Artificial Intelligence and Environmental Sustainability
Challenges and Solutions in the Era of Industry 4.0
Algorithms for Intelligent Systems

Series Editors
Jagdish Chand Bansal, Department of Mathematics, South Asian University, New Delhi, Delhi, India
Kusum Deep, Department of Mathematics, Indian Institute of Technology Roorkee, Roorkee, Uttarakhand, India
Atulya K. Nagar, School of Mathematics, Computer Science and Engineering, Liverpool Hope University, Liverpool, UK
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Rapid economic developments have led to serious environmental issues and challenges, which include air and water pollution, global warming, diminishing natural resources, as well as natural disasters and hazards. All these bring immense negative impacts on human health and well-being. Indeed, our mother earth has become the victim of industrialization. The unsustainable use of fossil fuels and other natural resources has caused considerable environmental pollution and global climate change, urging us to develop cutting-edge technologies for ensuring environmental sustainability pertaining to the emergence of a circular economy in the era of Industrial Revolution (IR) 4.0 and beyond.

In 2016, the United Nations Development Programme (UNDP) identified a number of “Sustainable Development Goals (SDGs)”, which is a global call aiming to end poverty, safeguard the environment, and provide peace and prosperity for all by 2030. A strategy plan focused on 17 critical sectors has been spearheaded in the UNDP; among them, “Good Health and Well-being”, “Clean Water and Sanitation”, “Affordable and Clean Energy”, and “Climate Action” are all closely linked to environmental sustainability as well as human health and well-being. In this respect, advances in technology offer opportunities for planning, predicting, overseeing, and managing environmental processes at various sizes and time periods. Artificial intelligence (AI), big data analytics, Internet of Things (IoT), robotics, and autonomous systems are examples of modern technologies that have the ability to unearth important data, extract insights, and devise novel solutions. As a result, researchers, engineers, policymakers, and stakeholders are able to make informed decisions at the right moment for environmental protection and sustainability, allowing AI and associated technologies to go from in vitro (laboratory-based) concepts to in vivo (real-world) implementations.

This edited book aims to address challenges and opportunities in utilizing AI and related technologies for achieving environmental sustainability. A total of 10 chapters are devoted to cutting-edge research and development initiatives as well as innovative solutions to undertake present and future environmental issues. In addition, new technological and application perspectives pertaining to AI for environmental
sustainability are presented in this book, along with future research directions and trends that can preserve our mother nature.

Chapter 1 addresses the issues concerning air pollution monitoring, which is costly and lacks the ability to determine contamination courses, spread, and spatio-temporal properties. The use of technologies such as IoTs, AI, and big data analytics in monitoring real-time air pollution is beneficial for devising rapid solutions and mitigation plans. This chapter brings the outlook on a multi-level socio-technical framework consisting of ecosystems and technologies in mitigating air pollution. Since AI has been demonstrated to be effective in pollution control and environmental management globally, Chap. 2 describes the usefulness of AI technologies in sustainable development, water and air pollution control, as well as the associated potential in various industrial sectors.

Water is a vital resource for all living beings, not only for humans. Chapter 3 presents a comprehensive review of the usage of AI for developing predictive wastewater treatment models to assist in decision-making processes. Case studies on AI-based operational optimization in wastewater treatment plants are given. Despite the fact that the rainfall-runoff (R-R) process is difficult, multi-variable, and non-linear, the use of AI in hydrology is crucial for understanding and simulating purposes. Indeed, real-time R-R modelling is beneficial in terms of flood forecasting and flood warning applications. As such, Chap. 4 discusses the strengths, limitations, and perspectives with respect to the improvement of AI-based systems for real-time R-R modelling. On the other hand, pharmaceutical plant process waste can be a source of emerging pollutants that are resistant to existing wastewater treatment methods. As a result, Chap. 5 explores AI and machine learning methods for optimizing process parameters and product formulation to eliminate traces of components invading ecosystems.

