swallowing respectively. All three systems are responsible for vital functioning of the human body. The relation among the three is accountable for adequate respiration and sensory experience. Ears are responsible for hearing sensation, nose is involved in respiration and humidification of air, throat helps in respiration and swallowing. Pharynx is the common pathway for both air and food. The ENT system is the first combat organ system for the outer environment. Therefore, pollution plays an essential role in ENT health.

**Air Pollution and Impact on Ear:**

**Inflammation and Infections:** Eustachian tubeis the link connecting middle ear to nasopharynx. Hence, upper respiratory tract infections can further lead to back pressure changes causing otitis media with effusion and middle ear infections. Chronic exposure to pollutants can cause recurrent upper respiratory tract infections and increase economic burden. Ear is divided into three parts: external ear, middle ear and inner ear. The mechanism of hearing occurs when sound waves travels from external ear to inner ear where it transforms to electrical impulses and is perceived by the auditory cortex in brain. Pathology at any level leads to impairment in hearing. Recurrent episodes of upper respiratory tract infections can cause otitis media, middle ear effusion, tympanic perforation and atelectasis. The susceptibility to bacterial and viral infection increases with prolonged middle ear infections.

**Impairment of Hearing:** Decreased perception of sound with ageing has been related with neuronal loss. Impaired hearing is a social concern and may be held responsible for low mood and even depression. Prolonged contact with pollutants can lead to repeated attacks of upper respiratory tract infections. Chronic otitis media can cause inflammation leading to release of toxins and this can cause sensorineural hearing loss by reducing signal transmission from inner ear. Fluid behind intact tympanic membrane in middle ear infection causes conductive hearing loss as fluid is a bad transmitter of sound waves. Recurrent

middle ear infections may lead to retraction of tympanic membrane further leading to tympanic membrane perforation. Discharging ear and impaired hearing can deteriorate quality of life and pose financial burden because of hospital visits.

**Air Pollution and Impact on Nose:**

**Rhinitis and Rhinosinusitis:** Air contamination in the form of automobile exhaust, industrial combustion has emerged manifold in the past few years. Tiny particulate matter is responsible for increased incidence of nasal congestion, rhinitis, rhinosinusitis and lower respiratory tract infections. The pollutants irritate the mucosa of nasal cavities and particles in direct contact are being held responsible for inflammation of nasal passages. Individuals predisposed to atopy and allergies are prone to develop congestion in contact with pollutants. Rhinorrhoea, nasal obstruction, post nasal drip, headache are the symptoms faced in chronic rhinitis. Regions with high pollution indices have increased incidence of rhinitis and rhinosinusitis. Recurrent episodes of rhinitis can lead to alteration in nasal mucosa, reduced sense of smell, altered sleep cycle and reduced quality of life. Upper respiratory tract is first to encounter allergens and pollutants and therefore subjected to after effects. This predisposes to increased risk of bacterial and fungal infections of nose and paranasal sinuses. Chronic rhinitis can cause alteration in nasal mucosa leading to polyp formation. Nasal polyp can block the nasal airways and natural ostia of paranasal sinuses. Individuals are subjected to surgical management as well as prolonged medical treatment. The severe implications of increased morbidity due to pollutants and allergens have a synergistic effect.

**Air Pollution and Impact on Throat:**

**Throat Congestion and Voice Change:** Various volatile organic and inorganic compounds after combustion are being released in the air and cause irritation of lining of throat. Recurrent pharyngitis and chronic cough are the resultant effects of throat irritation. Throat pain, dry cough, repeated throat clearing, foreign body sensation are the symptoms faced by affected individuals. Supraglottic larynx is predisposed to allergens and pollutants and direct contact leads to oxidative stress and release of free radicals. Inflammation of upper airway can cause voice disorders. Vocal cord inflammation can lead to edema and resultant change in quality of voice. Air pollution has detrimental effects on ENT health and pose a significant burden on quality of life. Serious measures need to be taken in order to combat air pollution and reduce morbidity related with air pollution. Long term consequences are to be sought and preventive measures to reduce air pollution. Study on air pollution has documented increased incidence of chronic rhinosinusitis and septal deviation. More studies addressing the measures to prevent air pollution are required to improve the quality life.

**Noise Pollution and Impact on ENT Health:** Human ear can perceive sound in the frequency range of 4-20 KHz. Loud noise has been related with sensorineural hearing loss. Affected individuals present with impairment in hearing and tinnitus. New onset sensorineural hearing loss affected young population that was predisposed to loud sounds in their workplaces. Noise induced health effects have been studied and over the years, government guidelines have come into action to prevent noise pollution. Under third schedule, Sections 89 and 90 of Factories

Act, noise induced hearing loss is defined as a notifiable disease and limits for noise exposure in work zone have been described. Stricter norms in public forum as well as in industries are required to protect exposed population.

**Water Pollution and Impact on Health:**

Industrial waste being dumped into water bodies poses a threat to human health. Presence of chemicals and radioactive material in water can cause serious threat to human health. Increased predisposition to carcinomas and congenital anomalies has been well seen. The effect can be seen up to several generations and is a matter of grave concern. Drives to clean water bodies have come into action in the past few years. Modification in industrial waste disposal requires stringent action and plans to reduce the waste.

**Soil Pollution and Impact on Health:**

Pollutants in soil have access to food chain and resultant cumulative effect of contaminants has been seen globally. Radioactive disasters like Chernobyl and Hiroshima–Nagasaki have radioactivity even after years of the incident. It takes several years for the effect of radioactive material to wean off. Use of chemicals and fertilisers in farming have detrimental consequences on human health. Reformed farming practices and effective waste disposal is the need of the hour.

**Prevention of Health Hazards by Pollutants:**

Role of pollution on ENT health can cause a severe havoc if not taken seriously. Preventive measures to reduce air, soil and noise pollution can significantly reduce morbidity. Several studies have found a relationship between air pollution and allergic rhinitis. Benign laryngeal lesions such as vocal cord nodules, polyps, cysts, sulcus vocalis and leukoplakia have been associated with smoking. Healthy lifestyle practices and abstinence from smoking are beneficial and can improve the quality of health. Pollutants can exacerbate ENT conditions like rhinosinusitis, laryngitis and pharyngitis. Prospective studies are needed to combat global trend of effects of pollution on health. Government guidelines and strict penalisation in case of not abiding with norms are the need of the hour to prevent pollution and its ill effects on health. Increased incidence of lifestyle diseases and pollution pose a severe threat to health and the quality of life has also deteriorated. Sharing knowledge and improving civic sense of the population, starting from young age and increasing awareness among the masses to follow fundamental duties is needed for a positive change.

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Chapter - 29

# Pollution and Ophthalmic Diseases: Is there any Relationship?

*Munish Dhawan, Gaurav Mahajan*

**Introduction:**

Air pollution refers to the alteration in the natural characteristics of the indoor and the outdoor air by a complex mixture of gas-phase pollutants and particles known as particulate matter (PM) either due to natural or human activities. The 2018 Environmental Performance Index has recognized air pollution as the most significant environmental threat to human health. Around 91% of the world's total population resides in regions exceeding recommended exposure levels as reported by the World Health Organization (WHO).[1] Table 1 shows the WHO 2021 air pollution guidelines in comparison with guidelines in 2005.[2]

**Table 1: WHO 2021 Air Pollution Guidelines in comparison with 2005 Guidelines.**[2]

| Pollutant (s) | Averaging Time | WHO 2021 | WHO 2005 | Change |
|---|---|---|---|---|
| $PM_{2.5}$ ($\mu g/m^3$) | Annual | 5 | 10 | −50% |
| | 24-h | 15 | 25 | −40% |
| $PM_{10}$ ($\mu g/m^3$) | Annual | 15 | 20 | −25% |
| | 24-h | 45 | 50 | −10% |
| $O_3$ ($\mu g/m^3$) | Peak season | 60 | N/A | Newly introduced |
| | 8-h | 100 | 100 | Unchanged |
| $NO_2$ ($\mu g/m^3$) | Annual | 10 | 40 | −75% |
| | 24-h | 25 | N/A | Newly introduced |
| | 1-h | 200 | 200 | Unchanged |
| $SO_2$ ($\mu g/m^3$) | 24-h | 40 | 20 | +100% |
| | 10-min | 500 | 500 | Unchanged |
| CO ($mg/m^3$) | 24-h | 4 | N/A | Newly introduced |
| | 8-h | 10 | N/A | Newly introduced |
| | 1-h | 35 | N/A | Newly introduced |
| | 15-min | 100 | N/A | Newly introduced |

Toxic gases released by burning the fossil fuels in motor vehicles or in the industrial sector include sulphur dioxide ($SO_2$), carbon monoxide (CO), nitrogen dioxide ($NO_2$), carbon dioxide ($CO_2$), nitrogen monoxide (NO), nitrogen oxides (NOx), ozone ($O_3$) volatile organic compounds, particulate matter 2.5 ($PM_{2.5}$) and particulate matter 10 ($PM_{10}$). These components contribute to the ever-increasing menace of outdoor air pollution. Tobacco smoking, cooking activities that produce CO, NOx and volatile organic compounds make-up for most of the indoor air pollution.[3]

**Air Pollution and its Association with Eye:**

The detrimental effects of air pollution on the health of an individual could be attributed to its effect on the various body systems which include the respiratory system, cardiovascular system, central nervous system and even the ocular surface leading to life threatening complications and even death.[4-7] It has been reported that the persons travelling to highly polluted areas with PM level five times higher than the WHO annual average limit of 60 µg/$m^3$ seemingly suffer from extensive subclinical ocular surface changes.[7] Majority of the studies done have studied the role of air pollution on the respiratory and the cardiovascular systems but have routinely overlooked the deleterious effects of air pollution on the ocular surface. The cornea, conjunctiva and the tear film constitute the part of ocular surface which acts as a protective barrier against a multitude of outside environmental insults. A healthy and adequate tear film allows the individuals to remain asymptomatic. However, the capability of the eyes' ocular surface to provide adequate lubrication and protection is hampered due to air pollutants such as CO, NOx, PM and $O_3$ and toxic weather conditions that result in the hyperactivity of corneal nerves, leading to dry eye symptoms including sensations of dryness, itching, tenderness and burning.[8,9]

It has been reported that the persons travelling to highly polluted areas with PM level five times higher than the WHO annual average limit of 60 µg/$m^3$ seemingly suffer from extensive subclinical ocular surface changes.[7] Most common symptoms at presentation include; irritation and inflammation along with allergic conjunctivitis due to the adverse effects of air pollutants such as CO, NOx, PM and $O_3$.[9] PM is further categorized into organic and inorganic matter based on its composition. Particles from microbes, plant and animals described as airborne bioaerosols suspended in the air make up the organic PM. All other airborne particles including dust (silica), calcium and heavy metal particles for example lead constitute the inorganic PM. The role of indoor air pollution as a significant contributor could not be more emphasised considering the fact that an average individual spends around 80% of his time indoors. The indoor and the outdoor air pollution should not be viewed as separate entities rather they are interlinked as there occurs a continuous exchange of gases, aerosols through windows, doors and other openings.[8] The association of $PM_{2.5}$ with allergic conjunctivitis and glaucoma and the exposure to tobacco smoke leading to the formation of cataracts and age-related macular degeneration has been well documented.[10-15]

**Air Pollution and Ocular Surface Disorders:**

The death toll of 3.7 million worldwide in 2012 and 4.2 million in 2016 has been associated with outdoor air pollution making it a major environmental health hazard.[16, 17] An increase in the outdoor air pollution from 1990 to 2015 is considered responsible for deaths in low- and middle-income countries.[18] The major source of outdoor air pollution in developed urban areas is automobile traffic,

the components of which are complicated and dynamic and include $O_3$, $NO_2$, $SO_2$, lead (Pb), CO and PM. Human activity and unpredictable climatic events have a considerable effect on the concentration of these components.[19]

Indoor smoking leads to an increase in the level of $PM_{2.5}$ that is 10 times higher than that in non-smoking homes. The changes on the ocular surface on contact with tobacco smoke includes alteration of the lipid layer of the tear film which further causes reduced tear secretion and decreased corneal and conjunctival sensitivity and as a result leads to atopic kerato-conjunctivitis and allergic conjunctivitis (Figure 1).

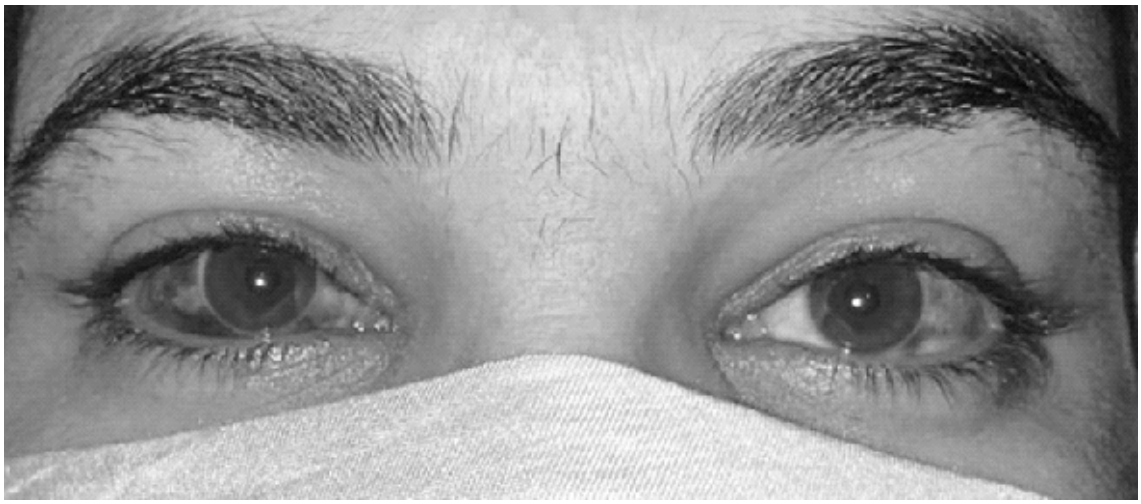

**Figure: 1 Allergic Conjunctivitis.**

Electronic cigarettes and vape flavouring too contribute to the instability of the tear film as they release aldehydes and free radicals that result in the damage to the lipid layer through peroxidation. Inflammatory response to the nicotine and acrolein compounds incigarette vapours, in the corneal epithelium result in dry eye syndrome.[2]

It has been observed that people who used two/three wheelers are more prone to the deleterious effects of outside air pollution and often complain of ocular surface symptoms which includes redness, irritation, lacrimation, burning and dryness.[7] The resulting discomfort affects the daily work efficiency of the people. The higher levels of NO and $NO_2$ concentrations which are released by the diesel vehicles leads to severe conjunctivitis.[20] Conjunctival diseases can manifest as subclinical ocular surface changes that most commonly cause major discomfort and may require a clinical visit.[2] Discomfort eye syndrome (DES) has been coined to describe 'minor' subjective symptoms which include heaviness of the lids, foreign body sensation, burning, stinging and photophobia and in whom the clinical observation does not show significant signs suggesting ocular disease. Goblet-cell hyperplasia occurring in response to the cellular transformation in the human conjunctival epithelium has been reported to occur because of constant exposure to air pollution.[21]

The increase in the incidence of dry eye is another major impact area of outdoor air pollution. Hyperosmolarity and tear film instability are the two mechanisms that result in tear dysfunction,

often present in conjunction with each other. The expression of inflammatory mediators in the tear film induced by a series of inflammatory events in the ocular epithelium leads to changes in the ocular surface that may lead to tear hyperosmolarity. Thus, the damage to the epithelium causes cell death via apoptosis, loss of goblet cells and decreased mucin production and hence causing tear film instability. Therefore, the hyperosmolarity of the tear film is altered starting a vicious cycle.[2]

**Air Pollution and Glaucoma:**

$PM_{2.5}$, of all the component of air pollutants, is one of the strongest and most consistent predictors of mortality. It has been reported to be positively associated with the rise in the intraocular pressure.[12] $PM_{2.5}$ has been shown to be toxic to intraocular tissues and contributes to the development of ocular hypertension and glaucoma (Figure 2).

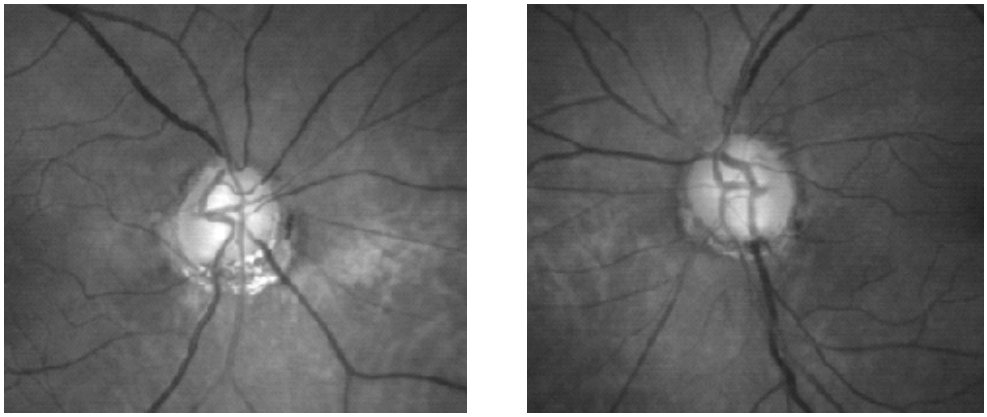

**Figure 2: Glaucomatous optic Neuropathy.**

It has been hypothesised that $PM_{2.5}$ and $PM_{10}$ induce the production of NO and interleukin 8, causing increased oxidative stress which further leads to NLRP3 inflammation mediated pyroptosis, a form of non-apoptotic cell death in trabecular meshwork cells.[22, 23] The increased apoptosis in neural retina cells may result in the abnormal development of the neural retina which has been known to occur due to the exposure to $PM_{2.5}$.[24] The diagnosis of primary open angle glaucoma (POAG) and a thinner macular ganglion cell–inner plexiform layer (GCIPL), measured by spectraldomainoptical coherence tomography (SD-OCT) has been observed to occur more in people with higher exposure to $PM_{2.5}$ than their counterparts.[13, 25] Furthermore, the exposure to $PM_{10}$ has also been linked to the occurrence of childhood glaucoma.[2]

**Air Pollution and Cataract:**

The association of cataract with cigarette smoking is well known. The effects of the inhaled toxic substances either directly or indirectly have been reported to lead to the changes in the lens fibres and hence formation of cataract. Although the exact compounds in cigarettes responsible for lens toxicity are still unknown, naphthalene, one of the compounds, is known to be cataractogenic.[26, 27] It along with lead which is present in biomass fuel smoke lead to the development of cataract.[28] Another strong risk factor for age-related nuclear cataracts is smoking.[29] Oxidative stress induced by smoking consumes plasma ascorbate, carotenoids and glutathione, which offer antioxidant

protection against cataract formation.[2]

**Air Pollution and Uveitis:**

Uveitis is inflammation of the iris, ciliary body and the choroid. The Pacific Ocular Inflammation Study revealed that cigarette smoking was significantly associated with new-onset uveitis.[30] Cigarette smoke upregulates the expression of TLR4 by human macrophages, promoting NF-κB activation and the production of interleukin(IL)-8 in response to the chronic exposure to reactive oxygen species. Nicotine also plays a similar role by generating peroxynitrite, a nitrate isomer that binds acetylcholine receptors to promote NF-κB-mediated cytokine IL-8 transcription.[31-33] The migration and activation of macrophages have been reported to occur in response to the increased concentrations of IL-8, along with IL-6 and TNF-α and hence lead to uveitis.[34-36]

**Air Pollution and Retinopathy and Maculopathy:**

The exposure to visible light, high consumption of oxygen and high proportion of polyunsaturated fatty acids makes the retina more susceptible to the damage by oxidative stress.[37] It has been hypothesised that epithelial–mesenchymal transition and activation of cellular reactive oxygen species may be responsible for $PM_{2.5}$ induced dysfunction in retinal cells and hence, make the aging retina potentially more susceptible to the damage caused by air pollution.[38, 39]

The risk of developing myopic macular diseases increases in response to the exposure to $PM_{2.5}$ and NOx due to ocular surface inflammation and retinal inflammation. The exposure to higher $PM_{2.5}$ and $PM_{10}$ concentrations results in the increased thinning of the inner and the outer retinal layers.[40] Chronic exposure to a higher concentration of ambient $NO_2$ or CO significantly increases the risk of Age Related Macular Degeneration (ARMD) as well as diabetic retinopathy.[15, 40, 41]

The development of ARMD has a positive correlation with tobacco smoking which is attributed to the smoke-induced proteostasis and autophagy impairment. The polypoidal choroidal vasculopathy and inflamed cystoid macular edema in adults caused by tobacco smoke are the major contributing factors towards the occurrence of ARMD. The inhalation of tobacco smoke has also been reported to decrease the retinal and choroidal thickness. Maternal smoking is a stand-alone risk factor for stage 3 and 4 retinopathy of prematurity.[42]

**Air Pollution Mitigation Strategies:**

To combat the harmful effects of air pollutants on the eye, the following can be adopted into our daily routine:

- Usage of protective eye gear which includes use of ultraviolet blocking goggles while going out or commuting in a two/ three-wheeler.
- Limiting the outdoor activities especially during peak pollution hours.
- Adequate ocular hydration to stabilize the tear film using artificial lubricating eye drops.
- Consuming a diet rich in antioxidants to decrease the harmful effects of reactive oxygen species.
- Avoidance of tobacco smoking, electronic cigarettes and vape.
- Usage of latest technology like air purifiers to improve the air quality at home or in the car.
- Regular eye examination to rule out any adverse effects of air pollutants.

The implementation of appropriate screening and protection measures along with introduction of better technologies and standardized methods of tracking air pollutants' levels in the air should be considered, as these can be cost-effective means to prevent and treat ocular diseases, which are significantly associated with air pollution.[43]

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Chapter - 30

# Is there any Gender Bias of Effect of Air Pollution on Health?

*Shibba Takkar Chhabra, Anshuman Gupta*

**Introduction:**

Air pollution is considered one of the main risk factors for public health. Air pollution is caused by a complex mixture of various chemical substances, mainly sulphur dioxide ($SO_2$), nitrogen dioxide ($NO_2$), carbon monoxide (CO), benzopyrenes and particulate matter with a diameter of 2.5 µm or less ($PM_{2.5}$) and 10 µm or less ($PM_{10}$). These are formed directly during the burning process, which is associated with industries or heating devices at homes or car traffic, while others are produced by photochemical reactions occurring in the air under the influence of ultraviolet radiation. Intensification of these processes and the atmospheric conditions influence the mixture of air pollutants and their potential effects on public health and life. Indian households, predominantly in hands of Indian women, still rely on bio-fuels, such as wood, dung and crop residues, for cooking and heating purposes. Burning unprocessed bio-fuels like animal dung, charcoal, coal, crops and wood in traditional and inefficient stoves generates large amounts of air pollutants. Pollutant levels during cooking hours in Indian houses are very high. Pollutants released indoors are far more hazardous than those released outdoors because of the close proximity of people. Also, given their biological differences, women respond variably and adversely visa vis their male counterparts. The present review brings to light this variant effect of air pollution on women aiming for awareness as well as prompt aggressive measures to curb the deadly menace in female sex.