Energy generation from solar sources for outdoor Photovoltaic (PV) modules is susceptible to solar spectral irradiance, which varies with respect to locations. Chapter 6 compares the performance of 12 different types of commercial PV modules at different locations, as well as the actual performance of PV modules under local climate conditions in Peninsular Malaysia. The Genetic Algorithm is leveraged to examine the influence of local solar irradiance on outdoor PV modules.

Chapter 7 describes a Peer-to-Peer (P2P) energy trading paradigm, which enables direct exchange of energy between consumers as well as commercialization of renewable energy sources, particularly in smart cities. An energy-trading model based on a multi-agent system is developed, while simulations on P2P energy trading are conducted using real data. Another paradigm on Circular Economy (CE) is introduced in Chap. 8, which aims to secure a cyclic economy where materials are recirculated. A hybrid framework of a decision-making trial and evaluation laboratory model and the fuzzy cognitive map has been developed and implemented in country-level economies as a method for mapping causal networks of drivers and obstacles to CE transition, as well as for empirically training the causal networks.

A study on the coastal region of Bangladesh utilizing a Remote Ecosystem Monitoring Assessment Pipeline (REMAP) cloud system is presented in Chap. 9. The use
of REMAP to track changes in land use-land cover maps in the studied area is able to help improve land management and forest conversation policies.

In Chap. 10, the scenario of oil pipeline fires destroying sensitive ecosystems and causing environmental damage in Nigeria is presented. The benefits of using a machine learning method to extract and detect Moderate Resolution Imaging Spectroradiometer (MODIS) fire products in real time are discussed. The goal is to use MODIS as an early warning tool for environmental management and sustainability.

The editors are grateful to all the authors for sharing expertise through their book chapters, as well as all the reviewers and others who have directly or indirectly contributed to this book edition. In addition, the effort of the Springer editorial team in assisting in the publication of this book is highly appreciated.

Jejawi, Malaysia          Hui Lin Ong
Hsinchu, Taiwan          Ruey-an Doong
England, UK              Raouf Naguib
Melbourne, Australia     Chee Peng Lim
England, UK              Atulya K. Nagar
# Contents

1. **AI and Environmental Health: A Platform Ecosystem Perspective** ................................................... 1  
   Anitha Chinnaswamy and Nigel Walton  

2. **Artificial Intelligence in Pollution Control and Management: Status and Future Prospects** ........................ 23  
   Tuan-Dung Hoang, Nguyen Minh Ky, Nguyen Thi Ngoc Thuong, Hoang Quy Nhan, and Nguyen Vo Chau Ngan  

3. **Artificial Intelligence in Wastewater Treatment Systems in the Era of Industry 4.0: A Holistic Review**  ............. 45  
   W. Ashane M. Fernando, Sabeeha N. B. A. Khadaroo, and Phaik Eong Poh  

4. **Artificial Intelligence in Real-Time Rainfall-Runoff Modelling and Flood Forecasting**  .................................. 87  
   Amin Talei  

5. **Rough Set Approach to Pharmaceutical Process Waste Reduction** .......................................................... 105  
   M. J. Capili, K. B. Aviso, and R. R. Tan  

6. **Commercial Photovoltaic Performance Optimization Using Genetic Algorithms** ............................................. 117  
   Manjeevan Seera, Choo Jun Tan, Kuldeep Kaur Randhawa, and Kok-Keong Chong  

7. **Smart Cities Energy Trading Platform Based on a Multi-agent Approach** ..................................................... 131  
   Alfonso González-Briones, Pablo Chamoso, Francisco Lecumberri de Alba, and Juan M. Corchado
8 Cross-Validation of Circular Economy Causal Network Maps ...... 147
Ivan Henderson V. Gue, Raymond R. Tan, and Aristotle T. Ubando

9 Application of Cloud-Based Machine Learning Approach to Analyse Remotely Sensed Data for Coastal Monitoring in Bangladesh ............................................................. 171
Husni Mobarak Prince, Iffat Ara, Helmi Zulhaidi Mohd Shafri, Alireza Hamedanfar, Shattri Mansor, Mohammed Oludare Idrees, Nur Shafira Nisa Shaharum, and Mehedi Iqbal

10 Near Real-Time Fire Management and Environmental Sustainability: Towards a Machine Learning Approach to Monitor Oil Pipeline Spill Fires with MODIS Fire Products in Nigeria .............................................................. 193
Michael Gbenga Ogungbuyi, Iffat Ara, and Peter Martinez
About the Editors

**Hui Lin Ong** is currently an Associate Professor at the Faculty of Chemical, Universiti Malaysia Perlis, Malaysia. She was a Deputy Dean of Centre for Graduate Studies, Universiti Malaysia Perlis from year 2011 to 2013. She obtained her Ph.D. in Advanced Materials, from Universiti Sains Malaysia, Malaysia in 2010. Her research interests are on nanomaterials from agricultural waste and polymer based nanocomposites for packaging, membrane and energy storage applications. Dr. Ong has successfully complicated ten research projects funded by Malaysian government, L’Oreal and UNESCO, Malaysia, Toray, Japan and Ministry of Education, Taiwan. She received several innovation awards at national and international levels, which include Gold Medal at International Invention, Innovation Technology Exhibition, Malaysia, Special Award and Gold Medal at Malaysia Technology Expo, Malaysia, and Silver Medal at Geneva International Exhibition of Inventions, Switzerland. Dr. Ong served as Visiting Professor in De La Salle University, Philippines during year 2014–2019. She was also a Visiting Scholar at National Chiao Tung University (2017), National Tsing Hua University (2018) and National Kaohsiung University Science and Technology (2019), Taiwan. She has been invited as speaker to share her research in industries, conferences and universities in Malaysia, Thailand, Philippines, Taiwan, Japan and United States of America. She published more than 50 papers in international journals and conferences. Dr. Ong was named one of the three top young women scientists in Malaysia in 2011 and was awarded the For-Women-In-Science fellowship (FWIS) by L’Oreal and UNESCO Malaysia. In 2019, she received an Endeavour Australia Cheung Kong Research Leadership Award provided by Department of Education and Training, Australia.

**Ruey-an Doong** is a Chair Professor at the Institute of Analytical and Environmental Sciences, and the Dean for NTHU International College at National Tsing Hua University (NTHU), Taiwan. He was also the former Dean of the College of Nuclear Science at National Tsing Hua University in 2011, and Distinguished Professor at National Chiao Tung University before re-joining NTHU. Prof. Doong received his Ph.D. degree in environmental engineering from National Taiwan University,
and now is internationally known for his research in environmental nanotechnology, energy materials, and biosensors and nanosensing devices. Prof. Doong has published over 250 papers in reputable journals with 10000+ citations. He is also serving as an editorial member of several reputed journals like Journal of Environmental Engineering and Management and Global Journal of Environmental Science and Technology. He has received many awards and honors for his contribution in research and teaching in the field of environmental engineering and science. In 2000, Prof. Doong was honored as a fellow of Alexander von Humboldt Foundation, Germany. He is a recipient of the International Honorable Member Award from the American Academy of Environmental Engineers and Scientists in 2016 for his worthy and sustained contributions to the advancement of environmental protection and his eminence in the field of environmental engineering and sciences. He was also awarded several important and prestigious National Awards, including Outstanding Research Award of the Ministry of Science and Technology in 2008 and 2015, Y. Z. Hsu Scientific Award in Technology and Innovation (2017), and Outstanding Award provided by THS Foundation in 2018.