Exposure to relatively high levels of air pollution is associated with myocardial infarction, arrhythmias, endothelial dysfunction, acute respiratory infections, chronic obstructive lung disease such as chronic bronchitis, asthma, adverse pregnancy outcomes, blindness, lung cancer, cognitive decline etc. (Figure 1)

Females are more prone to these hazards of air pollution. Women in the densely-populated region are disproportionately hit by high levels of poor-quality air indoors as they tend to be primarily responsible for cooking and firewood continues to be widely used as a source of cooking fuel. Women are exposed to a high level of indoor pollution because they are the main caretakers in most households. Indian women who are actively coming in contact with cooking fuels get affected by the introduction of pollutants like $PM_{2.5}$ into their bodies.

It is not just indoor air pollution, women also engage in low-paying jobs such as street sweeping, construction and street vending, therefore, face high levels of exposure to air pollutants. In India alone, an estimate finds that 0.61 million deaths were attributable to indoor air pollution, though the

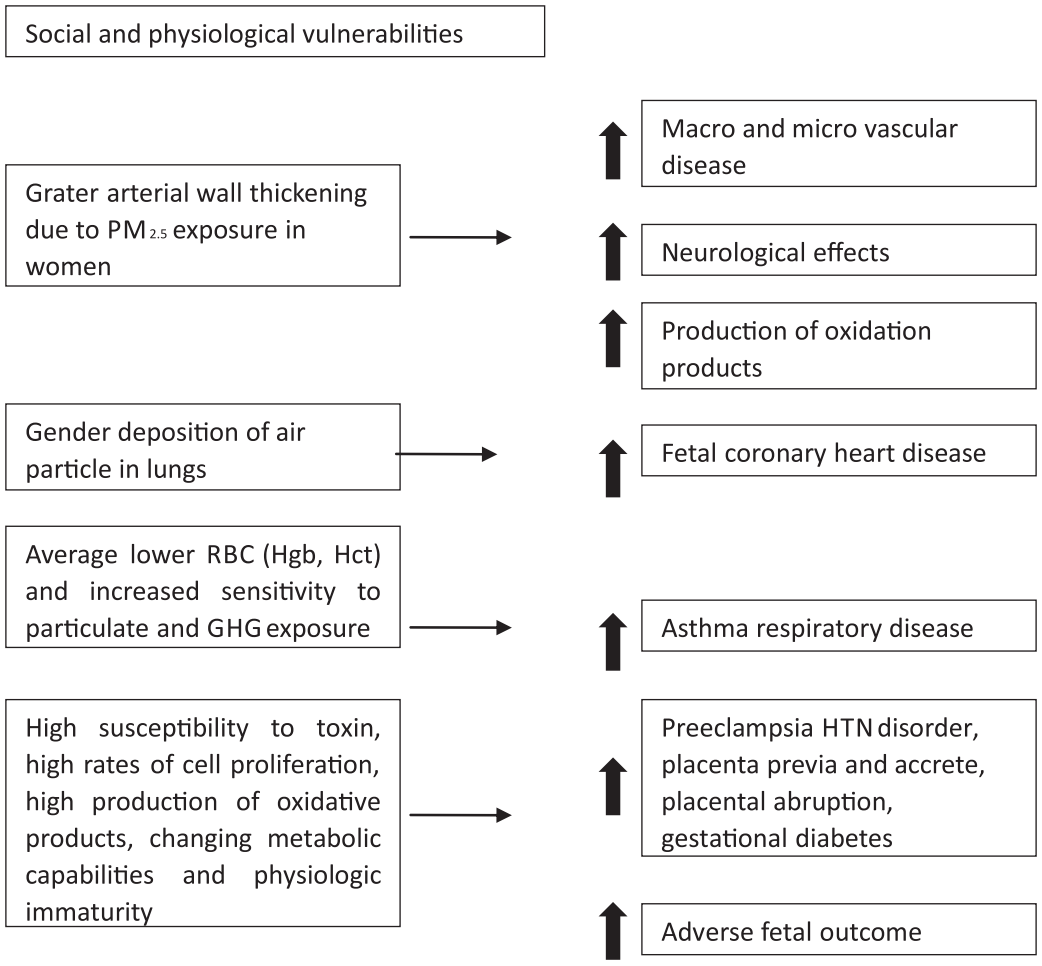


**Figure 1: Systemic Effects of Air Pollution in Women**

data was not segregated by gender. Gender differences may exist and could be due to physiological differences in inflammatory responses to air pollutants as compared to men, different hormonal profile of women or due to different lifestyle and activity patterns in men and women.

Air pollution can affect the endocrine system, causing hormonal disorders in females. These pollutants can occur naturally or artificially and they are termed as Endocrine Disrupting Chemicals (EDCs). These chemicals have a direct impact on the reproductive health of women. (Figure 2)

Exposure to air pollution during pregnancy is associated with complications or adverse events during pregnancy e.g. pre eclampsia, miscarriage, gestational diabetes, high blood pressure and adverse birth outcomes such as preterm birth, low birth weight or in some cases, still birth. A large amount of scientific research shows that women who are exposed to air pollutants for a longer period are more likely to have premature babies. Some studies have also linked air pollution with low fertility rates or depression among pregnant women.

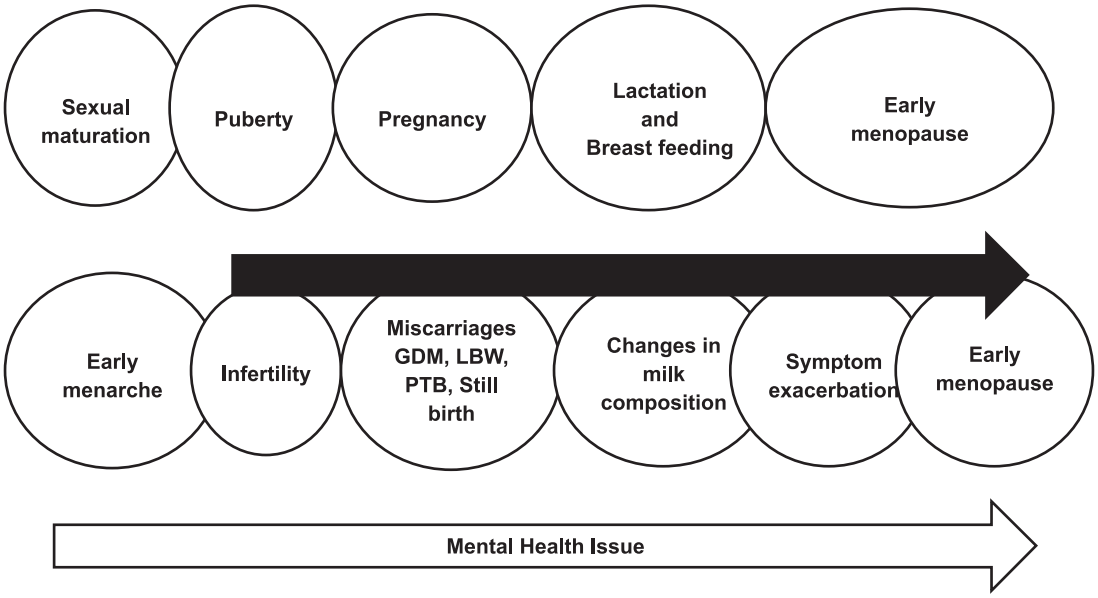


**Figure 2 : Effect of Air Pollution Across Different Stages of Reproductive Cycle in Women.**

Abbreviations: Gestational diabetes mellitus (GDM), Low birth weight (LBW), Preterm birth (PTB)

Chronic exposure to air pollution also increases the risk of dysmenorrhoea which affects the menstrual cycle causing severe period cramps. Menopausal women with increased levels of lead in their bloodstream when combined with exposure to air pollutants can give rise to hypertension, reduced kidney function and decreased cognitive functions. EDCs can have negative effects on reproductive health through anti estrogenic effects.[1] Female sub fertility or infertility can be disrupted by EDCs by causing altered hormone production, menstrual cycle abnormalities, anovulation and early reproductive senescence.[2] The most vulnerable periods of exposure to EDCs are prenatally, by the transplacental transfer of EDCs and postnatally via breast feeding. Disturbance to hormonal activities during these times can lead to health problems including reproductive health and behavioural problems throughout life.[1,3,4,5]

**Air Pollution and Risk of Diabetes in Women:**

The results of meta-analyses substantiate the possibility of long-term exposure to particulate matter ≤ 2.5µm ($PM_{2.5}$), particulate matter ≤ 10µm ($PM_{10}$) and nitrogen dioxide ($NO_2$) is significantly related to the incidence of diabetes mellitus (DM).[6,7] The relationships between DM and air pollution show that this association may differ by gender. In some of the study, exposure to $NO_2$, a marker of traffic-related air pollutants, was associated with DM prevalence among women but not in men.[8,9] The gender dependent effect of particulate matter exposure on insulin resistance also leads to an increased risk of DM in women.

**Effect of Air Pollution on Mental Health and Cognitive Function in Women:**

Bad air quality can also impact on the mental health of women in the long run. The air pollutants have a direct impact on the way our body metabolizes hormones like serotonin which stabilizes our

mood and boosts our mind. An emerging connection can be witnessed between air pollutants and a wide range of mental health disorders like anxiety, depression, dementia and childhood cognitive development especially among women. Duan and co-authors reported that exposure to $PM_{10}$, CO and $NO_2$ during the whole pregnancy and exposure to $SO_2$ during the second trimester were associated with an increased risk of developing postpartum depression at 6 weeks after delivery.[10] Another study found that postpartum depression occurrence 6 months after childbirth was related to $NO_2$ exposure during early pregnancy (first trimester) but not to $PM_{2.5}$ and CO.[11] Other authors reported an association between $NO_2$ exposure during the entire pregnancy and $PM_{2.5}$/$NO_2$ exposure during mid-pregnancy (second trimester) with maternal depression onset 12 months after childbirth.[12] These toxins can contribute to increased systemic inflammation, $NO_2$ exerts strong oxidizing effects, while $PM_{2.5}$ induces DNA damage. Chronic over-inflammation has a negative effect on the Central Nervous System (CNS) for the passing of different cytokines through the blood brain barrier and the consequent dysregulation of neurotransmission. The excessive inflammation in the CNS induces the activation of the indoleamine 2, 3-dioxygenase that accelerates the degradation of tryptophan from which serotonin is synthesized.[13] Second, $PM_{2.5}$ is able to pass through the blood brain barrier exerting a direct toxic effect in the CNS. Women also had a higher risk for decreased cognitive[14] function associated with increased exposure to $PM_{10}$ and $PM_{2.5}$.

**Air Pollution and Cardiovascular Diseases in Women:**

Air pollution is also tied to cardiovascular risks in women. Exposure to relatively high levels of air pollution is associated with myocardial infarction, arrhythmias, endothelial dysfunction. The women who had greater exposure to fine-particle air pollution were at increased risk for both fatal and nonfatal cardiovascular conditions, including heart attack, stroke and coronary bypass surgery. No other pollutants appeared to be associated with cardiovascular risk. "Fine particles" are those up to 2.5 microns in size, or about 1/30th the width of a human hair. These fine particles generally come from power plants, industry and automobile exhaust. The researchers estimated that each increase in fine-particle concentration of 10-micrograms per cubic meter of air increased the risk of a cardiovascular event by 24% and increased the risk of death from cardiovascular disease by 76%. Long-term exposure to fine particulate air pollution is associated with the incidence of cardiovascular disease and death among postmenopausal women.[15]

Moreover, exposure to air pollution during pregnancy is associated with complications or adverse events during pregnancy e.g. preeclampsia, miscarriage, gestational diabetes, high blood pressure and adverse birth outcomes such as preterm birth, low birth weight or in some cases still birth. All these complications have a bearing on cardiovascular risk profile of women and predispose a woman to adverse cardiovascular events.

**Air Pollution and Respiratory Diseases in Women:**

Although the respiratory tract has multiple protective mechanisms, such as mucosal cilia and air-blood barrier, air pollutants are able to accumulate in or pass through lung tissues dependent on the size and chemical nature of pollutants.[16] The vapour of air pollutants is prone to be absorbed by human tissues or dissolved in body fluids, mainly relying on their hydrophilicity and hydrophobicity. $PM_{10}$ particles with larger size (≥10 μm) are able to reach the proximal airways and be mostly

eliminated by mucociliary clearance. $PM_{2.5}$, as a notable risk factor for health, can invade more deeply into the lungs. The ultrafine particles are capable of translocation through blood circulation to distal organs and tissues, such as liver tissue for detoxification and placental tissues during pregnancy. Air pollutants have been shown to cause multiple respiratory diseases, including respiratory infections, asthma, chronic obstructive pulmonary disease (COPD), interstitial lung diseases (ILD), lung cancer etc.

As already discussed women are exposed to a high level of indoor as well as outdoor pollution therefore are at high risk for developing respiratory diseases and also have recurrent exacerbations of asthma, COPD and ILDs. In one study, author estimated the relative increase in the frequency of hospital admissions coinciding with increases in air pollution levels. The hospital admission was more in case of females 56.5% as compared to males 43.5% with respiratory complaints.[17]

**Air Pollution and Malignancy in Females:**

Harmful pollutants like Nitrogen Oxides ($NO_2$ and NO), sulphur dioxide and fine particulate matters ($PM_{10}$ and $PM_{2.5}$) have been linked to the rise in lung cancer, breast cancer and ovarian cancer cases. The researchers saw that the largest increases in breast cancer incidence was among women who on average had higher particulate matter levels $PM_{2.5}$ near their home compared to those who lived in areas with lower levels of $PM_{2.5}$. Particulate matter is a mixture of solid particles and liquid droplets found in the air. It comes from numerous sources, such as motor vehicle exhaust, combustion processes (e.g., oil, coal), wood smoke/vegetation burning and industrial emissions. Researchers also observed an 8% increase in breast cancer incidence in women living in areas with higher $PM_{2.5}$ exposure. They also found that $PM_{2.5}$ was associated with a higher incidence of ER+ breast cancer, but not ER- tumours.[18] This suggests that $PM_{2.5}$ may affect breast cancer through an underlying biologic pathway of endocrine disruption. Sulphur dioxide exposure was linked to an increase in ovarian cancer death rates in all women.[19] Prolonged air pollution exposure might affect ovarian tumorigenesis through possible mechanisms of estrogen-like effects and genetic mutations.

**Dermatological Consequences:**

Existing evidence indicates that particulate matters coated with polycyclic aromatic hydrocarbons and volatile organic compounds can easily cross the cutaneous lipid barrier because of their lipophilic properties. Upon entering the skin, air pollutants trigger the production of reactive oxygen species (ROS), which subsequently causes oxidative damage by depleting the enzymatic and non-enzymatic antioxidant capacities of the skin. The interaction of ROS with lipid components of the plasma membrane can further cause skin tissue injury by triggering lipid peroxidation. Excessive ROS production by pollutants can increase the production of pro-inflammatory mediators, which can act in combination with oxidative stress mediators to induce DNA damage, activation of various transcription factors associated with cell proliferation and differentiation and degradation of dermal connective tissues.

Frequent exposure to high levels of air pollutants can lead to premature aging, photo damage, patchy skin, solar lentigo, atopic dermatitis, psoriasis and even skin cancers.

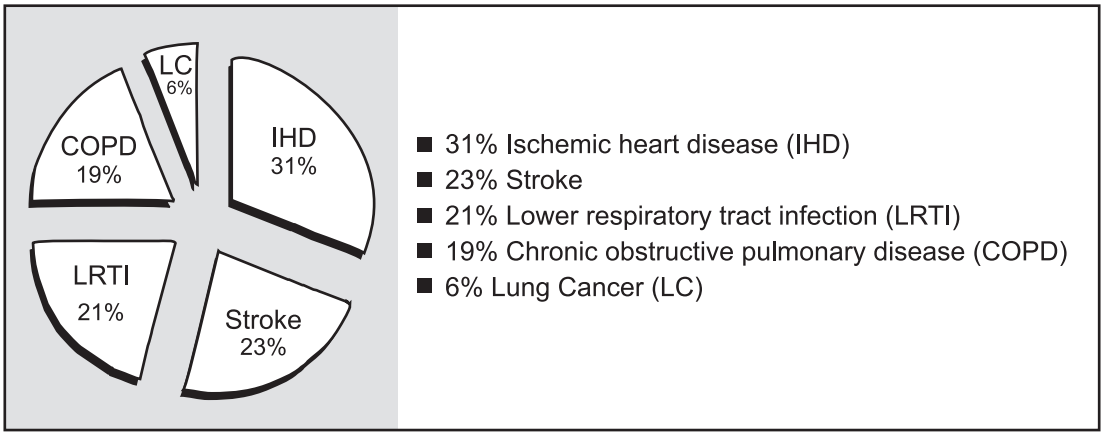


**Figure 3: Household Pollution and its Impact on Women**

Figure 3 shows impact of household air pollution on women that is Ischemic heart disease, stroke, lower respiratory tract infection, chronic obstructive disease, lung cancer in 31.0%, 23.0%, 21.0%, 19.0%, 6.0% of patients respectively. About 2.3 billion people, or one-third of the world's population, cook on open flames or inefficient stoves that run on kerosene, coal and biomass, which includes wood, animal dung and agricultural waste. In homes, this results in hazardous air pollution. In 2020, household air pollution was blamed for an estimated 3.2 million fatalities annually, including approximately 2, 37,000 deaths of children under the age of five. Each year, the combined effects of ambient and residential air pollution are blamed for 6.7 million preventable deaths. Reliability to household air pollution for noncommunicable diseases (NCDs) such as lung cancer, ischemic heart disease, stroke and chronic obstructive pulmonary disease (COPD) is high. Women typically handle home tasks like cooking and gathering firewood because they are the ones doing them. Figure 3 shows the percentage of NCD due to air pollution.

**Conclusion:**

Gender specific differences as regards to effect of air pollution are tremendous and need to be addressed right at grassroots. Women are exposed to household as well as outdoor pollution especially jeopardizing their reproductive, respiratory and cardiovascular profile. Given their potential as endocrine disrupting chemicals they notoriously affect not only reproductive system and increase incidence of diabetes in women, they also have adverse dermatogical and malignant effects. Addressing these gender specific issues by apt education of the recipient and necessary measures by required institutions and public health bodies can prove to be rewarding.

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Chapter - 31

# Public Health and Socio-Economic Perspective of Pollution in India

*Rakesh Kakkar, Ankita Kankaria*

**Introduction:**

As a rapidly developing nation, India faces significant challenges due to escalating pollution levels primarily driven by industrialization, urbanization and vehicular emissions. There is a need to explore the multifaceted consequences of air, water, and soil pollution on human health, including the rise in respiratory illnesses, cardiovascular diseases and other chronic conditions. These morbidities are linked with the socio-economic dimensions, highlighting how pollution exacerbates poverty, increases healthcare costs and hampers economic productivity. Pollution disproportionately affects vulnerable populations, including low-income communities and marginalized groups, which can be explained by integrating epidemiological data and financial analysis. Furthermore, appropriate policy responses and public health interventions are needed to mitigate pollution's adverse effects, emphasizing the prerequisites for sustainable development practices and robust regulatory frameworks. There is a need to accentuate the urgency of addressing pollution as a critical public health issue and a socio-economic challenge, advocating for a holistic approach to environmental governance in India.

Pollution is the presence of undesirable substances released in the air and land that harm human and planetary health.[1,2] Pollution is responsible for 9 million premature deaths annually, contributing to 1 in every six deaths globally. The majority of these deaths (90%) occur in low-middle-income countries.[3] (Table 1) Majority of deaths are caused by air pollution (6.7 million), followed by water pollution (1.4 million) and lead pollution (0.9 million). Most of the cities in India have high pollution levels that are well above the limits recommended by WHO.[4]

Household and water pollution have reduced among all types of pollution, but ambient air and chemical pollution are steadily increasing, resulting from urbanization, industrialization and population growth. As per the GBD 2019 study, men are more likely to die from ambient air pollution, lead pollution and occupational pollution, whereas women and children are likely to die from water pollution.[2] One in every three children has blood lead levels above the recommended level (≥5 µg/dL).[5]

In addition to increasing human morbidity and mortality, pollution adversely affects the global economy loss of USD 4.6 trillion.[6]

**Type of Pollution, their Source and Impact:**

This includes air pollution (ambient air and indoor air), water pollution, soil pollution and noise

**Table 1: Global Estimated Pollution-Attributable Deaths (Millions) by Type of Pollution and Sex, 2019**[2]

| | Female | Male | Total |
|---|---|---|---|
| Total air pollution* | 2-92 (2.53-3.33) | 3-75 (3.31-4.25) | 6-67 (5.90-7.49 |
| Household air+ | 1-13 (0.80-1.50) | 1-18 (0.79-1.66) | 2-31 (1.63-3.12) |
| Ambient particulate$# | 1-70 (1.38-2.01) | 2-44 (2.02-2.83) | 4-14 (3.45-4.8) |
| Ambient ozone$ | 0-16 (9-07-0.25) | 0.21 (0.09-0.33) | 0-37 (0.17-0.56) |
| Total water pollution* | 0-73 (0.40-1-26) | 0.63 (0.46-0.95) | 1-36 (0.96-1.96) |
| Unsafe sanitation+ | 0-40 (0.23-0.68) | 0.36 (0.26-0.54) | 0-76 (0.54-1.09) |
| Unsafe source+ | 0-66 (0.35-1.15) | 0.57 (0.39-0.88) | 1-23 (0.82-1.79) |
| Total occupational pollution* | 0-22 (0.17-0.28) | 0.65 (0.54-0.79) | 0-87 (0.74-1.02) |
| Carcinogens$ | 0-07 (0.05-0.09) | 0.28 (0.22-0.35) | 0-35 (0.28-0.42) |
| Particulates$@ | 0-15 (0.10-0.21) | 0.37 (0.27-0.47) | 0-52 (0.42-0.64) |
| Lead pollution*$ | 0-35 (0.19-0.53) | 0.56 (0.36-0.77) | 0-90 (0.55-1.29) |
| Total modern pollution* | 2-28 (1-86-2-67) | 3-55 (3.08-4.04) | 5-84 (5.03-6.61) |
| Total traditional pollution* | 1-85 (1.39-2.42) | 1-81 (1.36-2.38) | 3-66 (2.82-4.63) |
| Total pollution* | 3-92 (3.39-4.47) | 5-09 (4.57-5.68) | 9-01 (8.12-10.0) |

Data are N in millions (95%CI). * Custom aggregate from Institute for Health Metrics and Evaluation corrected for overlap. The totals for air, water, modern, traditional and all pollution are less than the arithmetic sum of the individual risk factors within each of these categories because their contributions overlap (eg, household air and ambient air pollution each can contribute to the same diseases). +Traditional pollution risk factor. $ Modern pollution risk factors. # Ambient particulate matter is $PM_{2.5}$ @ Occupational exposure to respirable, thoracic or inhalable particulate matter.

pollution. The air pollutants mainly include particulate matter (PM), carbon monoxide (CO), ozone ($O_3$), nitrogen dioxide ($NO_2$) and sulfur dioxide ($SO_2$). Water pollutants include mercury, plastic, phosphorus and petroleum waste. Soil pollutants include lead, arsenic, mercury, pesticides, radioactive waste, electronic waste, industrial chemicals and pesticides. These pollutants cross geographical boundaries through wind, water, food chain and consumer products. Further, these pollutants can be categorized as heavy metals, particulate matter, pesticides, plastic and plastic additives. Pollution is a leading cause of morbidity and mortality and dramatically impacts the environment and the global economy. Air pollution leads to acidification and eutrophication of soil and water and reduces the growth of plants. Soil pollution affects the growth of plants and organisms and affects wildlife. Similarly, pollution of freshwater and marine ecosystems leads to eutrophication.