Raouf Naguib was awarded his BSc from Cairo University in 1979 and his MSc (with Distinction) and Ph.D. from Imperial College of Science, Technology and Medicine, University of London, in 1983 and 1986, respectively. He is currently a Visiting Professor at Liverpool Hope University, UK. Prior to this he was Professor of Biomedical Computing and Head of the Biomedical Computing and Engineering Technologies Applied Research Group at Coventry University, UK, and subsequently the Director of BIOCORE Research & Consultancy International, UK. He has published over 400 journal and conference papers and reports in many aspects of health informatics, environmental health, social health, biomedical and digital signal processing, biomedical image processing and the applications of artificial intelligence and evolutionary computation in cancer research. He has also published a book on digital filtering, and co-edited a second book on the applications of artificial neural networks in cancer diagnosis, prognosis and patient management. He was awarded the Fulbright Cancer Fellowship in 1995-96 when he carried out research in the USA, at the University of Hawaii in Mānoa, on the applications of artificial neural networks in breast cancer diagnosis and prognosis.

Prof. Naguib is a member of several national and international research committees and boards, and has served on the Administrative Committee of the IEEE Engineering in Medicine and Biology Society (EMBS), representing Region 8, and the Society’s Distinguished Lecturers Committee and Infrastructure Committee, as well as the UK EPSRC Peer Review College. He also represented the IEEE-EMBS on the IEEE-USA Committee on Communications and Information Policy. He currently serves on several international review panels, including the European Commission, Qatar National Research Fund, UAE National Research Foundation and the Canadian Foundation for Innovation (CFI).

In 2003, Prof. Naguib was appointed as Adjunct Research Professor at the University of Carleton, Ottawa, Canada, and in 2005 he was appointed as Honorary Professor at De La Salle University, Manila, Philippines.
Chee Peng Lim completed his Ph.D. degree with the Department of Automatic Control and Systems Engineering, University of Sheffield, UK, in 1997. His research focuses on the design and development of computational intelligence-based systems for data analytics and decision support, with application in medical prognosis and diagnosis, fault detection and classification, and manufacturing process optimisation. He has published over 450 technical articles in journals, conference proceedings and books, and received 8 best paper awards in international conferences. He has also received many prestigious fellowships for international research collaboration, including Australia-India Senior Visiting Fellowship (Australian Academy of Science), Australia-Japan Emerging Research Leaders Exchange Program (Australian Academy of Technology and Engineering), Commonwealth Fellowship (University of Cambridge), Fulbright Fellowship (University of California, Berkeley), and Visiting Scientists Program of US Office of Naval Research Global (Harvard University and Stanford University). In collaboration with co-workers, he has designed and developed innovative software systems that have won over a dozen of awards, which include Gold Medal at Invention and New Product Exposition (INPEX), Pittsburgh, USA, Gold Medal and Special Award at British Innovation Show, UK, Gold Medal at Geneva International Exhibition of Inventions, Switzerland, and Silver Prize at Open Source Software World Challenge, South Korea. He is currently Professor of Complex Systems, Institute for Intelligent Systems Research and Innovation, Deakin University, Australia.

Prof. Atulya K. Nagar holds the Foundation Chair as Professor of Mathematical Sciences and is the Pro Vice-Chancellor (Research) at Liverpool Hope University, United Kingdom. He is responsible for developing Sciences and Engineering and has been the Head of the School of Mathematics, Computer Science and Engineering which he established at the University. He received a prestigious Commonwealth Fellowship for pursuing his doctorate (DPhil) in Applied Nonlinear Mathematics, which he earned from the University of York (UK) in 1996. He holds BSc (Hons), MSc, and MPhil (with distinction) in Mathematical Physics from the MDS University of Ajmer, India. Prior to joining Liverpool Hope, he was with the Brunel University, London. He is an internationally respected scholar working at the cutting edge of nonlinear mathematics, theoretical computer science, and systems engineering. He has edited volumes on Intelligent Systems, and Applied Mathematics. He is well published with over 450 publications in prestigious publishing outlets. He has an extensive background and experience of working in Universities in the UK and India. He has been an expert reviewer for the Biotechnology and Biological Sciences Research Council (BBSRC) grants peer-review committees for Bioinformatics Panel; Engineering and Physical Sciences Research Council (EPSRC) for High Performance Computing Panel; and served on the Peer-Review College of the Arts and Humanities Research Council (AHRC) as a scientific expert member. Prof. Nagar sits on the JISC Research Strategy group, and he is a fellow of the Institute of Mathematics and Its applications (FIMA) and a fellow of the Higher Education Academy (FHEA).
1 Background on Air Pollution