Pollution leads to economic loss resulting from premature deaths and welfare losses, which varies across regions. As per the 2017 Lancet Commission, welfare loss was equal to 6.2% of the world GDP and mainly contributed by air pollution. As per a World Bank study in 2019, welfare loss due to air pollution ($PM_{2.5}$) amounted to 6.1% of economic output. These losses were severe in South Asia (10.3% of GDP) and East Asia and Pacific (9.3% of GDP) regions. The following tables discuss different pollutants, their source, and their effect on health, environment, and socio-economic perspectives. (Table 2 and Table 3).

**Table 2: Major Environmental Pollutant, their Source and Impact on Health** [7–14]

| Pollutants | | Source | Impacts On Human Health |
|---|---|---|---|
| Heavy Metals | Lead | Paints, Lead-Acid Batteries | Encephalopathy, peripheral neuropathy, anaemia. Damage to the liver, kidney and brain, neurobehavioral changes, abnormalities in fertility and pregnancy |
| | Mercury | Thermal Power Plants, Hospital Waste | Hypertension, myocardial infarction, proteinuria, cardiovascular diseases. |
| | Arsenic | Wood Preservatives, Pesticide | Respiratory cancer, dermatomes, genetic toxicity |
| | Nickel | Smelting Operations, Battery Industries | Cancer, dramatis |
| | Cadmium | Tobacco Smoke, Batteries | Proteinuria, glucosuria, osteomalacia, aminoaciduria, emphysemia |
| Gases | Sulphur dioxide | Fossil Fuels Combustion | Irritated airways and lungs. Prolonged exposure may lead to chronic bronchitis. |
| | Carbon monoxide | Vehicular Emission, Open Fire | Cardiovascular and pulmonary diseases, asphyxiation |
| | Nitrogen oxides | Fuel Combustion | No, gases can exacerbate respiratory illnesses and cardiovascular diseases |
| Particulate matters | $PM_{2.5}$, $PM_{10}$ | Vehicular Emission, Agricultural Waste, Fuel, Wood Burning | Chronic pulmonary disease, bronchitis, asthma, respiratory and cardiovascular illness and mortality |
| Pesticides | Organo-chlorine compounds | Dichlorvos Diphenyl-Trichloroethane, Dichlorvos, Dicofol, Eldrin, Dieldrin | It damages the human liver, kidneys, neural and immune systems. It induces congenital disabilities cancer, causes neurotoxicity, reproductive toxicity, inflammation of upper respiratory tract, bronchitis and blood effects such as aplastic anemia. |
| | Organo-phosphorus Compound | Malathion, Parathion, Diazinon, Fenthion, Dichlorvos, Chlorpyrifos, Ethion. | Reproductive effects, immunotoxicity, cancer and immunosuppression hypertension tachycardia, paralysis. |
| | Carbamates | Sprays | Impair child development and iq, Decrease lung function, Central nervous system tumor |
| | Pyrethrin & Pyrethroids | Sprays, Dust, Pet Shampoos | Paranesthesia, respiratory tract, eyes, skin irritations, cardiovascular diseases |
| Plastics | High-density polyethylene | Plastic Containers, Pipes | Mild dermatitis, respiratory damage, hormone disruption |
| | Low-density polyethylene | Shrink Wraps, Squeeze Bottles | Mild dermatitis, burning sensation in eyes, asthma |
| | Polyvinyl Chloride | Cosmetic, Containers Wrap | Respiratory damage, immune system damage |
| Plastic Additives | Bisphenol A Phthalates | Food Storage Containers, | Endocrine disruptor interference with testosterone, sperm motility, testicular cancer |
| | Dioxins | Personal Care Products, Vinyl Flooring, Polyvinyl Chloride Plastics | Carcinogen interferes with testosterone |
| | Polycyclic aromatic hydrocarbons (PAHs) | Tobacco Smoke, Combustion of Wood, Coal, Oil, Pesticides | Developmental and reproductive toxicity |
| | Poly-chlorinated biphenyls (PCBs) | Tobacco Smoke, Burning Coal, Oil, Gas, Wood, Garbage Contaminated Fish, Meat, Dairy Products | Interferes with thyroid hormone |

## Table 3: Different Types of Pollution, Effect on Public Health and Socio-Economic Perspective.

| Pollution and its Sources: | Effects on Public Health: | Socio-Economic Perspective: |
|---|---|---|
| **Air Pollution**<br>**Industrial Emissions:** Factories and power plants release pollutants like sulphur dioxide ($SO_2$), nitrogen oxides (NO), and particulate matter (PM).<br>**Vehicular Emissions:** Cars, trucks, and buses emit carbon monoxide (CO), hydrocarbons (HC), and nitrogen oxides ($NO_x$).<br>**Burning of Biomass:** Agricultural practices and domestic cooking using wood, crop residue, and dung produce significant smoke and particulate matter.<br>**Construction Activities:** Dust and emissions from construction sites contribute to local air pollution. | **Respiratory Issues:** Increased incidence of asthma, bronchitis, and other chronic respiratory conditions.<br>**Cardiovascular Diseases:** Higher risks of heart attacks and strokes due to long-term exposure to pollutants.<br>**Lung Cancer:** Prolonged inhalation of toxic substances like $PM_{2.5}$ increases lung cancer risk.<br>**Premature Deaths:** Elevated mortality rates due to chronic exposure to polluted air. | **Healthcare Costs:** Rising medical expenses for treating pollution-related illnesses.<br>**Lost Productivity:** Reduced workforce efficiency and increased absenteeism due to health issues.<br>**Economic Inequality:** Poorer communities are often more exposed to pollution and less able to afford healthcare, exacerbating socio-economic disparities |
| **Water Pollution**<br>**Industrial Discharges:** Factories release chemicals, heavy metals, and toxic substances into water bodies.<br>**Sewage and Waste Water:** Untreated or inadequately treated sewage from urban areas contaminates rivers and lakes.<br>**Agricultural Runoff:** Pesticides, fertilizers, and animal waste from farms leach into water supplies.<br>**Plastic Pollution:** Non-biodegradable plastics accumulate in waterways. | **Waterborne Diseases:** Increased prevalence of diseases like cholera, dysentery, and hepatitis.<br>**Chemical Toxicity:** Long-term exposure to contaminated water leads to chronic health issues such as kidney damage and cancer.<br>**Developmental Issues:** Pollutants like lead and mercury can cause developmental problems in children. | **Access to Clean Water:** Inequitable access to safe drinking water affects lower-income communities more severely.<br>**Agricultural Impact:** Polluted water reduces crop yields and quality, affecting farmers' livelihoods.<br>**Economic Burden:** Costs associated with cleaning polluted water and treating health conditions. |
| **Soil Pollution**<br>**Industrial Waste:** Disposal of hazardous waste and chemicals directly onto the land.<br>**Agricultural Chemicals:** Excessive use of pesticides and fertilizers contaminates soil.<br>**Mining Activities:** Release of heavy metals and toxic elements into the soil. | **Food Contamination:** Crops grown in polluted soil absorb harmful chemicals, leading to food borne illnesses.<br>**Health Risks:** Direct contact with contaminated soil can cause skin diseases and other health issues. | **Agricultural Decline:** Reduced soil fertility affects farm productivity and farmer income.<br>**Food Security:** Contaminated soil leads to unsafe food supplies, affecting overall food security.<br>**Land Degradation:** Long-term soil pollution leads to desertification and loss of arable land. |

| Pollution and its Sources: | Effects on Public Health: | Socio-Economic Perspective: |
|---|---|---|
| **Noise Pollution**<br>**Urban Traffic:** Road, rail, and air traffic contribute to high noise levels.<br>**Industrial Activities:** Machinery and industrial processes generate significant noise.<br>**Construction:** Building and infrastructure development produce continuous noise pollution. | **Hearing Loss:** Prolonged exposure to high noise levels can cause permanent hearing damage.<br>**Mental Health:** Increased stress, anxiety, and sleep disturbances due to noise pollution.<br>**Cardiovascular Issues:** Elevated blood pressure and risk of heart disease linked to chronic noise exposure. | **Quality of Life:** Diminished living conditions in noisy environments lead to lower property values and reduced quality of life.<br>**Workplace Productivity:** Noise pollution in industrial settings can reduce worker efficiency and increase accident rates.<br>**Healthcare Costs:** Expenses associated with treating noise-induced health conditions. |

**Social Determinants:** Some of the critical determinants linked with pollution and its adverse impact include low literacy level, low socio-economic status, poor sanitation, overcrowding, poor housing standards, lack of access to quality health care services, lack of affordable eco-friendly alternatives, lack of legislation or inadequate implementation of legislative policies, lack of advocacy.

**Prevention and Control:**

A multi-pronged approach is required to prevent and control pollution and related adverse effects. These include the development and implementation of uniform and evidence-based monitoring and reporting systems for all types of pollution, strengthening of health systems in the management and treatment of pollution-related diseases, implementation of remediation techniques, public awareness generation through mass media among communities, schools, factories, etc., development and enforcement of legislative measures and multisectoral engagement at the global level.

**Global Efforts:** Different international and national agencies are working to control pollution and prevent pollution-related diseases. However, these efforts need to be coordinated and cohesive. In 2017, pollution was prioritized as a global agenda in the United Nations Environment Assembly. An implementation plan, "Towards a Pollution-free Planet," was developed by the United Nations Environment Program.[15] The goal is to have a pollution-free planet for the health and well-being of people and an environment where the right to a clean, healthy, and sustainable environment for all is ensured. (Figure 1) The common approach to pollution is guided by ten principles and approaches, namely: intergenerational equity; participation, access to information and access to justice; polluter pays principle; precautionary principle; leave no one behind; human rights-based approach; prevention; science and evidence-based decision making; circular economy; and the one health approach.[15]

The common approach to pollution is structured to achieve an impact in three areas: people, planet, inclusive and social growth. There are 11 objectives and 30 outcomes.[15]

Similarly, the WHO has developed guidelines for global air quality and medical management of lead exposure and established an association between low air pollution and decreased risk of NCDs and

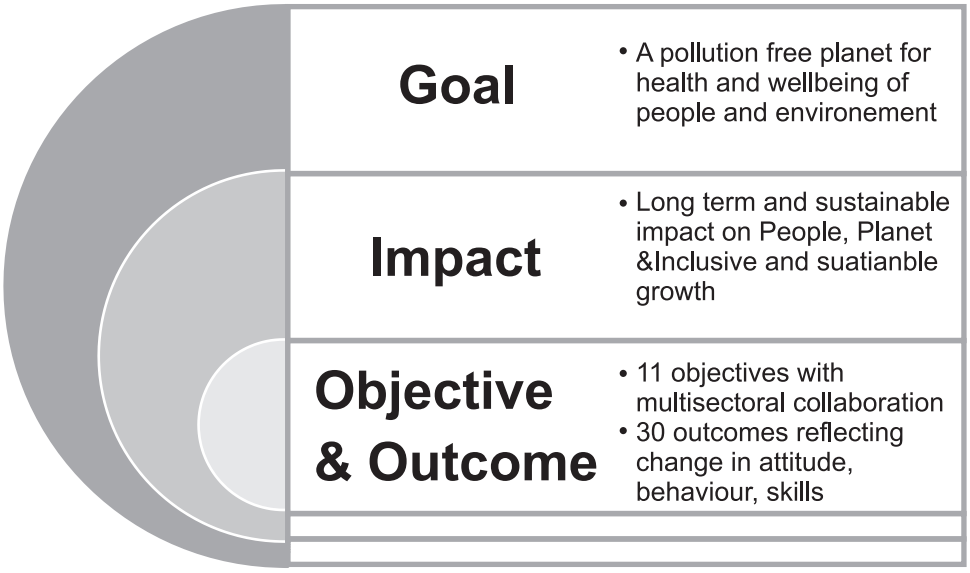


**Figure 1: A Common Approach to Pollution under the United Nations Environment Program.**

climate change.[16,17] In 2022, the UN Environmental Assembly established a science-policy interface for chemicals and waste.[18] One of the solutions is to prepare a Health and Pollution Action Plan (HPAP), especially for LMICs, to identify pollution-related problems and implement solutions. However, the need for more sustainable funding for HPAP would limit its utility.[19]

**Monitoring Mechanism:** WHO has developed air quality guidelines that suggest recommended levels of specific pollutants.

**Initiatives in India:**

**National Programme on Climate Change and Human Health (NPCCHH):**

MOHFW approved the National Programme on Climate Change and Human Health (NPCCHH) under NHM in February 2019, focusing on air pollution, heat-related illnesses and creating green and climate-resilient healthcare facilities with the aims to address the multifaceted challenges of climate change, focusing on its impacts on health and socio-economic conditions. The program's vision is to strengthen healthcare services for all the citizens of India, especially the vulnerable, like children, women and marginalized populations, against climate-sensitive illnesses. The program aims to create awareness of critical stakeholders like the community, health workers and policymakers, strengthen existing health systems' preparedness to assess, identify and reduce linked diseases and develop multisectoral partnerships.[20]

GOI enacted the AIR (Prevention and Control of Pollution) Act in 1981 and the National Air Quality Monitoring Program (NAMP) is executed by the Central Pollution Control Board (CPCB). Eight hundred eighteen operating stations cover 352 cities/towns in 29 states and 6 Union Territories. Parameters monitored in this program are $SO_2$, $NO_2$, SPM, CO, Pb, PAH and $O_3$ ($CO_2$, Benzene and Zn additionally monitored in Delhi). The agencies that monitor air quality include the State Pollution Control Board (SPCB) and Pollution Control Committees (PCCs), the National Environmental

**Table 4: Air Quality Guideline**

| Pollutant | Averaging Time | AQG Level |
|---|---|---|
| PM2.5 (μg/$m^3$) | Annual | 5 |
| PM2.5 (μg/$m^3$) | 24-hour* | 15 |
| PM10 (μg/$m^3$) | Annual | 15 |
| PM10 (μg/$m^3$) | 24-hour* | 45 |
| O3 (μg/$m^3$) | Peak Season# | 60 |
| O3 (μg/$m^3$) | 8-hour | 100 |
| NO2 (μg/$m^3$) | Annual | 10 |
| NO2 (μg/$m^3$) | 24-hour* | 25 |
| SO 2 (μg/$m^3$) | 24-hour* | 40 |
| CO (mg/$m^3$) | 24-hour* | 4 |

μg = microgram * 99th percentile (i.e., 3–4 exceedance days per year). # Average of daily maximum 8-hour mean $O_3$ concentration in the six consecutive months with the highest six-month running- average $O_3$ concentration.

Engineering Research Institute (NEERI), Nagpur and the Central Pollution Control Board (CPCB). The objectives of NMAP are to study ambient air quality trends, understand natural cleaning processes, identify cities with poor air quality and develop measures to prevent and control pollution. (CPCB Annual Report 2021).[21,22] One can check the AQI in National Air Quality: https://airquality.cpcb.gov.in/AQI_India_Iframe/

For water quality, CPCB has developed a Guideline for Water Quality Monitoring (2017), which includes guidance on the type of station, frequency of samples and parameters for analysis of surface and groundwater. This monitoring of aquatic resources is done at 3500 locations in 29 States and 6 Union Territories under the National Water Monitoring Programme. The present monitoring network covers 2541 locations on surface water and 989 on Wells (groundwater).[21]

**Challenges:**

Addressing the global pollution crisis presents numerous challenges. One of the challenges in international efforts to prevent and control pollution is the need for more collaboration across sectors like health, energy, environment, finance, urban development, etc. These sectors work in silos and the pollution crisis is not integrated into development strategies at the national level and not prioritized in the context of funding or investment. Additionally, pollution analysis from OECD figures suggests inadequate funds for addressing pollution-related diseases and deaths. Moreover, pollution control policies should be implemented in high-income and low-income settings most affected by pollution. Another challenge is the need for more data on trends for chemical pollution and its harmful effects on health and the environment. Most low- and middle-income countries do not have population-level blood lead or environmental lead monitoring

mechanisms. Another challenge is the need for more funding to research pollution and its health effects, especially in low- and middle-income countries. There are no dedicated SDG goals and targets for pollution, but they are scattered across different targets and capture less political attention.

To overcome these challenges, it is imperative to foster multisectoral collaboration, enhance funding for pollution control, improve data collection and monitoring, invest in research and advocate for dedicated global targets on pollution. By addressing these obstacles, we can better protect public health and socio-economic well-being from the adverse effects of pollution.

**Case Studies or Scenarios:**

These case studies or scenarios illustrate environmental pollution's profound and interconnected effects on individual health and socio-economic conditions. Addressing these challenges requires coordinated efforts to improve environmental policies, healthcare access and economic support for affected communities.

**Case Scenario 1: Respiratory Illnesses in Mumbai.**

Mumbai, a bustling metropolitan city in India, is grappling with rising levels of air pollution due to its dense traffic, industrial activities and construction projects. The city's air quality frequently exceeds safe limits, posing significant health risks to its inhabitants.

**Public Health Impact:**

Arjun, a 45-year-old taxi driver, has been diagnosed with chronic bronchitis and asthma, conditions exacerbated by prolonged exposure to polluted air while working. He has to frequently visit healthcare facilities for respiratory treatments, including inhalers and medication to manage symptoms. His respiratory issues have led to frequent absenteeism from work, reducing his ability to earn a stable income.

**Socio-Economic Impact:**

**Economic Burden:** Arjun faces high medical expenses, which strain his limited financial resources. The cost of treatment and medication is a significant portion of his income.

**Productivity Loss:** His inability to work consistently affects his earnings, pushing his family towards financial instability.

**Quality of Life:** The continuous health struggles and financial stress impact his overall quality of life, contributing to emotional and mental health challenges.

**Case Scenario 2: Water Contamination in Rural Bihar.**

In a rural village in Bihar, the local water supply has been contaminated due to industrial effluents being discharged into nearby rivers and streams. The community relies on this water for drinking, cooking and irrigation.

**Public Health Impact:**

Rani, a 30-year-old mother and her children suffer from recurring bouts of diarrhea, stomach infections and skin rashes directly linked to the contaminated water. Rani has visited the local clinic multiple times to treat waterborne diseases, which often require antibiotics and rehydration solutions. Chronic health issues have led to malnutrition and weakened immune systems in Rani's family.

**Socio-economic Impact:**

**Healthcare Costs:** Rani spends a significant portion of her household income on medical treatments, leaving little for other essential needs.

**Agricultural Impact:** Contaminated water used for irrigation has reduced crop yields, affecting the family's food security and income.

**Economic Hardship:** The family struggles with ongoing healthcare costs and reduced agricultural productivity, deepening their cycle of poverty.

**Case Scenario 3: Soil Pollution in Tamil Nadu.**

In Tamil Nadu, extensive use of chemical fertilizers and pesticides has led to severe soil pollution. This has affected local farmers who rely on agriculture as their primary source of income.

**Public Health Impact:**

Murugan, a 50-year-old farmer, has developed skin rashes and respiratory issues due to direct contact with polluted soil and inhalation of chemicals. He has to regularly visit a dermatologist and respiratory specialist to treat skin conditions and respiratory symptoms. Persistent health issues limit Murugan's ability to work effectively on his farm, impacting his productivity and well-being.

**Socio-economic Impact:**

**Agricultural Decline:** Soil pollution has decreased the fertility of Murugan's land, leading to lower crop yields and reduced income.

**Financial Strain:** The cost of medical treatments and declining agricultural revenue put significant economic pressure on Murugan's family.

**Rural Exodus:** Facing economic hardship and deteriorating health, Murugan's children consider migrating to urban areas for better opportunities, contributing to rural depopulation.

**Conclusion and Recommendation:**

Pollution significantly contributes to rising morbidity and mortality rates, posing a severe threat to public health and socio-economic stability. Addressing this crisis requires a comprehensive, multidisciplinary and multisectoral approach. Collaborative efforts on a global scale are essential, emphasizing developing standardized protocols and advanced data monitoring tools. These tools are crucial for accurately determining pollutant exposure, assessing health and economic outcomes and formulating effective, evidence-based mitigation strategies.

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Chapter - 32

# Role of Artificial Intelligence in Mitigation Pollution

*Shriram V Kulkarni, Shloka Hegde, Prashant Gaikwad*

**Introduction:**

Environmental pollution, terrorism and many other global threats do not stop at borders. We all bear global responsibility and thus need a global identity to enable us to cope with them. We must learn to integrate different levels of identity in ourselves. What matters is not either/or, but both/and, said Klaus Schwab, a German author, professor, economist, engineer, founder and leader of the World Economic Forum, creator of organizations such as "The Forum of Young Global Leaders and the Global Shapers Community" and author of 'The Fourth Industrial Revolution'.

Pollution is the presence in/or the introduction into the environment of a substance, which has harmful or poisonous effects. According to WHO (World Health Organization), air pollution is a major and pressing public health threat. Estimates show that around 7 million people die every year from exposure to fine particles in polluted air that lead to stroke, heart disease, lung cancer, chronic obstructive pulmonary disease and respiratory infections, including pneumonia.[1] Pollutants include particulate matter, carbon monoxide, ozone, nitrogen dioxide and sulphur dioxide. Both ambient (outdoor) and household (indoor) air pollution are harmful for health.[1]

Air pollution remains one of the most pressing environmental challenges of our time, impacting both human health and the environment. With the advancement of technology, particularly Artificial Intelligence (AI), there's a growing opportunity to leverage these tools in mitigating air pollution. This article explores the causes of air pollution, how AI can detect and address it, the effects on humanity and the potential future implications.

Air pollution is a global environmental issue with profound implications for human health, ecosystems and the economy. From industrial emissions to vehicular exhaust and agricultural activities, various factors contribute to the degradation of air quality. However, with the rapid advancement of technology, particularly, there is growing optimism about the role AI can play in mitigating air pollution. This article delves into the causes of air pollution, the role of AI in detecting and addressing it, the effects on humanity and the potential future directions in this critical area.

The application, innovation and development of Digital Technology (DT) and AI can not only provide refined, scientific and operational decision-making solutions for the environmental planning of market players but also provides opportunities and technical support for the optimization and efficiency improvement of top-down environmental regulation models that will help achieve the goal of reducing air pollutant emissions.[2]

**Major Forms of Pollutions:**

Air, water, food, electromagnetic, light, noise, plastic, soil contamination, radioactive and thermal

pollution.

**Global Effects of Pollution on the Environment Include:**

- Adverse air quality can kill many organisms, including humans.
- Ozone pollution causes respiratory diseases.
- Oil spills can cause skin irritation and rashes.
- Noise pollution induces hearing loss, high blood pressure, stress and sleep disturbance.
- Mercury has been linked to developmental deficits in children and neurologic symptoms.
- Older people are significantly exposed to diseases induced by air pollution.
- Those with heart or lung disorders are at additional risk.
- Children and infants are also at serious risk.
- Lead and other heavy metals have been shown to cause neurological problems, intellectual disabilities and behavioral problems.
- Chemical and radioactive substances can cause cancer and birth defects.
- Carbon dioxide emissions cause ocean acidification.
- Invasive species can out compete native species and reduce biodiversity.
- Invasive plants can contribute debris and biomolecules (allelopathy) that can alter soil and chemical compositions of an environment, often reducing native species competitiveness.
- Nitrogen oxides are removed from the air by rain and fertilize land which can change the species composition of ecosystems.
- Smog and haze reduce the amount of sunlight received by plants to carry out photosynthesis and lead to the production of tropospheric ozone which damages plants.
- Sulphur dioxide and nitrogen oxides can cause acid rain which lowers the pH value of soil.

**Endocrine Disrupting Chemicals (EDCs):** Are natural or human-made chemicals that may mimic, block or interfere with the body's hormones, which are part of the endocrine system. Nearly 85,000 human-made chemicals in the world and 1,000 or more of these could be endocrine disruptors, based on their unique properties. Phthalate, phytoestrogen, polychlorinated biphenyls, polybrominated diphenyls and dioxins are more common endocrine disruptors. Polybrominated biphenyls leads to early menarche, early pubic hair development. Polychlorinated biphenyls lead to delayed the larche. Pthalate causes decrease in testosterone levels. Lead causes delayed age of menarche and testicular dysgenesis syndrome. All these EDC's can be detected by using AI based tools in the contaminating substances.[3]

**Geospatial AI for Monitoring Air Pollution:**

Geospatial artificial intelligence and machine learning based models will be used to monitor air quality in key Indian cities including Delhi, Mumbai, Bengaluru, Chennai and Kolkata. Highlighting the increased use of mathematical modelling tools in India, ISRO chair professor at the National Institute of Advanced Studies emphasized the importance of linking sustainable development goals and air pollution indicators. Using geospatial technology, we need to establish well-distributed ground observation points to measure in-situ pollution parameters, integrating them with space data for accurate modelling. The scientists detailed how geospatial outlook and space-ground observations are essential for precise pollution estimates. The approach utilizes Aerosol Optical Depth (AOD) data derived from satellite sources like INSAT-3D/3DR, MODIs, along with weather

data, all managed as Big Data (BD).

**Use of AI to Mitigate Air Pollution:**

**Detection of Air Pollution Using AI:** AI technologies offer innovative approaches for detecting and monitoring air pollution in real-time.

**Key methods include:** micro & early detection of all the contaminants even in a very small quantity and at an early stage of toxicity, helping us to take action in time.

1. **Remote Sensing:** AI-powered satellite imagery and remote sensing technologies can monitor air quality over large geographical areas, providing valuable data on pollutant concentrations and their sources. Automated cooling tower detection through deep learning for Legionnaires' disease outbreak investigations, as compared to the conventional epidemiological methods, tells a model development and validation study.[4] Very aptly termed as "The lofty heights of digital health".[5]
2. **Sensor Networks:** Deploying networks of low-cost air quality sensors equipped with AI algorithms enables continuous monitoring of pollution levels at the street level, facilitating localized interventions.
3. **Data Analytics:** AI algorithms can analyze vast amounts of data from various sources, including air quality monitors, weather stations and traffic sensors, to identify patterns, trends and correlations related to air pollution.

**AI Solution for Mitigation of Air Pollution:**

AI offers several solutions for mitigating air pollution, including:

1. **Optimizing Traffic Flow:** AI-based traffic management systems can reduce congestion and idling, thereby minimizing vehicle emissions in urban areas, systems optimize traffic flow, reducing congestion and emissions in urban areas by minimizing idling and traffic jams. Singapore used the Smart Traffic Management System which uses AI algorithms to dynamically adjust traffic signal timings based on real-time traffic conditions, reducing congestion and air pollution at peak hours.
2. **Predictive Modelling:** AI models can forecast air quality levels based on meteorological data, traffic patterns and emission sources, allowing authorities to implement timely interventions such as traffic restrictions or emissions controls. The Air Quality Forecasting System developed by IBM uses AI and machine learning to predict air pollution levels up to 48 hours in advance, helping cities proactively manage pollution-related health risks and even issues warnings to the potential victims like people with COPD and asthma who are likely to face an emergency.
3. **Emission Reduction Technologies:** AI-driven innovations like catalytic converters, scrubbers and pollution control systems enhance the efficiency of industrial processes and reduce emissions. AI-driven innovations enhance the efficiency of industrial processes and reduce emissions through technologies such as catalytic converters, scrubbers and pollution control systems. Carbon capture and storage (CCS) systems, which use AI for optimization, capture carbon dioxide emissions from industrial sources and store them underground, preventing their release into the atmosphere.
4. **Smart Energy Management:** AI algorithms optimize energy consumption in buildings and industries, promoting the use of clean energy sources and reducing reliance on fossil fuels,

thereby lowering air pollution emissions. Google's DeepMind AI platform optimizes energy usage in data centers, reducing energy consumption by up to 40% and decreasing associated air pollution emissions.

**Air Pollution in India:**

Using artificial intelligence aided combination interventions to control air pollution by assessing areas of maximum contamination, installation of sprinkler system in construction sites and anti-smog machines, compulsory 35 ft iron sheet enclosures on all construction sites has been made mandatory, installation of independent air quality measuring devices and monitoring them. Using this computed Big Data civic body used vehicle mounted mist spraying machines, also known as anti-smog guns, at locations to control dust and serial measurements definitely showed a decline in air pollution.

**Soil Pollution in India:** We all underestimate soil pollution and to cite example from area of Navi Mumbai, Maharashtra which deals with the assessment of pollution status along the wetland of Thane Creek, which has been subjected to a lot of pollution from the Asia's biggest Thane Belapur Industrial Complex. This story can be of any industrial belt in our country. Investigations using data analysis and AI models, advocated habitat conservation and ecological studies with special reference to the physico-chemical characteristics and heavy metal pollution in the soil along the creek area. The pH, electrical conductivity, bulk density, alkalinity and chlorinity values recorded were observed to be high during dry seasons and low during rainy season. The soil samples were also analyzed for their heavy metal contents like nickel, zinc, cadmium, copper, iron, arsenic and mercury. It was observed that, the concentration of these heavy metals increases gradually in dry seasons, followed by a sharp decrease during rainy season. These heavy metals have a marked effect on the aquatic flora and fauna, which through bio magnification enter the food chain and ultimately affects the human beings as well. The present experimental data on heavy metal pollution in soil samples collected along Kalwa bridge of Thane Creek points out to the need of regular monitoring of water resources and further improvement in the industrial waste water treatment methods. If the present conditions continue for a long period, the creek may soon become ecologically inactive. High levels of mercury have been found in the soil and water around biomedical waste treatment facilities at Govandi near Deonar dumping and Uran, in a study by Amity School of Biotechnology. Soil pollution from Kanjur landfill killed fish less than 500m from the flamingo sanctuary. Bhosari industrial area in Pune, had chemical waste dumped in the open. Few districts of Vidarbha regions have a very high incidence of kidney stones and chronic renal failure (CRF). AI can help in detecting the micro contaminants at a smallest fraction before it becomes toxic. An article by Dr. Bawaskar et al[6] is an eye opener and one by Iyer et al tales that the other metro cities are also not behind.[7]

**Noise Pollution in India:**

AI-powered sensors and microphones can detect sound waves, differentiate between different types of sounds and detect patterns and anomalies in sound data that are difficult for humans to recognize. Data collected by AI-powered sensors and microphones are much more precise and reliable, makes real-time monitoring achievable, enabling immediate intervention in an instance of high noise levels. On top of that, comprehensive data analysis can provide insights into the impact of noise pollution on human health and the environment, helping policymakers to develop

appropriate mitigation strategies. By integrating APIs, hardware manufacturers can leverage trusted AI technology to enhance the accuracy and automation of sensors, gaining a competitive edge in the market. Using AI traffic flow to create awareness with regards to noise pollution in every crossway in the streets of Mumbai has become a compulsion. Such similar signs are particularly seen in busy crossways. Our festivals e.g. Ganesh Visarjan, too are a big source of noise pollution.[8]

**Waste Water Treatment:**

AI, as a rapidly developing and powerful tool to solve practical problems, has attracted much attention and has been widely used in various areas. Owing to their strong learning and accurate prediction abilities, all sorts of AI models have also been applied in wastewater treatment (WWT) to optimize the process, predict the efficiency and evaluate the performance, so as to explore more cost-effective solutions to WWT. Although, AI models have gained great success in WWT-related fields, there are some challenges and limitations that hinder the widespread applications of AI models in real WWT, such as low interpretability, poor model reproducibility and big data demand, as well as a lack of physical significance, mechanism explanation, academic transparency and fair comparison. To overcome these hurdles and successfully apply AI models in WWT, these models used for prediction and optimization can be classified into three main categories: Artificial Neural Network (ANN), Machine Learning (ML) and Search Algorithm (SA). These tools work in co ordination with sensors. The sensors are equipped with advanced technologies such as machine learning algorithms and data analytics capabilities. They continuously collect data on various water quality parameters, including pH levels, dissolved oxygen, turbidity and the presence of contaminants.[9]

**Using Robotic Process Automation (RPA):**

Many times we can't reach to the source of pollution or deep sites, crevices. A Robot by name "Ro-Boat" detects chemical pollution via different sensors, GPS and onboard cameras. It then sucks in the water and filters the pollutants before releasing the cleaned water. Its sensors can also be used to detect and recover waste in the river, collect debris and recover sludge deposited on the river bed. Ro-Boat can detect, collect and eliminate all kinds of pollutants, including chemical products and floating waste. The machine can be programmed to collect all kinds of sludge with its robotized arms and then unload the waste, works autonomously, with minimum human intervention. It is equipped with antifog lights and a panoramic zoom camera, allowing it to operate 24/7 in all weathers, array of solar panels and a double helix motor allows it to navigate while using less energy. It has the unique capacity to fully submerge in the river to extract pollutants lying on the river bed. It operates 12 hours a day and can carry a load of up to 15 kg. With these characteristics, it is capable of cleaning 600 kg of waste a day, which is 200 tons of waste a year. Similar efforts of AI in cleaning up the oceans, rivers, lakes and waste water management are seen in Netherlands. An environmental and AI aided organization called The Ocean Cleanup is using AI and other technologies.[10]

**Biological Contamination of Food and Supply Chain:**

Magnitude of food poisoning remains a serious problem around the world. In the US, 48 million people or one in six, get sick every year from a food borne illness. Of these, 128,000 are hospitalized and 3,000 people die. In the UK, it is calculated that there are 2.4 million cases of food

poisoning every year and an estimated 180 deaths. In India, the figures are always underreported but few estimate about 2 million deaths due to water and food contamination annually.

Meat, poultry, fish and lettuce are common sources. More the food market is being industrialized, the more it will be susceptible to pathogens. NTT's (a German start up) sensors are fitted to a 3D-printed plastic model of a human nose. Using this biosensor-based tech NTT is virtually monitoring for food and flavor quality control, food pathogen detection, non-invasive rapid disease diagnosis, sustainable-organic farming and environmental and wellness monitoring.

AI driven latest electronic noses, high-tech sensors that can detect and report specific smells are quick to improve their levels of speed and accuracy. This can transform food safety.[11]

Common types of potentially deadly food borne bacteria are salmonella and E. coli. Both of these have their own "electronic personality" and have their own electrical signal. The e-noses contain electrodes that are coated with nanoparticles of carbon and detect the smells or volatile organic compounds (VOC) given off by bacteria.

Different types of toxins are present in foods, including naturally occurring toxins in plants, bacterial toxins and fungal toxins (mycotoxins) which can be detected at earliest and small quantity.[12] Two very good reviews by C. Quain et al,[13] 'How Can AI Help Improve Food Safety?' and about 'detecting E .coli contamination by optical imaging' by Ma L.et al[14] discuss all the processes and points in logistics of food chain management in detail.

**Global Use of AI in Prevention of Air Pollution:**

**Mapping Deforestation with AI:** AI, satellite images and ecology expertise are also being used to map the impact of deforestation on the climate crisis. Space Intelligence, based in Edinburgh, Scotland, says it is working in more than 30 countries and has mapped more than 1 million hectares of land from space using satellite data. This AI aided technology remotely measures metrics, such as deforestation rates and how much carbon is stored in a forest.

AI is helping communities vulnerable to climate change and risks in Burundi, Chad and Sudan. The IKI Project uses AI technology to help predict weather patterns, so communities and authorities can better plan how to adapt to climate change and mitigate its impact, including improving access to clean energy, implementing proper waste management systems and encouraging reforestation.

**Using AI to Recycle More Waste:** Waste is a big producer of methane and is responsible for 16% of global greenhouse gas (GHG) emissions, according to the United States Environmental Protection Agency. Greyparrot, a software startup based in London, United Kingdom has developed an AI system that analyzes waste processing and recycling facilities to help them recover and recycle more waste material.

**AI Helps Predict Climate Disasters:** In São Paulo, Brazil, Sipremo is using AI to predict where and when climate disasters will occur and what type of climate disasters they will be like, landslides, water flooding and draughts.

**Wish List of AI Climate Tools:** This includes building a complete wish list of datasets that would advance global AI solutions for climate change. Google DeepMind is working on this with Climate Change AI, a non-profit organization set up by volunteers from academia and industry that see a key role for machine learning in combating climate change.

**How AI Can Help Industry Decarbonize:** Industrial sectors generate around 30% of greenhouse

gas emissions globally. Accurate AI aided toolshelp organisations in the metal and mining, oil and gas industries to decarbonize their operations. Reforesting hills in Brazil using Drones: An initiative, which launched in January 2024, is a partnership between Rio's city hall and start-up Morfo, aims to grow seeds in hard-to-reach areas. A single drone can disperse 180 seed capsules per minute, which is 100 times faster than using human hands for traditional reforestation.

**Advanced Air Quality Forecasting:** Traditional air quality forecasts rely on numerical models that have limitations in accuracy and lead time. However, AI models can predict pollution events up to 14 days ahead of time.

**AI Model that Specifically Predicts Ozone Pollution:** Ozone at ground level is harmful to our lungs and with climate change, we're likely to see more ozone spikes due to hot, sunny days. Local self governments (LSG) can explore various scenarios to improve air quality. For example, if the model identifies cars as the cause of a future high ozone event, policymakers can suggest ways to minimize car emissions, promote electric vehicles.[1]

**Hospital Preparedness:** AI predictions allow hospitals to prepare for an increase in pollution-related illnesses. During bad air events, hospitals can adjust staffing levels in the emergency room to handle potential cases.

**Democratizing Air Quality Data:** Wearable sensors equipped with AI can collect air quality data at the street level. This democratizes data collection, enabling ordinary citizens to understand their personal exposure to air pollution. Armed with this information, individuals can advocate for environmental justice and push for measures to improve air quality.

**Identifying Pollution Hotspots:** AI excels at managing complex interactions between spatial-temporal factors. It precisely identifies pollution hotspot areas, allowing targeted interventions. Whether tracking current pollution conditions or forecasting future levels, AI provides a quick and accurate method for identifying areas of concern.

**Shortcomings of AI in Indian Air Pollution Solution:**

As per the research publications till today, these are the potential barriers for India in its track to apply AI in mitigating pollution:

- **Absence of Data Ecosystems:** The current data situation in India needs to be much more promising for Artificial Intelligence to grow. By 'enabling data', they refer to the required volume of data that AI tools will utilize to produce an output efficiently. This output can be quantitative or qualitative depending on the task performed.
- **Low Intensity of AI Research:** India is a developing country with massive potential for AI in every major sector. However, the level of research being conducted for fundamental research is low. Also, most companies try hard to complete the transformation of core research into applications for the market.
- **Inadequate Availability of AI Expertise:** AI is a complex concept which requires expertise. However, India has yet to reach the level of skilling opportunities it needs to compete globally.
- **High Resource Cost and Low Awareness of AI Adoption in Business Processes:** The cost of implementing AI business processes has been increasing in the last decade in India.
- **The Issue with Cultural Barriers:** Human beings are known for resisting change. We are creatures of habit and once we develop a system of conducting a mission that seems to

effectively and efficiently get the job done, we prefer it. It often takes some encouragement before we witness the total gains AI will bring.

**Future Prospective for Artificial Intelligence:**

The future of AI in mitigating air pollution holds promise for further advancements and innovations:

**Integration with (IoT):** AI systems will increasingly integrate with Internet of Things (IoT) devices, enabling seamless communication, coordination among sensors, actuators and connected devices for efficient pollution monitoring and control.

**Enhanced Predictive Models:** AI algorithms will continue to evolve, incorporating more sophisticated data analytic techniques and machine learning models to improve the accuracy and reliability of air quality forecasts.

**Autonomous Systems:** Vehicles and drones equipped with AI capabilities will play a significant role in monitoring air pollution, conducting inspections and implementing targeted interventions in hard-to-reach or hazardous areas.

**Global Collaboration:** International cooperation and knowledge sharing will be essential for leveraging AI technologies effectively to address air pollution on a global scale, fostering partnerships among governments, industries, research institutions and NGOs.

**Robotics:** Robotics of high end are currently in experimental stages but in a high risk situation it can a boon. Regarding the front end of production, introducing AI and robot equipment to replace human labour can avoid or reduce the waste of resources and environmental pollution caused by the inefficiency of manual operation.[15] Very high precision, collaborative robots can help, require less operating space than traditional automated robots, in smaller spaces it will reduce heat and energy consumption. Strong, profound learning ability and swarm intelligence technology can accelerate technological innovation and diffusion. From the perspective of the production end, using DT and AI allows enterprises to increase a small amount of green investment, which can maximize the efficiency of the enterprise end treatment, improve pollution treatment capacity and thus reduce pollution emissions.[16]

**National and State Level Scenario in India:**

Air pollution, stemming from various sources, poses significant health risks, particularly impacting vulnerable populations. The Integrated Health Information Portal (IHIP) integrates AI and ML to combat air pollution's health impacts, crucial in rapidly urbanizing areas. The National Program on Climate Change and Human Health (NPCCHH) focuses on environmental sustainability and public health amid rising pollution levels. NPCCHH emphasizes community engagement and education to empower citizens to address air pollution-related health concerns. IHIP's AIML integration enables real-time monitoring, predictive modelling and evidence-based policymaking to tackle air pollution's health effects effectively. Predictive modelling helps forecast health risks, enabling targeted interventions and resource allocation to protect vulnerable groups. Public engagement initiatives foster advocacy and collective action in combating air pollution and promoting public health. AIML-driven policymaking facilitates the implementation of stringent regulations and sustainable practices to address air pollution challenges comprehensively. The IHIP portal represents a transformative tool in enhancing India's air quality management efforts and promoting environmental sustainability. Through innovation and collaboration, India can leverage AIML

technologies to build healthier, cleaner and more resilient communities.

**Conclusion:**

The role of AI in mitigating air pollution is crucial for addressing this complex environmental challenge and safeguarding human health and well-being. By harnessing the power of AI for detection, monitoring and intervention, society can achieve significant reductions in pollution levels, leading to a cleaner and healthier environment for current and future generations. Continued research, investment and collaboration are essential to realizing the full potential of AI in combating air pollution and building a more sustainable future. AI empowers us to proactively address air pollution by improving forecasting, enhancing preparedness and involving communities in the fight for cleaner air. Insights and potential applications into climate governance and the implications of emerging technologies such as AI and Blockchain in influencing environmental outcomes, locally, nationally and globally,[17] will preserve healthy earth for future generations.

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Chapter - 33

# Pollution Mitigating Strategies

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**Introduction:**

Health and pollution are intricately linked, with environmental pollutants posing significant risks to human health and well-being. The adverse effects of pollution on health are pervasive, affecting individuals across the lifespan and contributing to a wide range of diseases and health conditions. From air and water pollution to chemical contaminants and hazardous waste, the presence of pollutants in the environment poses complex challenges for public health professionals, policymakers and communities worldwide. Pollution, in its various forms, has been identified as a leading cause of morbidity and mortality globally, accounting for millions of premature deaths each year. Exposure to pollutants such as particulate matter, nitrogen dioxide, sulfur dioxide, volatile organic compounds, heavy metals and persistent organic pollutants has been linked to respiratory diseases, cardiovascular disorders, neurological impairments, cancer, reproductive problems and other adverse health outcomes. Mitigating the health impacts of pollution requires a multifaceted approach that addresses both the sources of pollution and the vulnerabilities of affected populations. This includes implementing regulatory measures to limit emissions and discharge of pollutants, promoting sustainable practices and technologies to reduce environmental contamination and enhancing public awareness and education on the health risks associated with pollution.

**Pollution and its Impact on Health:**

**Air Pollution and Health:** Air pollution poses significant risks to human health, affecting millions of people worldwide and contributing to a range of acute and chronic health conditions. The detrimental impacts of air pollution on health are well-documented, with both short-term and long-term exposure linked to various adverse health outcomes. One of the primary components of air pollution is particulate matter (PM), which consists of tiny particles suspended in the air. PM can vary in size, with fine particles ($PM_{2.5}$) and coarse particles ($PM_{10}$) being of particular concern due to their ability to penetrate deep into the respiratory system. Short-term exposure to PM has been associated with respiratory symptoms, exacerbation of asthma, cardiovascular events and premature death. Long-term exposure has been linked to chronic respiratory diseases, cardiovascular diseases, lung cancer and reduced life expectancy. Nitrogen dioxide ($NO_2$) and ozone ($O_3$) are two common air pollutants produced by combustion processes, vehicle emissions and industrial activities. Both pollutants can irritate the respiratory system and exacerbate existing respiratory conditions such as asthma and chronic obstructive pulmonary disease (COPD). A large number of restrictive lung diseases occur due to occupational exposure to particles like coal dust (coal worker pneumoconiosis), silica particles (silicosis), asbestos particles (asbestosis).(Figure 2)

**Water Pollution and Health:** Water pollution is a pressing global issue with severe implications for

public health. One of the primary concerns associated with water pollution is the presence of



**Figure 1: Gross Image of Lung In Coal Worker's Pneumoconiosis Showing Architectural Destruction**

(Image credit: National Institute for occupational safety and Health - NIOSH).