Air pollution affects the health and well-being of millions of people in the world and is one of the top global causes of mortality. The [1] states that 91% of the world’s population lived in places where air quality exceeded the standard levels causing 4.2 premature deaths as a result.

Air pollution is an environmental hazard and can cause considerable harm to the health of populations and also the environment [2]. Natural air comprises Nitrogen, Oxygen, Argon, Carbon Dioxide and a small amount of other gases; air is said to be polluted when it is contaminated by the presence of substances in it at concentrations, durations and frequencies that endanger health or the environment [2, 3].

Air pollution can result from anthropogenic and natural sources and is classified as primary and secondary pollution based on its source. Pollutants that are directly emitted from a source into the atmosphere are classed as primary pollution, and it includes either natural processes such as sandstorms or volcanic eruptions or human-caused pollution such as vehicle emissions, heating homes and manufacturing. Examples of primary pollutants include sulphur dioxide (SO$_2$), oxides of nitrogen (NO$_x$) and carbon monoxide (CO) [4]. Secondary pollutants are the result of chemical or physical interactions between the primary pollutants themselves or interactions of the primary pollutants with other components in the atmosphere. Photochemical oxidants and particulate matter are some major examples of secondary pollutants [5] (Fig. 1).
Fig. 1 Sources of air pollution and their effects. Source Defra

Air pollution arises from many sources such as mobile sources that include vehicular pollution from cars, trains, ships and planes; natural sources such as volcanoes and wildfires; area sources such as cities and agricultural areas or stationary sources that include factories, power plants and industries [6]. In Europe, 90% of ammonia emissions come from agricultural activities; 60% of sulphur oxides come from energy distribution, and 40% of nitrogen oxides and primary particulate matter come from road transport [7]. A list of common air pollutants and their sources are highlighted in Table 1.

Traffic-related pollution is stated to be one of the main causes for air pollution; it is found that levels of NO₂, the noxious gas that is detrimental to health, are at unprecedented levels. Brake dust produces some of the most harmful kinds of air pollution than vehicle exhausts [9]. Brake dust are minute particles that measure less than 2.5 thousandths of a millimetre, i.e. less than one-thirtieth the width of a human hair. These can then easily pass the nasal cavity reaching vital organs such
<table>
<thead>
<tr>
<th>Pollutant</th>
<th>Major sources</th>
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| **CO** | • Vehicles  
• Gas space heaters  
• Leaking furnaces  
• Gas stoves  
• Burning of wood at residential properties  
• Coal combustion  
• Cigarette smoke |
| **SO₂** | • Power plants  
• Industrial facilities  
• Extraction of metal from ore  
• Volcanoes  
• Locomotives |
| **NOₓ** | • Road transport  
• Energy production  
• Indoor gas stoves and heaters |
| **O₃** | • UV radiation  
• Chemical reactions between NOₓ and VOC  
• Fireworks |
| **PM** | • Natural sources: volcanoes, dust storms  
• Anthropogenic sources: Transport emissions  
• Power plants  
• Road dust  
• Construction |

Table 1 Common air pollutants and their sources [5, 8]

As the heart, lungs and bloodstream, weakening the immune system and resulting in cardiovascular diseases, cancers and in some instances even death.

Nitrogen dioxide (NO₂) is one of the most harmful pollutant gases, irritating the lungs and potentially causing breathing difficulties. Road traffic is a leading source [10]. The main sources of oxides of nitrogen are road transport, power plants, combustion and emissions from rail and ship transport [11].