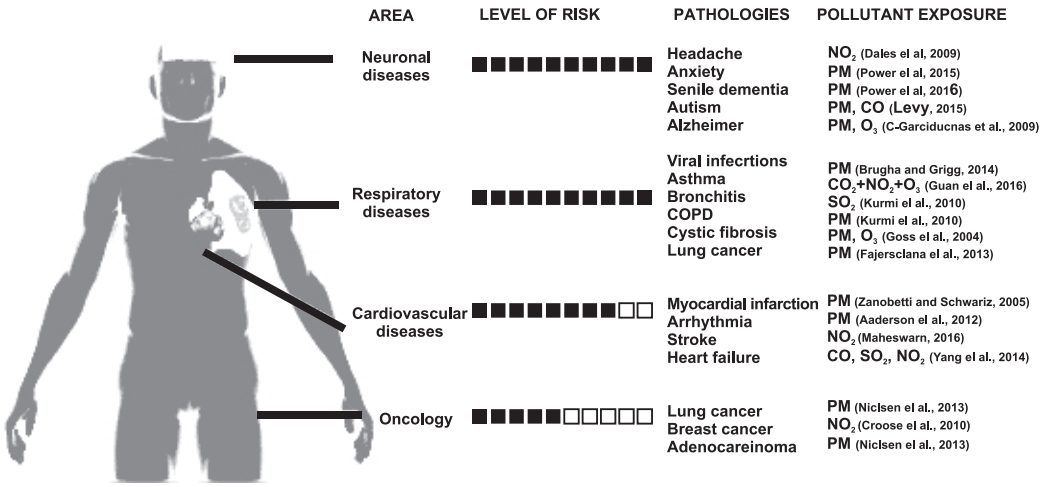


**Figure 1: Level of Risk the Pollutants Pose to Cause the Specific Diseases**

(Source: Environmental Science and Pollution Research, 2020).

pathogens such as bacteria, viruses and protozoa. Contaminated water can transmit waterborne diseases such as cholera, typhoid fever, dysentery and hepatitis A, leading to gastrointestinal infections, dehydration and even death, particularly in vulnerable populations such as children and the elderly. Water pollution also involves the release of chemical contaminants into water bodies, including heavy metals, pesticides, pharmaceuticals, industrial chemicals and hazardous waste. These pollutants can leach into drinking water supplies, posing serious health risks to those who consume contaminated water. Chronic exposure to chemical contaminants has been linked to various health problems, including cancer, neurological disorders, reproductive issues and developmental abnormalities.

**Noise Pollution and Health:** Noise pollution, defined as excessive or disruptive noise that interferes with normal activities and poses a risk to human health and well-being, is a significant environmental health concern. Prolonged exposure to high levels of noise can cause permanent

damage to the auditory system, leading to hearing loss or impairment. This is particularly common among individuals working in noisy environments such as construction sites, factories and airports. Chronic exposure to noise pollution has been associated with an increased risk of cardiovascular diseases, including hypertension, coronary artery disease and stroke. Noise pollution can disrupt sleep patterns and reduce the quality of sleep, leading to daytime fatigue, irritability and impaired cognitive function. Sleep disturbances caused by noise have been linked to an increased risk of insomnia, mood disorders and decreased overall well-being.

**Strategies to Tackle Pollution:**

**Strategies to Deal with Air Pollution:** Strategies to mitigate air pollution involve various approaches aimed at reducing the harmful substances in the air that can make people sick and harm the environment. Some of these strategies include:

A. **Promoting Clean Energy:** Transitioning to cleaner energy sources like solar, wind and hydropower can help reduce air pollution caused by burning fossil fuels such as coal and oil.
B. **Improving Transportation:** Encouraging the use of public transportation, walking and biking, as well as adopting electric and hybrid vehicles, can reduce emissions from cars and trucks, which are significant sources of air pollution.
C. **Implementing Emission Controls:** Installing pollution control technologies in industries and factories can help reduce the release of harmful pollutants into the air. This includes using scrubbers, filters and catalytic converters to capture pollutants before they are released into the atmosphere.
D. **Enforcing Regulations:** Enacting and enforcing strict regulations on emissions from vehicles, industries and power plants can help limit the amount of pollution released into the air.
E. **Raising Awareness:** Educating the public about the health impacts of air pollution and ways to reduce individual contributions, such as conserving energy, using energy-efficient appliances and reducing waste, can help foster a culture of environmental stewardship.
F. **Planting Trees and Green Spaces:** Increasing greenery in urban areas through tree planting and creating green spaces can help absorb pollutants and improve air quality.

The Central Pollution Control Board is currently implementing a nationwide initiative called the National Air Quality Monitoring Programme (NAMP). This initiative encompasses a network of 804 operational stations across 344 cities/towns in 28 states and 6 Union Territories of India. The primary objectives of NAMP include assessing the status and trends of ambient air quality, ensuring compliance with prescribed air quality standards, identifying non-attainment cities, developing preventive and corrective measures and comprehending the natural cleansing processes of the environment in relation to pollution. NAMP focuses on monitoring four key air pollutants - sulphur dioxide ($SO_2$), oxides of nitrogen (NO), respirable suspended particulate matter (RSPM / $PM_{10}$) and fine particulate matter ($PM_{2.5}$) - at all designated locations. Additionally, meteorological parameters such as wind speed, wind direction, relative humidity (RH) and temperature are also integrated into the air quality monitoring efforts.

**Strategies to Deal with Water Pollution:** To mitigate water pollution, several strategies can be implemented to reduce the contamination of water bodies and ensure safe and clean water for both humans and wildlife. Here are some key strategies:

A. **Waste Management:** Proper disposal and treatment of waste, including sewage and industrial effluents, are essential to prevent pollutants from entering water bodies.

Implementing advanced wastewater treatment technologies and enforcing regulations on waste disposal can significantly reduce water pollution.

B. **Protecting Watersheds:** Preserving and restoring natural habitats, such as wetlands and forests, in watersheds can help filter pollutants and prevent sediment runoff into rivers, lakes and oceans.

C. **Reducing Non-Point Source Pollution:** Implementing best management practices in agriculture, construction and urban development can help minimize non-point source pollution, such as runoff from fertilizers, pesticides and sediment, which can contaminate water bodies

D. **Monitoring and Regulation:** Regular monitoring of water quality and enforcement of water quality standards are essential for identifying sources of pollution and holding polluters accountable. Implementing comprehensive regulations on discharges and pollutants can help prevent water pollution.

E. **Promoting Sustainable Practices:** Encouraging water conservation, promoting eco-friendly farming practices and adopting sustainable urban development strategies can help reduce the overall environmental impact and mitigate water pollution.

F. **Investing in Infrastructure:** Investing in infrastructure projects, such as sewage treatment plants, storm water management systems and wastewater recycling facilities, can improve water quality and reduce pollution in urban areas.

G. **Public Awareness and Education:** Educating communities about the importance of clean water, the sources and impacts of water pollution and individual actions to prevent pollution can empower people to take proactive measures to protect water resources.

**Strategies to Deal with Noise Pollution:** Mitigating noise pollution involves a combination of legislative measures, urban planning strategies and individual actions. Here are some strategies:

A. **Regulations and Enforcement:** Implement and enforce noise ordinances that specify acceptable noise levels for different areas and times of day.

B. **Urban Planning:** Design urban areas with noise-reducing features such as sound barriers, green spaces and buffer zones between industrial and residential areas.

C. **Noise Barriers:** Construct physical barriers like walls or fences to block noise from reaching sensitive areas.

D. **Traffic Management:** Implement traffic calming measures such as speed bumps, roundabouts and traffic flow improvements to reduce vehicular noise.

E. **Noise-Reducing Materials:** Use noise-absorbing materials in construction and infrastructure projects, such as acoustic insulation, double-glazed windows and soundproofing.

F. **Public Awareness and Education:** Raise awareness about the effects of noise pollution and encourage individuals and businesses to take actions to reduce noise emissions.

G. **Technological Solutions:** Develop and promote the use of quieter technologies in transportation, machinery and appliances.

H. **Community Involvement:** Encourage community engagement in noise monitoring, reporting and planning processes to address local noise concerns effectively.

I. **Green Spaces:** Increase the presence of green spaces and urban parks, which act as natural buffers against noise pollution.

J. **Zoning Policies:** Implement zoning regulations that separate noisy activities from residential areas and designate quiet zones where noise levels are strictly controlled.

**Recommendations regarding Noise Levels to Mitigate Noise Pollution:** The World Health Organization (WHO) has published guidelines and recommendations regarding noise levels to mitigate noise pollution and protect public health.

A. The WHO recommends outdoor noise levels of less than 55 decibels (dB) during the day and 40 dB at night to prevent adverse health effects, including annoyance, sleep disturbance and cardiovascular problems.

B. For indoor environments, the WHO suggests indoor noise levels of less than 30 dB for bedrooms during the night to ensure restful sleep and less than 35 dB for other indoor areas during the day to promote a conducive environment for work and relaxation.

**Strategies to Deal Soil Pollution:** Mitigating soil pollution requires a multifaceted approach aimed at preventing the contamination of soil and restoring degraded land to ensure its health and productivity. Here are several strategies to achieve this:

A. **Contaminated Land Remediation:** Implementing remediation techniques such as soil washing, thermal treatment, bioremediation and phytoremediation can help remove or neutralize pollutants from contaminated soils.

B. **Waste Management:** Proper management of hazardous and non-hazardous waste is crucial to prevent soil contamination. Implementing waste reduction, recycling and safe disposal practices can minimize the release of pollutants into the environment.

C. **Pollution Prevention:** Adopting pollution prevention measures in industrial activities, agriculture and urban development can help minimize the use of toxic substances and reduce the risk of soil contamination. This includes implementing cleaner production technologies, using environmentally friendly pesticides and fertilizers and implementing erosion control measures.

D. **Land Use Planning:** Effective land use planning and zoning regulations can help prevent soil pollution by minimizing exposure to potential sources of contamination, such as industrial sites, landfills and hazardous waste facilities.

E. **Soil Conservation:** Implementing soil conservation practices such as terracing, contour farming, crop rotation and cover cropping can help prevent soil erosion and degradation, which can exacerbate soil pollution.

F. **Monitoring and Assessment:** Regular monitoring and assessment of soil quality are essential for detecting contamination early and implementing timely remediation measures. Implementing soil testing programs and establishing soil quality standards can help ensure the health and safety of agricultural land and urban soils.

G. **Education and Awareness:** Educating communities, farmers, industry stakeholders and policymakers about the importance of soil conservation and pollution prevention can foster a culture of environmental stewardship and promote the adoption of sustainable land management practices

**Biomedical Waste and its Management:** Biomedical waste encompasses a diverse range of materials generated in healthcare settings, including infectious waste, sharps, pathological waste, pharmaceuticals and chemical waste. Improper management of biomedical waste poses significant risks to public health and the environment, highlighting the need for robust waste management protocols in healthcare facilities. Proper management of biomedical waste is

essential to protect public health, minimize environmental impacts and comply with regulatory requirements. Healthcare facilities play a crucial role in implementing effective waste management practices, including segregation, handling, treatment and disposal of biomedical waste. (Figure 3 and 4)

**Conclusion:**

Implementing effective pollution mitigating strategies is paramount in safeguarding public health, preserving ecosystems and ensuring sustainable development. Throughout this discussion, we have explored a variety of strategies aimed at reducing pollution levels and minimizing its adverse impacts on human health and the environment.

From regulatory measures and technological innovations to public awareness campaigns and community engagement, there exists a diverse toolkit of solutions to address pollution at its source. By implementing stringent regulations to limit emissions and discharge of pollutants, governments can play a crucial role in curbing pollution levels and protecting public health. Moreover, investing in sustainable technologies and practices, such as renewable energy, green infrastructure and waste reduction initiatives, can help mitigate pollution while promoting economic growth and environmental sustainability. Additionally, raising public awareness about the health risks associated with pollution and empowering communities to advocate for clean air, water and soil can foster a culture of environmental stewardship and collective action. However, addressing pollution requires collaboration and concerted efforts from all sectors of society, including governments, businesses, academia, civil society and individuals. By working together to implement evidence-based strategies, monitor pollution levels and adapt to changing environmental challenges, we can create cleaner, healthier and more resilient communities for present and future generations. In conclusion, while the task of mitigating pollution may seem daunting, it is not insurmountable. By embracing innovation, fostering collaboration and prioritizing the well-being of people and the planet, we can achieve significant progress in reducing pollution and creating a more sustainable and equitable world for all.

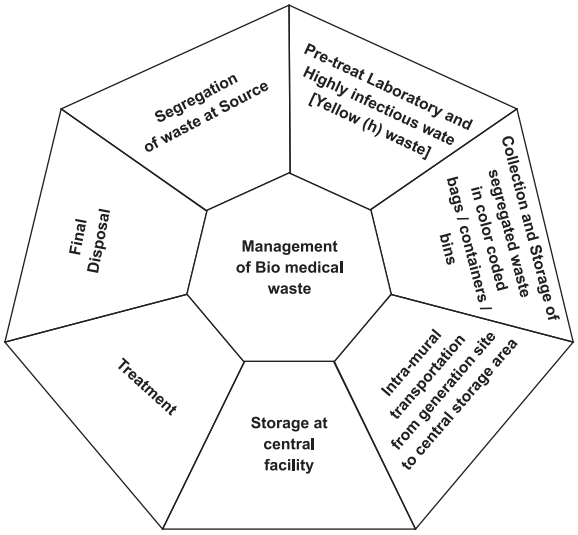


**Figure 3 : Management of Biomedical Waste.**

(Source: Waste management, Central Pollution Control Board)

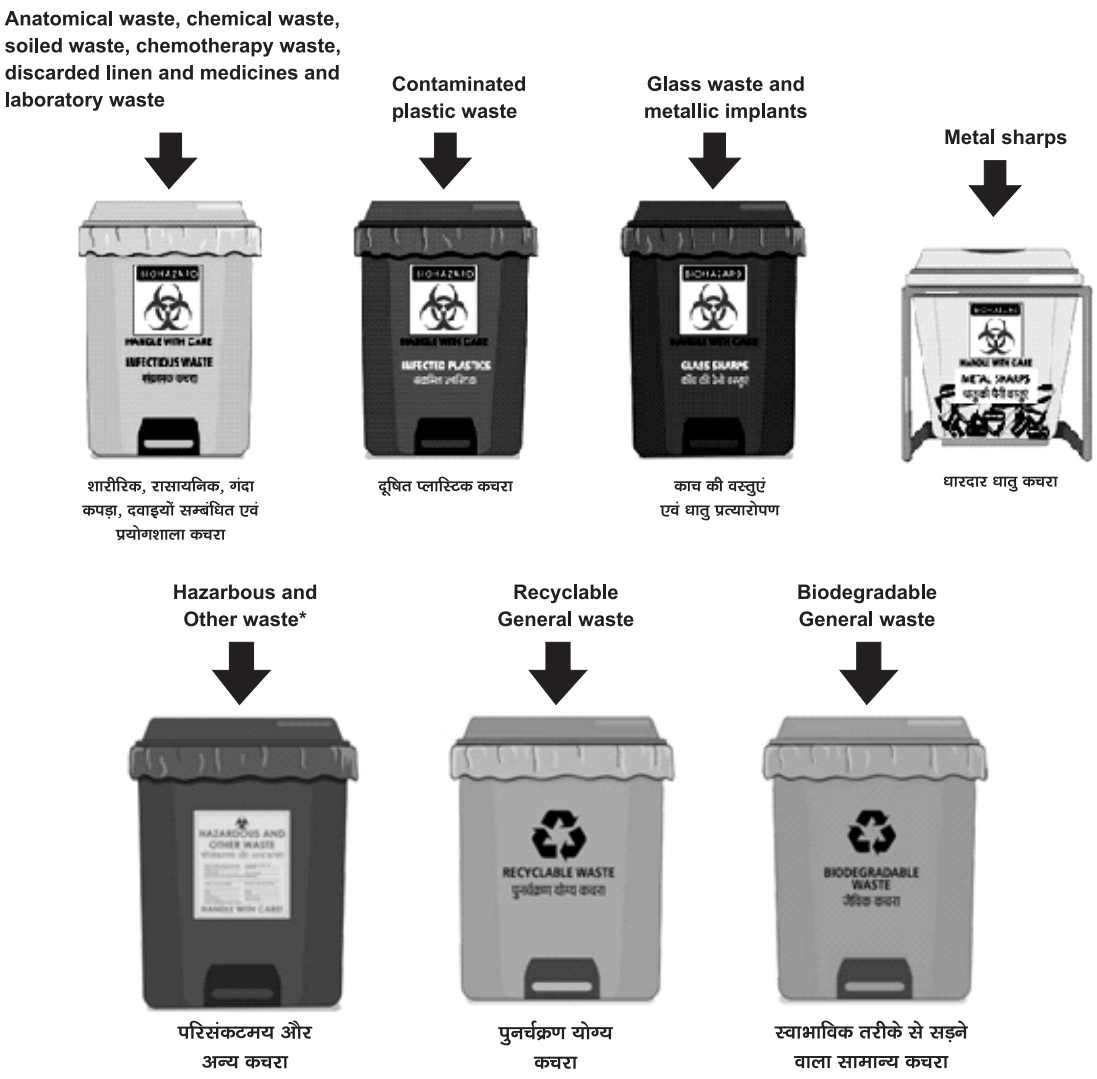


**Figure 4: Segregation of Biomedical Waste in Color-Coded Bin**

(Source: Waste management, Central Pollution Control Board)

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Chapter - 34

# The Spiritual Dimensions of Pollution: Healing Our Planet and Ourselves

*Shambo S Samajdar, Jyotirmoy Pal, Shashank R Joshi*

**Introduction:**

This chapter explores the intricate relationship between spirituality and environmentalism, illustrating how spiritual practices and beliefs can enhance our connection to nature and inspire sustainable behaviors. It delves into various spiritual traditions and their teachings on environmental stewardship, highlighting the significance of integrating ancient wisdom into modern environmental practices. The psychological and spiritual impacts of pollution are examined, revealing how environmental degradation can lead to mental health issues and a sense of spiritual disconnection. Practical spiritual practices such as meditation, eco-spiritual rituals and integrating spirituality into environmental activism are discussed for their potential to heal individuals and the planet. The chapter also emphasizes the role of communities in fostering eco-spiritual movements and reviews global initiatives that address the environmental crisis with a spiritual approach. The conclusion offers a call to action, encouraging readers to engage in personal and collective spiritual practices aimed at environmental healing.

**The Scope of Environmental Pollution:**

Environmental pollution encompasses various forms and sources that significantly impact health, ecosystems and global climates. Broadly, pollution can be categorized into air, water, soil and noise pollution. Each type poses unique challenges and hazards to both the environment and human health.

Air pollution, for instance, involves the release of harmful substances into the atmosphere, leading to respiratory diseases, cardiovascular problems and even cancer. Key pollutants include particulate matter ($PM_{2.5}$), sulfur oxides, nitrogen oxides, hydrocarbons and carbon monoxide (CO), which are predominantly emitted by vehicles, industrial processes and coal-fired power plants.[1] In cities like Delhi, $PM_{2.5}$ levels can reach dangerously high concentrations, posing significant risks to human health.[2]

Water pollution arises from contaminants like industrial discharge, untreated sewage, chemical fertilizers and pesticides. This form of pollution leads to the proliferation of waterborne diseases such as typhoid, cholera, amoebiasis and ascariasis.[3,4] Inorganic pollutants such as potentially toxic elements (PTEs) like lead (Pb), mercury (Hg) and cadmium (Cd) accumulate in water sources and food chains, causing severe health issues including developmental defects and chronic diseases.[5,6]

Soil pollution, often resulting from agricultural activities, industrial waste and improper waste disposal, leads to land degradation and contaminates food supplies. Toxic chemicals, including

heavy metals and persistent organic pollutants, persist in the environment and bioaccumulate in living organisms, disrupting ecosystems and human health.[7,8]

Noise pollution, though less visible, significantly affects quality of life and health, leading to stress, hearing loss and sleep disturbances. Urbanization and industrialization have exacerbated noise levels in many parts of the world, impacting both humans and wildlife.

Globally, low-income countries bear the brunt of environmental pollution, with an estimated 90% of deaths in these regions attributed to pollution-related causes.[9] The challenges faced by these countries include inadequate environmental regulations and insufficient waste management infrastructure, leading to high levels of air and water pollution.[10]

Addressing these global environmental issues requires comprehensive strategies that encompass policy reform, technological innovation and community engagement. International initiatives, such as the National Clean Air Program in India, aim to reduce particulate matter pollution through stringent regulations and increased public awareness.[2] Such efforts highlight the urgent need for collective action to mitigate pollution and protect both the planet and public health.

**Connecting Spirituality with Environmentalism:**

Spirituality in the context of environmentalism refers to a profound connection between human beings and the natural world. It encompasses a sense of reverence, respect and stewardship for the environment, recognizing the intrinsic value of nature beyond its utilitarian benefits. This spiritual connection is rooted in various religious traditions, cultural beliefs and personal experiences that emphasize the interdependence of all living beings and the earth.

Spirituality in environmentalism often includes practices such as meditation, prayer and rituals that celebrate and honor the natural world. It encourages individuals to reflect on their relationship with the environment and adopt behaviors that promote ecological balance and sustainability. The concept of spirituality in this context is not confined to organized religion, it also includes secular and indigenous perspectives that view nature as sacred and worthy of protection.[11,12]

The historical relationship between spirituality and the environment is long-standing and multifaceted, reflecting diverse cultural and religious traditions across the globe. Many ancient civilizations and indigenous cultures have historically viewed the natural world as imbued with spiritual significance. These perspectives often emphasize harmony with nature, sustainable living and the sacredness of natural elements.

Indigenous cultures worldwide have long maintained a spiritual connection to the earth, viewing it as a living entity that must be respected and cared for. For example, Native American traditions often emphasize the interconnectedness of all life forms and the importance of maintaining balance and harmony with nature. Practices such as the use of sacred herbs, ritual dances and storytelling are integral to their spiritual and environmental ethos, promoting a deep sense of responsibility towards the earth.[13]

Hinduism provides a multifaceted faith with numerous perspectives on human-nature relationships. It teaches that the five significant elements (space, air, fire, water and earth) that constitute the environment are derived from prakriti, the primal energy. Each of these elements has its own life and form; together, they are interconnected and interdependent. The human body is

composed of and related to these five elements, with each element connected to one of the five senses: the nose to earth, the tongue to water, the eyes to fire, the skin to air and the ears to space. This bond between our senses and the elements is the foundation of our relationship with the natural world.[14]

Major world religions have variously incorporated environmental ethics into their teachings. For instance, Christianity, particularly through the lens of stewardship, advocates for the care and preservation of God's creation. Biblical references to nature, such as the Book of Genesis, emphasize the role of humans as stewards who must protect and sustain the environment.

In Buddhism, the principle of interdependence or pratītyasamutpāda, teaches that all phenomena, including the natural world, are interconnected. This understanding fosters a compassionate and mindful approach to the environment, encouraging practices that reduce harm and promote ecological well-being. Buddhist teachings on simplicity, non-attachment and mindfulness further support sustainable living and respect for nature.[15]

Islamic teachings also highlight the importance of environmental stewardship. The Quran contains numerous references to nature and emphasizes the responsibility of humans to protect and preserve it. The concept of khalifah (stewardship) in Islam calls for the protection of the environment as a trust from God and various Hadiths (sayings of the Prophet Muhammad) advocate for the conservation of resources and the humane treatment of animals.[16]

In the contemporary era, spiritual environmental movements have emerged that integrate traditional spiritual beliefs with modern environmentalism. One prominent example is the creation of eco-theology, a field that explores the relationship between religion and ecology, advocating for a theological response to environmental issues. This movement includes various religious leaders and organizations that emphasize the moral and spiritual imperative to address environmental degradation and promote sustainability.[17]

The historical and contemporary connections between spirituality and environmentalism underscore the potential for spiritual beliefs and practices to inspire and guide efforts toward environmental sustainability. By drawing on diverse spiritual traditions and fostering a sense of sacred responsibility towards the earth, individuals and communities can be motivated to engage in behaviors that protect and preserve the natural world for future generations.

**Purpose and Structure of the Chapter:**

The primary objective of this chapter is to delve into the intricate relationship between spirituality and environmentalism, particularly in the context of pollution. By exploring the spiritual dimensions of pollution, the chapter aims to:

1. **Understand the Spiritual Connection to Nature:** Examine how various spiritual and religious traditions perceive the natural world and the ethical implications these views have for environmental stewardship.
2. **Highlight Historical Perspectives:** Trace the historical development of spiritual beliefs and practices related to nature and how they have influenced environmental attitudes and behaviors over time.
3. **Promote Ecological Awareness:** Foster a deeper ecological awareness and appreciation for

the environment by highlighting the spiritual significance of natural elements and ecosystems.

4. **Encourage Sustainable Practices:** Advocate for sustainable living practices inspired by spiritual and religious teachings that emphasize respect, care and stewardship of the earth.
5. **Integrate Spirituality with Environmental Action:** Explore how integrating spiritual beliefs with environmental activism can lead to more profound and lasting ecological conservation efforts.

**Historical and Cultural Perspectives on Nature and Pollution:**

**Indigenous Wisdom and Environmental Stewardship:** Indigenous communities have long maintained a profound spiritual connection to the natural world, viewing it as an integral part of their cultural identity and survival. This relationship is often rooted in a holistic understanding of the environment, where every element is interconnected and sacred.

Indigenous beliefs typically emphasize the unity and interdependence between humans and nature. Many Indigenous cultures consider themselves stewards of the earth, tasked with maintaining balance and harmony. This stewardship is often expressed through rituals, ceremonies and oral traditions that honor natural elements and cycles. For instance, Native American tribes perform ceremonies that pay respect to the earth, water and animals, reinforcing their role as caretakers of the environment.

In Hinduism, the concept of "Vasudhaiva Kutumbakam," meaning "the whole world is a family," reflects a similar sentiment. The belief that all elements of nature—space, air, fire, water and earth—are interconnected and derived from the primal energy prakriti emphasizes the sacredness of the natural world. This worldview is deeply embedded in Hindu rituals and daily practices, which honor these elements and their role in sustaining life.

Indigenous sustainable living practices are diverse and adapted to their specific environments. Traditional agricultural methods such as terracing, crop rotation and polyculture farming enhance soil fertility and reduce the need for synthetic inputs. Water management systems like the chinampas in the Valley of Mexico and raised fields in the Andes are sophisticated techniques that optimize water use and support agricultural productivity in varied climates.

In Hindu culture, the reverence for nature translates into practices that promote environmental sustainability. The Atharva Veda contains mantras that advocate for the respectful use of natural resources, urging individuals to treat the earth as a mother who provides sustenance. The Chipko movement, where villagers in India hugged trees to prevent deforestation, is an example of grassroots environmental activism inspired by spiritual beliefs.[18]

**Religious Teachings and Environmental Ethics:** Major world religions have long incorporated environmental ethics into their teachings, emphasizing the moral responsibility of humans to protect and sustain the natural world. These teachings often draw from sacred texts that highlight the sanctity of nature and the need for its preservation.

**Overview of Major World Religions' Perspectives on the Environment:**

Hinduism views the environment as an extension of the divine. The Vedas and Upanishads describe the universe as a manifestation of Brahman, the ultimate reality, emphasizing the interconnectedness of all elements. The concept of dharma includes the duty to protect nature,

while karma underscores the consequences of actions on the environment. Rituals and daily worship practices often involve elements of nature, reinforcing their sacredness.

Christianity promotes the idea of stewardship, where humans are seen as caretakers of God's creation. Biblical references, such as those in Genesis, highlight the role of humans in managing and protecting the environment. This stewardship is reflected in various Christian environmental movements that advocate for sustainable living and conservation efforts.

Islam emphasizes the balance and harmony of creation. The Quran and Hadith stress the importance of acting as stewards of the earth, avoiding wastefulness and protecting the environment. The principle of Tawhid (unity) reinforces the interconnectedness of all life and the responsibility of humans to maintain ecological balance.

**Sacred Texts and their References to Nature and Pollution:**

Sacred texts across religions contain numerous references to nature and the ethical responsibilities of humans. In Hinduism, the Atharva Veda includes hymns that advocate for the respectful use of natural resources. The Bhagavad Gita describes the interconnectedness of all life forms and the importance of living in harmony with nature.

In Christianity, the Bible includes passages that call for the care of creation, such as in Genesis, where humans are instructed to "work and take care of" the Garden of Eden. The Quran, in Islam, emphasizes the stewardship of the earth, with verses that highlight the need to protect the environment and use resources wisely.

**Evolution of Environmental Awareness:**

The awareness and understanding of environmental issues have evolved significantly over time, influenced by various cultural, scientific and political developments.

**Historical Timeline of Environmental Movements:** The conservation movement in the late 19th and early 20th centuries marked the beginning of organized efforts to protect natural landscapes and wildlife. Pioneers like John Muir and Theodore Roosevelt were instrumental in establishing national parks and promoting conservation as a public good.[19] The 1960s and 1970s saw the rise of modern environmentalism, spurred by increasing awareness of pollution and its effects. Rachel Carson's "Silent Spring," published in 1962, played a pivotal role in highlighting the dangers of pesticides and sparked widespread environmental activism. This period also saw the establishment of key environmental regulations and organizations, such as the Environmental Protection Agency (EPA) in the United States.[20]

**The Rise of Ecological Consciousness in the Modern Era:** The late 20th and early 21st centuries have witnessed a globalization of environmental awareness. Issues like climate change, biodiversity loss and pollution have gained international attention, leading to global frameworks such as the Kyoto Protocol and the Paris Agreement. These developments underscore the growing recognition that environmental health is crucial for human well-being and requires concerted action from all sectors of society.[21]

Understanding the historical and cultural perspectives on nature and pollution provides valuable insights into the diverse ways human societies have interacted with and impacted the environment. By integrating Indigenous wisdom, religious teachings and the evolution of environmental

awareness, we can develop more holistic and effective strategies for addressing the ecological crises of our time.

**The Psychological and Spiritual Impact of Pollution:**

**The Mental Health Consequences of Environmental Degradation:** Environmental degradation poses significant threats not only to physical health but also to mental health. The psychological toll of living in polluted environments is increasingly recognized as a critical area of concern. Numerous studies have linked various forms of pollution, including air, water and soil pollution, to mental health issues, highlighting the profound impact of environmental degradation on psychological well-being.[22]

**The Psychological Toll of Living in Polluted Environments:** Living in environments with high levels of pollution can lead to chronic stress, anxiety and depression. The constant exposure to polluted air, contaminated water and degraded land affects not only physical health but also psychological well-being. Individuals in such environments may experience a persistent sense of helplessness and anxiety about their health and the health of their loved ones. The uncertainty and fear associated with pollution-related health risks can contribute to chronic stress and anxiety disorders.

Furthermore, the degradation of natural environments can disrupt community cohesion and social support networks. As pollution degrades natural resources and ecosystems, communities may face displacement, loss of livelihoods and social fragmentation. These disruptions can exacerbate feelings of isolation, depression and anxiety, particularly among vulnerable populations who rely heavily on natural resources for their well-being and cultural practices.[23]

**Studies Linking Pollution to Mental Health Issues:** Research has consistently demonstrated the link between environmental pollution and mental health issues. For instance, studies have shown that exposure to air pollution, particularly fine particulate matter ($PM_{2.5}$), is associated with increased rates of depression and anxiety. Research has found that interquartile range increases in $PM_{2.5}$, NOx and $NO_2$ are associated with 18–39% higher odds of common mental disorders and 33% increased odds of psychotic experiences for $PM_{10}$. Similarly, long-term exposure to air pollution has been correlated with higher rates of anxiety disorders and suicidal ideation.[24]

Water pollution too has been linked to mental health problems. Communities exposed to contaminated water sources often report higher levels of psychological distress. A study conducted in Flint, Michigan during the water crisis revealed significant increases in anxiety, depression and stress-related disorders among residents due to the contaminated water supply and the ensuing health crisis. The mental health impacts of soil pollution and exposure to toxic substances are also well-documented. Communities living near industrial sites or landfills often experience higher rates of mental health disorders, including anxiety and depression, due to the contamination of their environment and the associated health risks. The psychological burden of living in such environments is compounded by the social and economic hardships that often accompany environmental degradation.[24, 25]

**Spiritual Disconnection and Environmental Crisis:** Pollution not only affects physical and mental health but also leads to a profound sense of spiritual disconnection. The degradation of

natural environments can disrupt the spiritual connection that many individuals and communities have with the earth. This disconnection can exacerbate feelings of loss, despair and hopelessness, further impacting mental health.

**How Pollution Leads to a Sense of Spiritual Disconnection:** Spirituality often involves a deep connection with the natural world. Many spiritual traditions view nature as sacred and integral to spiritual practices and beliefs. Pollution, by degrading natural environments, can sever this connection, leading to a sense of spiritual dislocation and loss. When natural spaces that hold spiritual significance are polluted or destroyed, individuals may feel disconnected from their spiritual roots and communities.

This disconnection can manifest in various ways. For some, it may lead to a loss of meaning and purpose, as their spiritual practices and beliefs are intrinsically tied to the health and vitality of the natural world. For others, the destruction of sacred natural spaces may result in a deep sense of grief and mourning, comparable to the loss of a loved one. This spiritual disconnection can exacerbate mental health issues, contributing to feelings of depression, anxiety and existential despair.

**The Impact of Losing Sacred Natural Spaces:** Sacred natural spaces, such as rivers, forests and mountains, play a crucial role in the spiritual lives of many communities. These spaces are often seen as embodiments of the divine, places where individuals can connect with higher powers and find spiritual solace. The loss or degradation of these sacred spaces due to pollution can have devastating spiritual and psychological impacts.

For instance, the pollution of the Ganges River, considered sacred by millions of Hindus, has profound spiritual implications. The contamination of this holy river not only affects physical health but also disrupts religious practices and the spiritual connection of believers with the river. Similar impacts can be observed in other cultures where natural sites hold spiritual significance. The destruction of these spaces can lead to a loss of cultural heritage and identity, further deepening the sense of spiritual and psychological disconnection.[26]

**Healing through Reconnection with Nature:** Reconnecting with nature can play a vital role in healing both psychological and spiritual wounds caused by environmental degradation. Practices and rituals that foster a renewed connection with the earth can help individuals and communities restore their sense of spiritual well-being and resilience.[27]

**Practices and Rituals that Foster Spiritual Reconnection with the Earth:**

Various spiritual and therapeutic practices can help individuals reconnect with nature and heal from the psychological and spiritual impacts of pollution. Practices such as meditation, mindfulness and nature-based rituals can foster a sense of peace and connectedness. For example, forest bathing or Shinrin-yoku involves immersing oneself in a forest environment to experience its calming and restorative effects. Research has shown that spending time in nature can reduce stress, anxiety and depression and promote overall well-being.

In many Indigenous cultures, traditional ceremonies and rituals play a crucial role in maintaining the spiritual connection to the land. These practices often involve offerings, prayers and dances that honor the natural elements and seek to restore balance and harmony. Such rituals not only reinforce spiritual beliefs but also provide a sense of community and continuity, helping individuals

cope with the impacts of environmental degradation.[27, 28]

**Case Studies of Communities and Individuals Finding Healing in Nature:** [28]

Numerous case studies highlight the healing potential of reconnecting with nature. For example, the Chipko movement in India, where villagers hugged trees to prevent deforestation, not only protected the environment but also reinforced the community's spiritual bond with the forest. This act of environmental stewardship was deeply rooted in the villagers' spiritual beliefs and provided a sense of purpose and resilience.

Similarly, urban gardening and community green spaces have been shown to promote mental health and social cohesion. In cities around the world, initiatives to create green spaces and community gardens have helped residents reconnect with nature, reduce stress and build stronger community ties. These spaces provide a refuge from the urban environment, offering a place for reflection, relaxation and social interaction.

The psychological and spiritual impacts of pollution are profound and multifaceted. Addressing these impacts requires a holistic approach that includes fostering reconnection with nature through spiritual and therapeutic practices. By recognizing the interconnectedness of mental, spiritual and environmental health, we can develop more effective strategies for healing and resilience in the face of environmental degradation.

**4. Spiritual Practices for Environmental Healing:**

**Meditation and Mindfulness in Nature:** [27, 28] Meditation and mindfulness in nature are powerful practices that can foster a deep connection with the earth, promoting both personal well-being and environmental healing. Techniques for practicing mindfulness and meditation in natural settings include:

- Forest Bathing (Shinrin-yoku): Originating in Japan, this practice involves immersing oneself in a forest environment, engaging the senses to absorb the natural surroundings fully. Participants are encouraged to walk slowly, breathe deeply and take in the sights, sounds and smells of the forest.[29]
- Walking Meditation: This involves walking slowly and mindfully in a natural setting, focusing on the sensation of each step, the contact of feet with the ground and the rhythm of breathing. This practice helps to ground the individual and cultivate a deep sense of presence.
- Sitting Meditation in Nature: Finding a quiet spot in nature to sit and meditate can be profoundly calming. Practitioners can focus on their breath, the sounds of nature or a specific natural object like a tree or stream. This practice can help to cultivate a sense of unity with the natural world.
- Mindful Observation: This involves taking the time to closely observe elements of the natural environment, such as the patterns of leaves, the flow of water or the behavior of animals. This practice enhances appreciation and understanding of nature's intricacies.

Benefits of these practices include reduced stress and anxiety, enhanced mental clarity and a greater sense of well-being. Additionally, spending time in nature can lead to a heightened awareness of environmental issues and a stronger motivation to protect natural spaces.

**Rituals and Ceremonies for Earth Healing:** Rituals and ceremonies have been used across

cultures for centuries to honor the earth and seek its healing. Examples of eco-spiritual rituals from various cultures[28,29] include:

- **The Chipko Movement:** Originating in India, the Chipko movement involved villagers, especially women, hugging trees to protect them from being cut down. This form of protest was both a spiritual and environmental act, emphasizing the sacredness of trees and forests.
- **Native American Earth Ceremonies:** Many Native American tribes perform ceremonies to honor the earth and its elements. For instance, the Hopi tribe conducts the rain dance to invoke rain and ensure a bountiful harvest, emphasizing their deep connection with the natural cycles.
- **Buddhist Earth Healing Practices:** In Buddhism, practices such as the Green Tara Mantra are recited to protect and heal the environment. Monks and practitioners also engage in rituals that bless and purify natural spaces.

**How to Create and Conduct Personal and Community Rituals for Healing the Planet:**

- **Setting Intentions:** Begin by setting a clear intention for the ritual. This could be to honor a particular element of nature, to seek healing for a polluted area or to express gratitude for the earth's resources.
- **Choosing a Natural Setting:** Select a location that is meaningful and conducive to the ritual, such as a forest, riverbank or garden.
- **Incorporating Elements of Nature:** Use natural objects such as stones, leaves, water, or fire in the ritual. These elements can represent the different aspects of nature and help to ground the ceremony.
- **Group Participation:** Encourage community involvement. Each participant can contribute by sharing their intentions, prayers or blessings for the earth.
- **Closing the Ritual:** End the ritual with a moment of silence or a shared meditation, allowing participants to reflect on their connection to the earth and their commitment to its healing.

**Integrating Spirituality into Environmental Activism:** Combining spiritual practices with environmental activism can enhance the effectiveness of efforts to protect and heal the earth. Here are ways to integrate spirituality into environmental activism:

- **Spiritual Retreats and Workshops:** Organize retreats and workshops that combine environmental education with spiritual practices. These events can include meditation, yoga and discussions on environmental issues, fostering a holistic approach to activism.
- **Sacred Activism:** Engage in activities that are both spiritually fulfilling and environmentally beneficial, such as planting trees, cleaning up natural spaces or advocating for sustainable practices within communities.
- **Eco-Spiritual Gatherings:** Create spaces where like-minded individuals can gather to share their spiritual practices and discuss environmental issues. This can build a supportive community and inspire collective action.

**Inspiring Stories of Spiritual Environmental Activists:**

- **Wangari Maathai:** The founder of the Green Belt Movement in Kenya, Maathai combined her environmental activism with her spiritual beliefs, advocating for the planting of trees and the

protection of forests. Her work earned her the Nobel Peace Prize and inspired millions worldwide.[30]

- **Satish Kumar:** An Indian activist and editor of Resurgence and Ecologist magazine, Kumar walked 8,000 miles for peace and the environment, carrying a message of nuclear disarmament and environmental consciousness. His journey was a pilgrimage, blending spirituality and activism.[31]
- **Thich Nhat Hanh:** A Vietnamese Zen master and peace activist, Thich Nhat Hanh promotes "Engaged Buddhism," which includes mindfulness and meditation as tools for environmental activism. His teachings emphasize the interconnectedness of all life and the importance of living in harmony with the earth.[32]

Integrating spiritual practices into environmental healing efforts can provide profound benefits for both individuals and the planet. Meditation and mindfulness in nature, eco-spiritual rituals and spiritually-informed activism can deepen our connection to the earth and inspire meaningful action to protect and heal our environment. Drawing on ancient wisdom and modern practices, we can foster a holistic approach to environmental stewardship that honors the sacredness of the natural world.

**The Role of Community in Spiritual Environmentalism:**

**Building Eco-Spiritual Communities:** Forming and nurturing communities with a shared spiritual and environmental vision requires a foundation of common values, beliefs and practices. Key steps to building such communities include:

- **Establishing a Shared Vision and Mission:** Clearly define the community's spiritual and environmental goals. This involves creating a mission statement that reflects the group's dedication to ecological sustainability and spiritual growth.
- **Inclusive Participation:** Engage a diverse group of members from various backgrounds to bring different perspectives and ideas. Inclusivity strengthens community bonds and fosters a sense of belonging.
- **Shared Practices and Rituals:** Develop common spiritual practices that reinforce environmental values, such as meditation, prayer and eco-friendly rituals. Regular gatherings for these activities help solidify the community's commitment.
- **Sustainable Living Practices:** Implement sustainable practices in daily life, such as organic farming, renewable energy use and waste reduction. These practices should align with the community's spiritual beliefs and environmental goals.
- **Education and Skill Sharing:** Provide continuous education on sustainable living and spiritual practices. Workshops, seminars and skill-sharing sessions can empower community members to contribute more effectively to the group's mission.

**Successful Examples of Eco-Villages and Spiritual Environmental Groups:**

- **Auroville (India):** Auroville is an experimental township in southern India founded with the vision of creating a universal town where people from all countries can live in peace and harmony. It integrates sustainable living with spiritual development, emphasizing renewable energy, organic farming and ecological building practices.[33]

- **Findhorn Foundation (Scotland):** Established in 1962, the Findhorn Foundation is an intentional community and ecovillage in Scotland known for its spiritual and ecological focus. It combines holistic education, spiritual practices and sustainable living to create a model of ecological and spiritual sustainability.[34]

**Collective Action and Spiritual Solidarity:** Collective spiritual practices can significantly impact fostering environmental change by uniting individuals around a common cause and amplifying their efforts. The power of collective action lies in the ability to harness the spiritual energy and dedication of a group to drive environmental initiatives.

**Case Studies of Community-Driven Environmental Initiatives:**

- Chipko Movement (India): Originating in the 1970s, the Chipko Movement is a prime example of community-driven environmental activism rooted in spiritual beliefs. Villagers, especially women, hugged trees to prevent deforestation, driven by their spiritual connection to nature and a desire to protect their environment.[35]
- Green Belt Movement (Kenya): Founded by Wangari Maathai in 1977, this grassroots organization empowers communities, particularly women, to conserve the environment and improve livelihoods through tree planting and sustainable land use. The movement integrates spiritual values with environmental stewardship, fostering a deep connection to the land.[36]

**Education and Outreach:** Education and outreach are crucial for raising awareness about the spiritual dimensions of pollution and fostering a broader environmental consciousness.

**Effective strategies include:**

- **Community Workshops and Seminars:** Organize educational events that highlight the connection between spirituality and environmentalism. These can cover topics such as the spiritual significance of nature, sustainable living practices and the health impacts of pollution.
- **Collaborations with Religious Institutions:** Partner with temples, churches, mosques and other religious institutions to integrate environmental education into their activities. Religious leaders can play a pivotal role in disseminating these messages to their congregations.
- **Use of Media and Technology:** Utilize social media, websites and other digital platforms to reach a wider audience. Create content that combines spiritual teachings with environmental education, making it accessible and engaging.
- **Outreach Programs in Schools:** Develop curriculum modules that incorporate spiritual perspectives on environmentalism for schools and colleges. Engaging younger generations ensures the long-term sustainability of these values.

**Impact of Outreach Programs:** [37, 38]

- **Earth Ministry (USA):** This organization works with faith communities to educate and mobilize individuals around environmental stewardship. Their outreach programs have successfully integrated environmental concerns into religious education and advocacy.
- **EcoSikh (Global):** Launched in 2009, EcoSikh is a global initiative that connects Sikh values with environmental activism. Through educational programs, tree planting campaigns and sustainable farming projects, EcoSikh has raised awareness about environmental issues within the Sikh community and beyond.

By forming eco-spiritual communities, engaging in collective action and implementing effective education and outreach strategies, communities can play a vital role in addressing environmental challenges. These efforts not only promote ecological sustainability but also reinforce the spiritual connection to the Earth, fostering a holistic approach to environmental stewardship.

**Global Movements and Future Directions:** Global Spiritual Environmental Movements: In recent years, global movements that integrate spirituality and environmentalism have gained prominence, recognizing the deep interconnection between the well-being of the earth and human spiritual health. These movements aim to foster a harmonious relationship with nature, advocating for sustainable practices rooted in spiritual values.