Transport for London noted that diesel vehicles produce 22 times as much particulate matter and four times as much NOₓ as petrol vehicles. A research study conducted by [12] highlighted the exposure of air pollution on outdoor workers in drive-through chains and the high levels of pollution at several drive-through locations across the UK. Traffic-related air pollution has been associated with significant health impacts.
including respiratory conditions such as asthma, dementia, cognitive decline and delayed lung development in children [13].

2 Air Pollution and Impact on Health

Air pollution exposure results in long- and short-term health effects; short-term exposure is associated with bronchitis, pneumonia, allergic reactions, respiratory infections, headaches and nausea [14]. In the longer term, air pollution exposure can attack the defence system causing damage to the lungs, brain, liver, kidneys and nerves. Air pollution has been found to also result in cancer, exacerbate cardiovascular diseases and even result in death. Continuous exposure to high levels of pollutants impacts the health and growth of children and exacerbates the health conditions of the elderly and vulnerable [14].

A review by states that chronic exposure to air pollution can affect every organ in the body (Fig. 2), causing and exacerbating existing health conditions.

Air pollution also has considerable economic impacts, cutting lives short, increasing medical costs and reducing productivity through working days lost across the economy.

2.1 Types of Air Pollution

The most harmful and common outdoor pollutants include

- Sulphur Dioxide [SO₂].

![Fig. 2 Health impacts of air pollution. Source EEA [7]](image_url)
- Oxides of Nitrogen [NO\textsubscript{x}].
- Ozone [O\textsubscript{3}].
- Particulate Matter [PM].

2.1.1 Sulphur Dioxide [SO\textsubscript{2}]

Sulphur Dioxide [SO\textsubscript{2}] is a colourless gas with a pungent odour and suffocating smell. SO\textsubscript{2} is formed from the burning of coal and oil at power plants, petrol refineries and manufacturing of cement. SO\textsubscript{2} is emitted in significant quantities from the smelting process of sulphide ores for producing copper, lead or zinc. Power generation, heating and diesel vehicles are also significant sources of SO\textsubscript{2} [15].

Effects on Health

Exposure to SO\textsubscript{2} can cause irritation to the eyes, mucous membranes and the skin [16]. It can also exacerbate lung conditions, including bronchitis, wheezing, shortness of breath and coughing. SO\textsubscript{2} can aggravate attacks of asthma, heart and lung disease and worsen respiratory conditions in children and vulnerable groups [17].

As studies have identified an association between SO\textsubscript{2} and mortality [18], exposure to the pollutant began to be recognised as a major health concern. Hence, governments around the world began to formulate policies, in particular, the use of low sulphur content in fuels to mitigate the negative health impacts of the pollutant. As a result of the interventions and policies, it has been increasingly observed that levels of SO\textsubscript{2} have been decreasing in many parts of the world.

2.1.2 NO\textsubscript{x}

Nitrogen Oxides exist in the air [2] as

- Nitric Oxide [NO].
- Nitrogen dioxide [NO\textsubscript{2}].
- Nitrogen Trioxide [NO\textsubscript{3}].
- Nitrogen Tetroxide [N\textsubscript{2}O\textsubscript{4}].
- Dinitrogen Pentoxide [N\textsubscript{2}O\textsubscript{5}].

Nitrogen dioxide is a highly reactive gas, along with NO nitrogen dioxide is artificially generated, the sum of their concentrations referred to as Nitrogen Oxides (NO\textsubscript{x}). Nitrogen dioxide is caused mainly by vehicles, energy production, off-road equipment, power plants and volcanoes. Indoor pollution sources also contribute to NO\textsubscript{x} such as tobacco smoking, heating appliances and may also include emissions from vehicles that infiltrate the indoor settings [16].
Effects on Health

Long-term exposure to high levels of NO\textsubscript{x} results in significant health impacts such as irritation to the nose and throat, may decrease lung function and exacerbate respiratory conditions such as bronchitis, especially in the elderly, vulnerable and children [17]. Exposure to NO\textsubscript{2} is associated with increased incidences of asthma and also increased allergic reactions to pollens. NO\textsubscript{x} and NO\textsubscript{2} are harmful to human health when inhaled due to the deleterious effects they have on the respiratory system. Several studies have demonstrated the significant associations between exposure to NO\textsubscript{x} levels and the increase in daily mortality [19–21].