**Overview of Prominent Global Movements:**

- **The Chipko Movement (India):** Initiated in the 1970s, this grassroots environmental movement is renowned for its tree-hugging actions to prevent deforestation. Inspired by spiritual reverence for nature, the Chipko Movement underscored the role of local communities in protecting their environment.[35]
- **The Green Belt Movement (Kenya):** Founded by Wangari Maathai in 1977, this movement focuses on tree planting, environmental conservation and women's empowerment. Maathai's work was deeply influenced by her spiritual beliefs, emphasizing the sacredness of nature and the need for its protection.[36]
- **Faith for Earth Initiative (UN Environment Programme):** This initiative engages faith-based organizations in environmental advocacy, recognizing the powerful role that religious leaders and communities play in promoting sustainability. It seeks to harness the moral and spiritual teachings of various religions to address environmental challenges.[37]
- **EcoSikh (Global):** Launched in 2009, EcoSikh connects Sikh values with environmental activism, promoting tree planting, sustainable agriculture and education on environmental issues. The movement encourages Sikhs worldwide to integrate environmental stewardship into their spiritual practices.[38]

**Profiles of Key Organizations and Leaders:**

- **Wangari Maathai:** The founder of the Green Belt Movement and the first African woman to receive the Nobel Peace Prize, Maathai combined environmental conservation with social justice, emphasizing the spiritual duty to protect the earth.[36]
- **Sadhguru Jaggi Vasudev:** Through the Isha Foundation and initiatives like Project GreenHands and Rally for Rivers, Sadhguru integrates spiritual teachings with large-scale environmental projects, advocating for sustainable land and water management.[39]
- **Pope Francis:** In his encyclical "Laudato Si'," Pope Francis calls for an "ecological conversion," urging people to see the earth as a sacred home and to take action against environmental degradation.[40]

**Policy and Spiritual Advocacy:** The intersection of spirituality, policy-making and environmental advocacy is becoming increasingly significant as leaders and organizations recognize the importance of spiritual values in shaping sustainable policies.

**Examples of Policies Influenced by Spiritual Principles:** [37-40]

- **Laudato Si':** Pope Francis' encyclical has influenced global environmental policy by framing climate change as a moral issue and urging countries to adopt policies that protect the planet and the poor.
- **UN's Faith for Earth Initiative:** This initiative collaborates with religious organizations to develop policies that align with spiritual teachings on stewardship and care for creation. It has led to the inclusion of faith-based perspectives in environmental governance.
- **Rally for Rivers (India):** Spearheaded by Sadhguru, this campaign advocates for policy changes to rejuvenate India's rivers. It emphasizes the spiritual and cultural significance of rivers, influencing water management policies at both regional and national levels.
- **#Plant4Mother Campaign (India):** On World Environment Day, Indian Prime Minister Shri Narendra Modi inaugurated the (#Plant4Mother) campaign by planting a Peepal sapling at Buddha Jayanti Park in New Delhi. Highlighting the profound parallel between the nurturing role of Mother Earth and human mothers, the Prime Minister called upon citizens globally to honor their mothers by planting a tree. This campaign is part of a broader initiative aimed at halting land degradation, building drought resilience and preventing desertification. It includes an ambitious plan to plant 80 crore trees by September 2024 and 140 crore trees by March 2025, employing a "Whole of Government" and "Whole of Society" approach. Various governmental departments, local bodies and community organizations will contribute to this massive tree plantation effort.[41]

**Vision for a Spiritually Integrated Environmental Future:**[42-44] Envisioning a future where spiritual values guide environmental stewardship involves integrating ethical, spiritual and ecological principles into daily life, policy-making and global governance.

**Steps Individuals and Communities Can Take:**

- **Adopt Sustainable Practices:** Individuals can incorporate sustainability into their daily lives by reducing waste, conserving water, using renewable energy and supporting eco-friendly products and businesses.
- **Engage in Spiritual Practices Connected to Nature:** Practices such as meditation, mindfulness and rituals in natural settings can deepen the spiritual connection to the environment and inspire protective actions.
- **Promote Environmental Education:** Communities can organize workshops, seminars and educational programs to raise awareness about the spiritual dimensions of environmental stewardship and the practical steps for sustainability.
- **Participate in Collective Actions:** Joining or supporting environmental movements and initiatives that align with spiritual values can amplify the impact of individual efforts. Collective actions such as tree planting drives, river clean-ups and advocacy campaigns can lead to significant environmental improvements.
- **Advocate for Policy Changes:** Engaging with policymakers to advocate for laws and regulations that protect the environment based on spiritual and ethical principles is crucial. This can involve lobbying, participating in public consultations and using platforms to voice concerns and solutions.

ting in public consultations and using platforms to voice concerns and solutions.

- **Foster Global Collaboration:** Building networks with international organizations and movements can facilitate the exchange of ideas and strategies, promoting a unified global approach to environmental challenges.

**Envisioning a Future:** [43, 44]

A spiritually integrated environmental future envisions a world where the sacredness of nature is universally recognized and respected.

**This future includes:**

- **Holistic Education:** Integrating spiritual teachings on environmental stewardship into educational curricula at all levels.
- **Eco-Spiritual Communities:** Establishing communities that live in harmony with nature, practicing sustainable agriculture, renewable energy use and waste reduction as part of their spiritual discipline.
- **Global Policy Frameworks:** Developing international policies that prioritize ecological health and incorporate spiritual values, ensuring that economic development does not come at the expense of environmental degradation.

By embracing these steps and envisioning a spiritually guided approach to environmentalism, individuals and communities can contribute to a sustainable and harmonious future for all life on earth.

**Conclusion:**

**Recap of Key Insights:** This chapter has delved into the profound relationship between spirituality and environmentalism, illustrating how spiritual practices and beliefs can foster a deeper connection with nature and motivate sustainable behaviors. We explored various spiritual traditions and their teachings on environmental stewardship, highlighting the significance of integrating these ancient wisdoms into modern environmental practices. We examined the psychological and spiritual impacts of pollution, noting how environmental degradation can lead to both mental health issues and a sense of spiritual disconnection. Furthermore, we discussed practical spiritual practices such as meditation, rituals and integrating spirituality into environmental activism, demonstrating their potential to heal both individuals and the planet. Lastly, we examined the role of communities in fostering eco-spiritual movements and the global initiatives that have emerged to address the environmental crisis with a spiritual approach.

**Final Reflections:** The journey through the spiritual dimensions of pollution has been enlightening and transformative. It has revealed that the crisis we face is not merely environmental but also deeply spiritual. Our disconnection from nature reflects a broader disconnection from our own inner selves and each other. By rekindling our spiritual connection to the earth, we can find not only solace and healing but also the motivation and resilience needed to confront the environmental challenges ahead. The insights gained from various spiritual traditions underscore the importance of viewing the earth as sacred and recognizing our role as stewards of the environment. This perspective can inspire a profound shift in how we approach environmental conservation, leading to more sustainable and compassionate practices.

**Call for Action:** As we conclude this exploration, it is imperative to turn these insights into action. We encourage readers to engage in both personal and collective spiritual practices aimed at healing the planet. This can begin with simple daily rituals such as mindful nature walks, planting trees, or participating in community clean-ups. On a larger scale, consider joining or forming eco-spiritual communities that advocate for environmental justice and sustainable living. Let us integrate spiritual values into our activism, drawing on the strength and wisdom of ancient traditions to guide our efforts. By doing so, we can contribute to a global movement that not only addresses environmental degradation but also fosters a deeper, more harmonious relationship with the earth and all its inhabitants. The time for action is now and together we can create a future where spiritual values and environmental stewardship go hand in hand, ensuring a healthy, vibrant planet for generations to come.

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# MONOGRAPH

# POLLUTION & HEALTH

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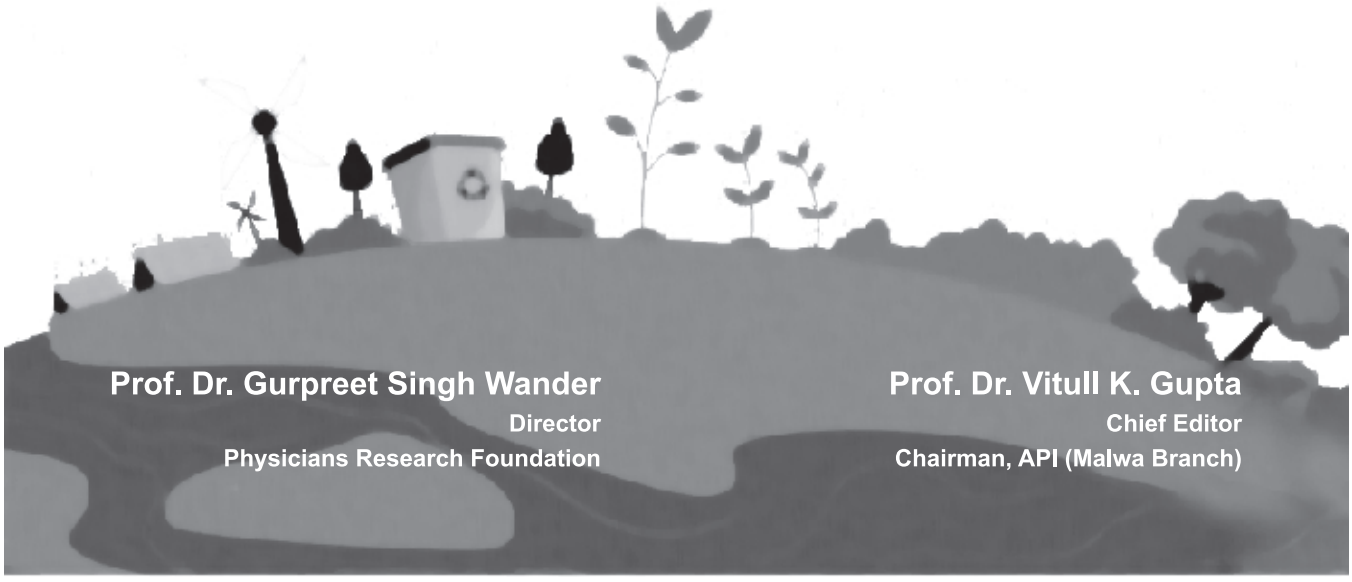


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Chapter - 1

# Pollution Perils: Unveiling the Neurological Nexus

*Man Mohan Mehndiratta, Vasundhara Aggarwal*

"Pollution is not just about harming the environment; it's about poisoning the intricate workings of our neurological health."

**Introduction:**

Pollution, encompassing air, water and soil contamination, poses a significant threat to neurological health. Environmental toxins, comprising poisonous substances and by-products, detrimentally impact human physiology, leading to carcinogenesis, cardiovascular, respiratory and neurological disorders. Despite known interference with cellular functions, underlying mechanisms remain elusive. Landrigan et al. reported a staggering 9 million premature deaths globally in 2015 due to pollution-related diseases, surpassing fatalities from communicable diseases and violence combined.[1] Urbanization and climatic shifts exacerbate pollution, notably from fossil fuel combustion, exacerbating neurotoxicity. The Lancet Commission highlights pollution as a major determinant of ecosystem destruction and climate change, underlining its profound implications for neurological well-being.[1]

**Environmental Pollutants and Mechanism of Neurotoxicity:**

In the intricate landscape of human biology, the brain reigns supreme, orchestrating our productivity and functionality within society. Yet, amidst contemporary environmental challenges, pollution emerges as a formidable adversary, threatening the delicate equilibrium and functionality of our neurological system. Neuronal processes, meticulously sequenced, are disrupted by encounters with neurotoxic pollutants, instigating enduring impairments at macroscopic, microscopic and functional levels. Even mature neuronal networks, thought resilient, succumb to the onslaught of toxin-induced injuries, triggering apoptosis and disrupting neural circuitry. While protective barriers like the blood-brain barrier and blood-axon barrier strive to shield the central and peripheral nervous systems, certain vulnerable regions remain exposed. The area postrema, hypothalamus, pineal gland and diverse nerve terminals lack adequate fortification, rendering them susceptible to infiltration and harm by neurotoxic pollutants. Penetrating the central nervous system via various routes, these toxicants disrupt normal cellular physiology, inciting neuroinflammation and neurodegeneration. Interleukin-1β, tumor necrosis factor α and interferon γ cascade forth as the harbingers of neuroinflammation, catalyzing the demise of neurons, microglia, astrocytes and oligodendrocytes alike. Table 1 and 2 lists various environmental pollutants causing neurological disorders.[2]

**Factors Influencing Neurological Vulnerability to Pollutants:**

**Urbanization and Climatic Shifts** compound the peril, exacerbating pollution's impact on neurological health. The Lancet Commission underscores pollution, particularly from fossil fuel combustion, as a key catalyst for ecosystem degradation and climate change. In low and middle-income countries, rapid urbanization intensifies environmental hazards, auguring overcrowding, diminished air quality and heightened vulnerability to airborne infections. The timing, concentration and duration of exposure to environmental toxins shape the trajectory of neurotoxicity. Extremes of

**Table 1: Environmental Pollutants Causing Neurological Disorders**

| Environmental Pollutants | Comments |
|---|---|
| **Chemical Toxins:** Organic Polychlorinated biphenyls (PCBs) or Chlorinated hydrocarbons, TCDD (2, 3, 7, 8 tetrachloro dibenzopdioxin). Fluorinated organic substances (per- and polyfluoroalkyl substances [PFAs] or perfluorinated compounds [PFCs]). | Used in plastics and dyes, rubber products and pigments. Persist in aquatic ecosystems. |
| **Inorganic Compounds.** Heavy metals like arsenic, mercury, lead and cadmium. Warfare agents like Sarin. | Peripheral neuropathies Encephalopathies |
| **Radiation:** Sunlight, x-rays, radio waves, particle radiation, i.e., alpha and beta Particles and neutrons | Predispose to or skin burns, cancer and congenital disabilities. |
| **Pesticides:** DDT, Pyrethroids | Responsible for bio-magnification within a food web and bio-accumulation of chemicals |
| **Biological Agents:** | |
| Phytotoxins-derived from food plants and fruits | Phytotoxins e.g., Lathyrussativus causing lathyrism, Litchi fruit causes hypoglycaemic encephalopathy, Cassava ingestion leads to cassavism due to cyanide toxicity, Annona muricata associated with atypical parkinsonism. |
| Mycotoxins-derived as metabolite of fungi which act as neurotoxin for animals and human | Ergot, fumonisin B1 and ochratoxinhave neurotoxic effects. Neurological manifestations can include encephalopathy, movement disorders like choreoathetosis, spasms and ballismus, epileptic encephalopathy. |
| Algae toxins cyanobacteria or blue-green algae bloom in higher temperatures in aquatic ecosystem which is associated with climate change. | They produce cyanotoxins which can result in neurotoxicity due to seafood poisoning e.g., paralytic shellfish poisoning (PSP), neurotoxic shellfish poisoning (NSP) and amnesic shellfish poisoning (ASP). |

**Table 2: Environmental Pollutants Causing Neurological Disorders**

| Environmental Pollutants | Comments |
|---|---|
| **Infectious Diseases:** Neurotropic viruses, Bacteria e.g., Diphtheric toxin, Protozoa e.g., malaria | West Nile encephalitis, Zika virus yellow fever, dengue, COVID-19. |
| **Air pollutants:** Carbon monoxide/Carbon dioxide, Sulphur dioxide, Lead | Most common and widely distributed air pollutant.<br><br>Released from fossil fuels, domestic fires etc.<br><br>Children and pregnant women are affected the most. Affects blood and brain in children |
| Ozone | Strongest oxidizing agent. |
| Particulate matter | Complex mixture of organic and inorganic substances. Coarse particles with an aerodynamic diameter of 2.5 to 10 um ($PM_{10}$), fine particles of less than 2.5 um ($PM_{2.5}$) and ultrafine (UFPs) or Nano-sized (NP) particles less than 0.1 um. |

age bear the brunt, as toxins infiltrate the developing brain via placental transmission or postnatal exposure through breast milk. Elderly populations, with compromised hepatic, renal and neurological functions, face augmented susceptibility to pollutants' adverse effects. The concentration and duration of exposure delineate the clinical presentation, with acute manifestations precipitated by high toxin concentrations over short durations, while chronic exposure engenders prolonged and insidious neurological impairments.[3]

**Impact of Pollution on the Human Brain:** [2,4,5,6,7]

Exposure to neurotoxic pollutants in our environment precipitates various neurological manifestations, including encephalopathies, dementia, movement disorders, autism, neuropsychiatric symptoms and peripheral neuropathies, either in isolation or in combination.[1,4] Acute neurological conditions, such as encephalopathies, can arise from exposure to neurotoxins like lead, aluminium, cannabis and organic solvents. Symptoms may include headache, delirium, short-term transient memory loss and gait disturbances. While these symptoms may resolve upon isolation from the exposure site, acute encephalopathy can progress to chronic forms with cognitive impairment and psychomotor slowing, particularly with heavy metal exposure like aluminium, cadmium and lead.

Air pollution has also been strongly associated with stroke, with pollutants like $NO_2$, $SO_2$, $PM_{2.5}$ and

$PM_{10}$ contributing to vascular thrombotic events responsible for ischemic strokes and acute coronary syndromes. The detrimental effects of environmental toxins extend to neurodegenerative disorders, including dementia and disorders of movement. Continuous exposure to $PM_{2.5}$ in the air is linked to the development of dementia and Alzheimer's disease, leading to rapid and progressive grey matter atrophy.

Air pollution, including particulate matter, nitrogen dioxide and biomass fuels, is linked to headache disorders like migraine. Mechanisms involve are neuroinflammation and TRPA1 activation.

Movement disorders, such as Parkinsonism, dystonias and dyskinesias, have been observed following exposure to environmental toxins like mercury, lithium and 5-Fluorouracil. Notably, excessive exposure to toxins present in drugs of abuse can induce Parkinsonism. Furthermore, multiple sclerosis is believed to be causally associated with air pollution, as exposure to particulate matter triggers systemic cytokine release, leading to neuroinflammation and central nervous system demyelination.

Neurodevelopmental delay, characterized by cognitive impairment, attention deficits, hyperactivity disorder, behavioural and executive dysfunction and autistic disorders, is strongly correlated with in utero exposure to environmental toxins. These toxins, including polychlorinated biphenyls and mercury, result in decreased IQ, delayed attention span and birth defects like microcephaly. Fetal exposure to pollutants like $PM_{2.5}$ and $O_3$ during early pregnancy is associated with reduced levels of brain-derived neurotrophic factor and neurodevelopmental delay.

Neuropsychiatric manifestations, such as depression and schizophrenia, are linked to prolonged exposure to air pollutants like $PM_{2.5}$, $PM_{10}$, $NO_2$, $SO_2$ and CO. These pollutants stimulate adrenal glands to secrete excess cortisol, leading to neuroinflammation, cognitive impairment and depression. Short-duration exposure to pollutants like $PM_{10}$, $SO_2$ and $NO_2$ increases the risk of developing schizophrenia, highlighting the intricate relationship between environmental neurotoxins and mental health disorders.

**Assessing Environmental Neurotoxicity:**

Identifying neurotoxins and developing effective testing methods remains challenging, limiting large-scale screening efforts. Current assessments focus on clinical symptoms, motor activity, sensory responses and neuropathological examinations.[8]

**Addressing Pollution Challenges:**

Strategies for Sustainable Environmental Management in India: Environmental neurotoxicity poses a grave concern in India, yet data on neurological diseases due to pollutants is scarce. Studies reveal alarming levels of heavy metals like iron, mercury, lead, chromium and fluoride in patients, linking to cancers and neurodevelopmental disorders. India's rivers, notably the Ganga, suffer heavy metal pollution from industries like mining and plating. Despite environmental legislation (Water Prevention and Control of Pollution Act, 1974; Air Prevention and Control of Pollution Act, 1981; Environment Protection Act, 1986; Forest Conservation Act, 1980; Biological Diversity Act, 2002), lax implementation persists. Urgent measures include establishing an independent environmental regulatory body and enforcing the "Polluter pays principle"; "The User Pays Principle—(UPP)"; and "The Precautionary principle."[9] India requires comprehensive

strategies, including tighter environmental regulations, improved waste management and investment in clean energy sources. The COVID-19 lockdown temporarily improved air quality, underscoring the impact of industrial activities on pollution levels and the urgent need for sustainable environmental management.

**Future Directions for Managing the Nuisance of Pollution on Mental Health:**

Urban development planning must prioritize conservation to mitigate harm from environmental neurotoxins. Policies addressing air, water and soil pollution require comprehensive planning, land development strategies and emission-reducing transportation systems. Increasing green spaces in cities reduces pollution and mitigates the urban heat island effect, benefiting mental health by reducing stress and enhancing cognition. Public education is crucial to minimize risks from environmental neurotoxins, raising awareness of health concerns and promoting public action. Controlling pollution through interventions like green spaces and emission controls is vital for mental health and environmental sustainability.[10]

**Conclusion:**

Exposure to environmental neurotoxic chemicals can lead to various neurological and psychiatric disorders like Parkinson's disease, Alzheimer's dementia and cognitive alterations, even after many years of exposure. Lack of widespread screening policies for environmental toxins persists. Integrating clinical, epidemiological and toxicological studies with cost-effective risk assessments is crucial. Developing new biological markers for subclinical neurotoxic effects through in vitro and animal studies is essential. Enhanced exposure surveillance systems are needed to mitigate toxin effects. Urgent formulation of experimental designs is required to assess the risk of exposure to environmental neurotoxic agents, aligning with the intersection of pollution and neurology for comprehensive health management.

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Chapter - 2

# Pollution and Cardiac Diseases: An Unseen Connection

*Kamaldeep Chawla*

In the hustle and bustle of modern life, the invisible threat of pollution looms large, casting a shadow over public health. Among the myriad of health issues it causes, cardiac diseases stand out, given their severity and rising incidence. The link between pollution and heart health is complex yet significant, shedding light on the urgent need for environmental and health policies to intertwine.

Pollution, particularly air pollution, comprises a mix of particulate matter (PM), nitrogen dioxide, sulfur dioxide, carbon monoxide and ozone, among other pollutants. These particles, especially fine particulate matter known as $PM_{2.5}$, can penetrate deep into the lung tissues and enter the bloodstream, wreaking havoc on the cardiovascular system. The World Health Organization (WHO) has identified air pollution as a major environmental risk to health, highlighting its close association with cardiovascular diseases (CVDs) such as coronary artery disease, heart failure and stroke.

The mechanism through which pollution affects heart health is multifaceted. Inhalation of polluted air leads to systemic inflammation and oxidative stress, which are pivotal in the pathogenesis of atherosclerosis, a condition characterized by the build up of plaques in the arterial walls. This not only restricts blood flow but also increases the risk of plaque rupture, leading to heart attacks and strokes. Moreover, exposure to high levels of air pollutants has been linked to changes in heart rate variability and blood pressure, further exacerbating the risk of cardiac events.

Epidemiological studies have provided compelling evidence of the correlation between air pollution and cardiac diseases. For instance, research indicates that long-term exposure to $PM_{2.5}$ is associated with a significant increase in the incidence of acute myocardial infarction and other cardiovascular events. Similarly, short-term exposure to elevated pollution levels has been observed to trigger acute cardiac incidents, underscoring the immediacy of the threat posed by polluted air.

The demographic most at risk includes the elderly, children and those with pre-existing health conditions. However, the ubiquity of pollution means that no one is truly safe and even healthy individuals can suffer the consequences of prolonged exposure. This underscores the importance of comprehensive strategies to mitigate pollution at its source, such as transitioning to cleaner energy sources, implementing stricter vehicle emission standards and promoting public transportation and other eco-friendly modes of travel. Individuals can also take steps to protect themselves, such as monitoring air quality forecasts, using air purifiers indoors and wearing masks in heavily polluted areas. However, these measures are palliative at best. The crux of the solution lies in robust policy action and global cooperation to tackle pollution at its root.

In conclusion, the connection between pollution and cardiac diseases is a pressing public health issue that demands immediate attention. As the evidence mounts, the need for concerted efforts to combat pollution becomes ever more apparent. It is a call to action for policymakers, health professionals and the public to forge a sustainable path forward, ensuring a healthier planet and a healthier future for all.

Chapter - 3

# Pollution and Health

*M. E Yeolekar*

**Definition:** Introduction of harmful materials into the environment naturally (volcanic ash), human activity, trash, run-off produced by industries resulting in damage to the quality of air, water and land.

**The Civilisational Advantage:** In the ancient Indian tradition, people have always valued rivers, mountains, forests and trees, with the thought that fire, water, wind, earth and space have influence on life and are integral to harmonious living.[1]

**The Current Scenario:** Climate change, biodiversity loss and air pollution arising out of usage of fossil fuels, unsustainable agricultural practices and rapid and large scale urbanization have produced damage to ecosystems and health.

**Morbidity and Mortality:** Combined effect of ambient and household air pollution can cause 6.7 million premature deaths annually associated with Stroke, CAD, COPD, Lung Cancer. (WHO 15 Dec 2023.) A rise in non communicable, autoimmune, inflammatory, metabolic, allergic and neuropsychiatry disorders has been noticed.[2] Extreme heat impacts on the human body detrimentally.[3]

**Role of Medical Profession:** The current state of the climate change and the biodiversity crisis appears to meet WHO criteria for Global Health Emergency wrote the authors of a coordinated editorial published simultaneously in over 200 health journals including the Lancet/ BMJ. Damage to one system leads to damage in others, droughts, wildfires, floods and other effects of climate change destroy plant life, create soil erosion, impact Earth's capacity for carbon storage.

**Physicians Role and Responsibility:** The physician has to play the role of practitioner, advocate and leader for the public to be viewed as a role model to be emulated. Using public transport, turning off lights when not in use, recycling and reuse encouraged, usage of fans than air conditioner, filters for exhausts and chimney, minimum amount of detergents usage, phosphate free soaps, do not dispose chemicals, oils, automation fluids into sanitary sewers / storm sewer system and above all to adhere to all norms of biomedical waste disposal at nursing homes and hospitals. Cooperation with all related authorities is of utmost importance.

**Local Action:** The First Mumbai Climate Action Plan (MCAP) to civic body is submitted (WRI). Climate Hazard and Vulnerability Assessment (CHVA) is a continuous process.

To summarise, pollution is a matter of concern for the present and future generations, it deserves priority consideration, compliance and action in which physicians have an important role to play and counsel / guide public at large.

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Chapter - 4

# Pollution and Kidney Diseases

*Sree Bhushan Raju*

**Introduction:**

In recent times, there has been a notable escalation in pollution levels across the globe, posing a significant peril to human well-being. While the immediate impact of pollution on the respiratory and cardiovascular systems has been extensively documented, a burgeoning body of research suggests a less acknowledged yet equally worrisome correlation between pollution and kidney diseases.

**The Association between Pollution and Kidney Diseases:**

**Air Pollution:** Air pollution, a pervasive global problem primarily caused by vehicular emissions, industrial activities and the combustion of fossil fuels, has been linked to an augmented risk of kidney diseases. Fine particulate matter ($PM_{2.5}$) and nitrogen dioxide ($NO_2$), common constituents of air pollution, are known to infiltrate the bloodstream and exert adverse effects on the kidneys.[1] Prolonged exposure to elevated levels of air pollution is correlated with a heightened incidence of chronic kidney diseases (CKD). The minute particles present in polluted air can incite inflammation and oxidative stress, thereby contributing to the progression of kidney damage. Lee et al found an association between exposures to air pollution even at lower concentrations and the risk of the first hospital admission with AKI for a 5-$\mu g/m^3$ increase in $PM_{2.5}$, for a 10-ppb increase in $NO_2$ and a 10-ppb increase in summer-period $O_3$.[2]

**Water Pollution:** Water pollution, stemming from the release of industrial chemicals, heavy metals and untreated sewage, also contributes to the development of kidney diseases. Elevated levels of contaminants such as lead, cadmium and arsenic in drinking water have been associated with an increased susceptibility to kidney dysfunction.[3] Over time, contaminants may accumulate in the kidneys, leading to chronic damage and impaired renal function.

**Conclusion:**

As the global community grapples with the adverse effects of pollution, it is imperative to recognize the intricate link between environmental factors and kidney health. Individuals should be made aware of the potential hazards posed by prolonged exposure to polluted air and water, thereby motivating them to adopt preventive measures. The implementation of more stringent regulations pertaining to industrial emissions, vehicle emissions and wastewater discharge is imperative in order to mitigate the sources of pollution that contribute to kidney diseases. More research is required by integrating the novel epidemiologic study designs and large biologic datasets with omics biomarkers.

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Chapter - 5

# Pollution and Chronic Kidney Disease of Unknown Etiology (CKDu)

*Sree Bhushan Raju*

**Introduction:**

India is grappling with a severe environmental crisis characterized by alarming levels of air and water pollution. This environmental degradation has far-reaching consequences on public health with emerging evidence suggesting a link between pollution and kidney diseases. Some important observations have been made in India relating pollution and kidney diseases.

**Air Pollution and Kidney Health:**

The high concentration of particulate matter (PM), nitrogen dioxide ($NO_2$) and sulfur dioxide ($SO_2$) in the air has been associated with an elevated risk of kidney diseases. Studies done by George et al. have indicated that long-term exposure to air pollutants may contribute to the progression of chronic kidney disease (CKD) highlighting the association between ambient air quality and renal dysfunction in patients with CKD.[1]

**Water Pollution and CKD of Unknown Eetiology (CKDu):**

CKDu has been observed in several regions where water sources are contaminated with heavy metals, pesticides and other pollutants. The high incidence of CKDu in parts of West Bengal has been linked to the consumption of water containing elevated levels of heavy metals like cadmium and arsenic.[2] The studies conducted in Uddhanam of Andhra Pradesh, emphasized the heavy metal contamination in groundwater and its impact on human health, shedding light on the water pollution aspect in affected areas.[3]

**Heat Stress Nephropathy:**

Heat stress nephropathy, a condition where heat-related stress contributes to kidney damage, is becoming increasingly prevalent. A study highlighted the impact of heat stress on kidney health in a rural community in South India, emphasizing the need to address both temperature-related stress and pollution.[4]

**Conclusions:**

The exact mechanisms linking pollution to CKD are complex and multifactorial. Genetic susceptibility, poor nutrition and inadequate healthcare access may further amplify the impact of pollutants. Long term observational studies are required to elucidate the multifaceted nature of environmental pollutants in specific pockets of India and their intricate relationship with kidney health. Comprehensive strategies such as stricter emission controls, better waste management, sustainable urban planning and improved water quality monitoring are essential.

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Chapter - 6

# Microplastics and Autoimmune Diseases: The Emerging Problem

*Atul Kakar, Tanvi Batra, Rahul Kumar*

**Introduction:**

Autoimmune diseases is a wide spectrum encompassing conditions that arise when one's own immunity inappropriately attacks their own system, hence causing the production of antibodies. The etiology of autoimmune diseases still remains largely unknown but it has been hypothesized that environment as well as genetic factors play a major role in it's occurrence. Various studies have shown that about 40-70% of these autoimmune diseases can be attributed to environmental factors.[1] As one of the major causes of environmental pollution of 21st century, plastic pollution has been found to have a strong association in the development of autoimmunity. The origin of plastic dates back to 1862 and since then, the usage of plastic in the form of it's polymers such as microplastics (MPs) and nanoplastics (NPs) has been impacting environment as well as humans in various ways, directly or indirectly.[2] Microplastics are defined as particles smaller than 5mm and nanoplastics are those which are ≤ 100nm in size. A rough estimate of 6.3 billion tons of plastic waste is known to have been generated from 1950s to 2015, which is further expected to rise to 26 billion if it's production continues at same rate by 2050.[3] It is of utmost importance that we recognize the toxicities MNPs have on humans and other living organisms, such as reproductive toxicity in oysters, liver toxicity in zebrafish and tissue bioaccumulation in mice.[4] Microplastics can be primary, which are directly produced, or secondary, which are fragmented segments of larger particles.

- Ingestion of seafood or water releases microplastics in the gut causing damage to intestinal barriers and leading to gut microbiota dysboisis.[5] Various studies have shown that Helicobacter pylori also attaches to MPs, forming biofilms and causing a more severe inflammatory response in the cells.[6]
- Inhalation of MPs can be lethal as heavy metals such as arsenic, cadmium, mercury are adsorbed on it's surface, hence leading to toxicity once inhaled.[7] Moreover, it was studied that SARS-Cov-2 easily attaches to the surface of MPs, resulting in easier penetration in lungs and causing severe infections in humans.[8]
- Exposure of surfaces with open wounds, hair follicles or sweat glands can also act as another entry point for MPs.

**Possible Mechanisms for Autoimmunity:**

- Experiments show that the exposure to microplastics induces a variety of toxic effects, including oxidative stress, metabolic disorder, immune response, neurotoxicity, as well as reproductive and developmental toxicity.[9]
- Microplastics are not only toxic itself but also carriers for many pollutants to enter biological tissues and organs. SARS-CoV-2 can attach to the surface of MPs and utilize MPs as a carrier for intracellular transport, in consequence leading an increase infection of the virus.[8]
- Microplastics can induce immune response in the body. It has been observed that toxic

chemicals can initiate the development of autoimmune disease or propagate inflammatory autoimmune responses in genetic susceptible individuals.[10]

- Toxic environmental chemicals (persistent organic pollutants, toxic metals, solvents, and endocrine disruptors) induce several physiological mechanisms that lead to autoimmunity. These chemicals can bind to gamma aryl hydrocarbon and peroxisome proliferator activated receptors, leading to abnormal antigen presenting responses and lymphocyte dysregulation.[11]
- In addition to directly binding to receptors throughout the body, toxic chemicals can bind directly to nucleic acids and promote the activation of anti-nuclear antibodies, or simply bind to circulating proteins found throughout the body and induce protein misfolding, thereby configuring proteins into neoantigens. These mechanisms all contribute to direct immune activation and dysregulation.[11]

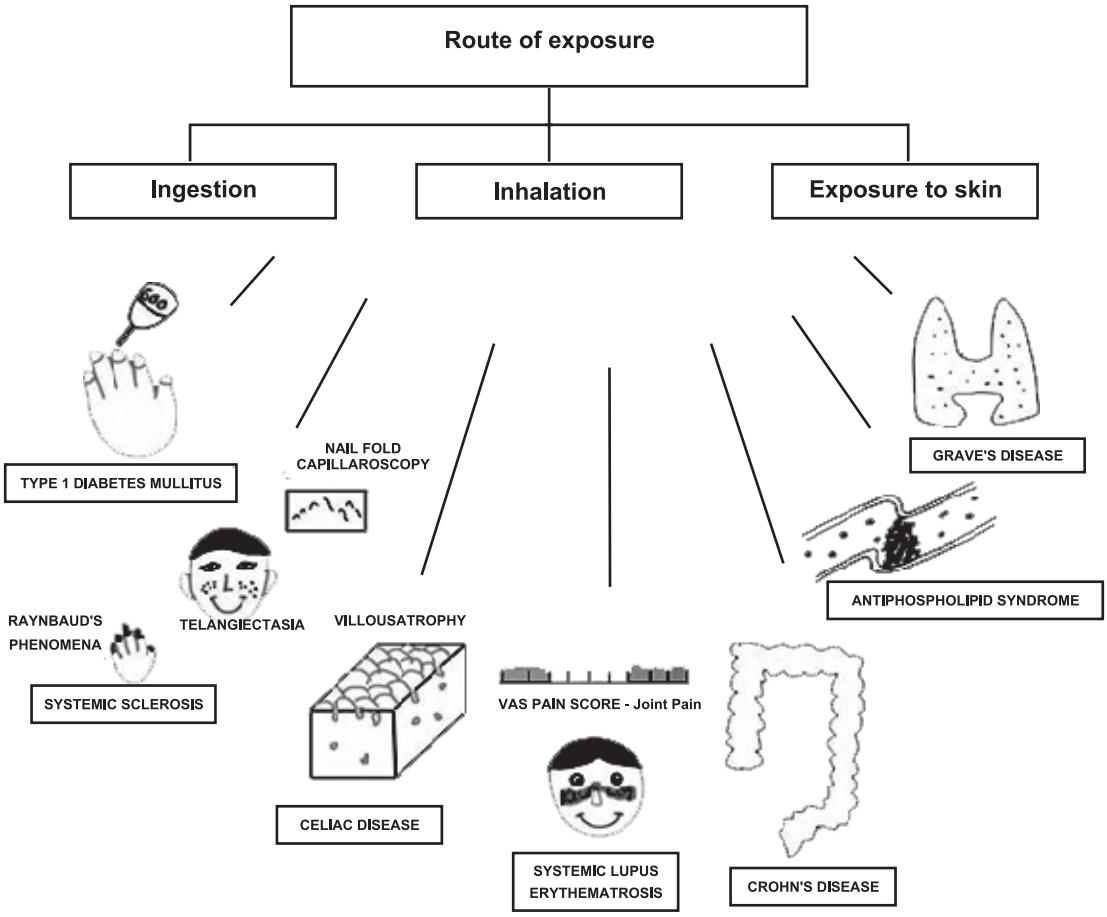


**Figure 1: Various Routes of Exposure for Microplastics and it's effects on the Immune System.**

- Toxic chemicals deplete antioxidants such as glutathione and promote immune dysregulation and deterioration of immune barriers, including the blood-brain barrier, the intestinal barrier, and the pulmonary epithelial barrier. Toxic chemicals that possess endocrine-disrupting properties can bind to estrogen and pituitary receptors, leading to immune dysfunction.[11]
- Bisphenol A is a chemical found in MNPs which has oestrogen mimicking effects and can stimulate inflammatory pathways, triggering autoimmune diseases. It also stimulates prolactin release, which further has a stimulatory effect on the immune system, leading to development of diseases such as type I diabetes mellitus, systemic lupus erythematosus, antiphospholipid syndrome, grave's disease etc.[12]
- The combination of these physiological alterations, in combination with genotypes that have polymorphisms in immune regulatory regions, leads to autoimmune reactivity or autoimmune disease development.

## Conclusion:

Microplastics have a high resistance to degradation, because of which they persist and accumulate in the human body for a long time, posing a constant danger to human health. There is a lack of data to ascertain the full spectrum of toxicity that occur in humans and no safety threshold for the human body has been established. Therefore, more studies are needed on the effect of microplastics on human health. It is strongly recommended to reduce the accumulation of these microplastics in the environment and avoid use of plastic in our day to day activities as much as possible.

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Chapter - 7

# Pollution and Mental Health Issues

*Gurvinder Pal Singh, Sahildeep Kaur.*

Pollution and mental health are both major challenges for humankind. Various mental health disorders including anxiety, mood and psychotic disorders are the outcome of this association between pollution and mental health. Poor air quality is associated with poor mental health. Depression and suicide were the most studied outcomes. Air quality is an important risk factors for psychotic phenomenon in psychiatric patients. Inadequate housing is more common in urban spaces, where outdoor and indoor air quality is poorer. Heat also leads to more anxiety and depressive symptoms and suicidal behaviours. Climate change appears to induce a broad spectrum of generally adverse effects on public health. It may increase the risk of psychiatric disorders.[1]

Exposure to air pollutants may lead to neurocognitive disorders and affect mental health through a range of potential causal pathways. Frontal-limbic brain areas responsible for emotional regulation and neuroinflammation and oxidative stress are implicated. In a systematic review air pollution was consistently associated with neurostructural and neurofunctional effects such as inflammation and oxidative stress, changes to neurotransmitters, neuromodulators and their metabolites, within multiple brain regions the hippocampus (66%), prefrontal cortex (7%) and amygdala.[2, 3] There is emerging evidence of air pollution in cognitive function and dementia.In air pollution, the olfactory bulb transmission pathway and nasal epithelial transmission pathway and mechanical inhalation pathway produces adverse effects on brain leading to dementia.[2]

The hallmarks of Alzheimer's and Parkinson's diseases, included hyperphosphorylated tau, amyloid plaques and misfolded α-synuclein is documented in literature. A recent systematic review suggests that depression, suicide and neurodevelopmental disorders (such as autism for pregnancy-related exposures) may be more common among those exposed to air pollution. [1,2,3]

Environmental pollutants modify the gut microbiota profile which further influences metabolic pathways and the brain functions. The country-specific data showed pollution exposure to be associated with bipolar disorder, depression, schizophrenia and personality disorder in developed countries. A recent systematic review and meta-analysis showed associations between air pollutants with depression, anxiety, bipolar disorder, psychosis and suicide in adults. The most apparent association was between long-term 6 months exposure to air pollution. The review highlighted a need for larger-scale longitudinal studies using representative samples and adjustments for area-level factors such as traffic noise, access to green space and socioeconomic status, to help better understand potential causality in observed associations.[3] Further research is needed on the mechanisms involved in these observed associations.

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Chapter - 8

# The Price of Progress: Pollution's Health Consequences in India

*Aushili M.*

**Introduction:**

Pollution poses a significant threat to public health worldwide and India is no exception. India has ascended to become the eighth most polluted nation globally, characterized by an annual average $PM_{2.5}$ concentration of 53.3 micrograms per cubic meter, surpassing the WHO's recommended levels by over tenfold. With rapid industrialization, urbanization and population growth, the country faces severe pollution challenges that adversely affect the health of its citizens. From the contamination of air and water to the degradation of soil, the repercussions of pollution extend widely and exhibit complexity. This paper explores the multifaceted relationship between pollution and health in India, focusing on air, water and noise pollution.

**Air Pollution:**

The Moiseless Killer: Air pollution is a major concern in India, with cities like Delhi often ranking among the most polluted in the world. The primary contributors to air pollution are vehicular emissions, industrial activities, construction and biomass burning. Fine particulate matter ($PM_{2.5}$) and other pollutants found in polluted air can penetrate deep into the respiratory system, causing inflammation and irritation of the lungs. Prolonged exposure to air pollution is associated with respiratory diseases such as asthma, chronic obstructive pulmonary disease (COPD) and lung cancer.[1]

**Water Pollution: India's Silent Crisis:**

Water pollution is another pressing issue in India, with contamination from industrial effluents, agricultural runoff and untreated sewage posing significant health risks. The lack of access to clean water exacerbates the problem, particularly in rural areas, where communities rely on polluted water sources for drinking and sanitation. multivariate studies have found that the average concentrations of Fe, Cr, Pb, Ni, Cd, Mn, Hg, Co and As in surface water of rivers far exceed the permitted limits established by both WHO and Bureau of Indian Standards. Consuming or coming into contact with contaminated water can lead to a range of health problems, including gastrointestinal illnesses, skin infections, reproductive issues and even neurological disorders. Additionally, water pollution can have long-term effects on public health, such as an increased risk of cancer from exposure to carcinogenic substances.[2]

**Unnecessary Noise:**

The most cruel abuse, noise pollution poses significant health hazards, impacting both physical and mental well-being. Prolonged exposure to high levels of noise can lead to hearing loss, sleep disturbances, increased stress levels and cardiovascular problems. Additionally, noise pollution can interfere with communication, concentration and overall quality of life. Addressing noise pollution is essential to mitigate its adverse effects and promote a healthier environment for all.[3]

## Conclusion:

Addressing pollution requires a multi-sectoral approach that involves government intervention, industry regulation, community engagement and public awareness campaigns. Investments in clean energy, sustainable transportation and wastewater treatment infrastructure are essential to mitigate pollution levels and protect public health. Additionally, efforts to improve access to clean water, promote green spaces and enforce noise pollution regulations can contribute to a healthier environment for all. By prioritizing pollution control measures, India can safeguard the health and well-being of its citizens and pave the way for a sustainable future.

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Chapter -9

# Pollution and Non-Respiratory Cancers: A Fact Ignored

*Satish Kumar Gupta*

Pollution is a well-established risk factor for lung cancer. But pollution can also significantly contribute to several other cancers. According to the International Agency for Research on Cancer (IARC), ambient air pollution not only caused 14.1% of lung cancer deaths but also led to 22.4% of laryngeal cancer deaths and 6.8% of bladder cancer deaths worldwide in 2010. [1] Recent scientific studies have also explored the possible associations between air pollution and other cancers, such as breast cancer and childhood leukaemia. A meta-analysis by Alexendra J white et al. (2024) found that increase in exposure to $PM_{2.5}$ by 10ug/$m^3$ was associated with 8% increased risk of breast cancer and that the effect was stronger for oestrogen positive breast cancers. [2] Similarly, a study by Ojeda Sánchez Carlos et al. (2023) reported that exposure to traffic-related air pollution was associated with an increased risk of childhood leukaemia.[3] Other types of cancer that may be linked to air pollution include bladder cancer, kidney cancer, and colorectal cancer. A meta-analysis of household air pollution from burning of solid fuels also noted adverse associations with oral, cervical, and oesophageal cancer.[4] Earlier studies have suggested some adverse associations of both $NO_2$ and NOx and breast cancer, with fewer clear associations with PM.[5] Recent studies, in analysis of 47,433 women in the United States Sister Study showed adverse associations of both $NO_2$ and $PM_{2.5}$ and overall breast cancer incidence.[6] Air pollution may also affect the risk of childhood cancers, such as brain tumors, neuroblastoma and Wilm's tumor. Notable positive associations were seen between certain cancers and environmental exposures e.g. leukemia was linked to pesticides and air pollution with increased risks of 33% and 27% respectively, CNS tumors and neuroblastoma were associated with pesticides showing a 53% and 43% increase in risk, and Wilms tumor along with other rare cancers showed a 50% increased risk related to air pollution.[7] The carcinogenic effects of air pollution may be mediated by DNA damage, epigenetic changes, immune system impairment, and inflammation. However, the evidence on the role of air pollution in causing non-respiratory cancers is still limited and inconsistent, and more research is needed to clarify the causal mechanisms and the dose-response relationships. Nonetheless, it is crucial to monitor and control the levels of air pollution and adopt preventive and protective measures to reduce exposure and the risk of cancer.

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