2.1.3 PM\textsubscript{10}

Airborne particulate matter is a mixture of solid particles and liquid droplets of various chemical compositions and sizes ranging from a few nanometres in diameter to around 100 \(\mu\text{m}\) [16]. They consist of both primary and secondary components that are generally released directly into the atmosphere from their source. Particulate matter arises from both natural and human activities. Primary particles are released directly into the atmosphere from vehicular emissions, burning of fuels and construction site activities. Secondary particulate matter is a result of chemical reactions of gases such as nitrate and sulphate [5]. Particulate matter has the ability to be dispersed over long distances and may even remain suspended in the atmosphere for a considerable length of time [22]. Particulate matter is generally measured and regulated based on mass and has been distinguished into 3 groups based on size ranges [23]:

- PM\textsubscript{10}—<10 \(\mu\text{m}\) in aerodynamic diameter and are referred to as thoracic particles.
- PM\textsubscript{2.5}—<2.5 \(\mu\text{m}\) referred to as fine particles.
- PM\textsubscript{10–2.5}—coarse particles.

Effects on Health

Depending on the varying sizes of particulate matter, they may end up in different areas of the human body. Figure 3 displays a comparison of the size between PM\textsubscript{2.5} and PM\textsubscript{10} against the average diameter of a human hair (~70 \(\mu\text{m}\)) and fine beach sand (~90 \(\mu\text{m}\)). While larger particles may be trapped within the nose itself, fine particles can lodge in the lungs and ultrafine particles may even reach the bloodstream. Of all the criteria air pollutants, particulate matter is said to be the most dangerous to human health. Particulate matter exposure can cause irritation to the throat and nose exacerbating asthma; it can lead to decreased lung function, cause or exacerbate heart disease and even result in premature deaths from lung and heart diseases [22].

Londahl et al. [5] stated that particles can penetrate within the respiratory tract initially by entering the nasal passages and into the alveoli. Due to their excessive penetrability, they then enter deep into the lungs. These particles are then deposited within the tracheobronchial tree, respiratory bronchioles and the alveoli where gas exchange occurs (Fig. 4). Eventually, they enter the bloodstream resulting
3 Historical Perspective of Air Pollutants

The knowledge of the deleterious effects of air pollution on health and environment is not new; this relationship has been contemplated over for centuries; in the UK, air pollution as a public health burden has been in consideration dating back to the thirteenth century [26]. Smog is air pollution that is notoriously recognised for reducing visibility. As a combination of smoke and fog, the term was initially coined in 1905 [27], it was at the height of the Industrial Revolution that smog was known in significant health problems.
to have become a significant issue [28]. As the focus turned to the financial growth and a prosperous economy during the Industrial Revolution, the significant negative impacts on the environment were not given much attention.

In December 1952, London was trapped in a deadly cloud of fog and smoke famously named as ‘The Great London Smog’. The city was using cheap coal for everything from heating homes to power generation. An anticyclone, however, caused the cold air to stagnate that resulted in the deaths of over 12,000 people [29]. There were other infamous air pollution episodes such as the one in Donora Pennsylvania in 1948 and the Meuse Valley episode in Belgium [30], these events spurred the governments to take action to mitigate air pollution. The Clean Air Act in the UK in 1965 was practically the first legislation in the world to tackle this issue which became a blueprint for other nations to follow. By implementing interventions and mitigating measures, developed countries have considerably reduced the impact of air pollution amongst their populations and the environment.

National Ambient Air Quality standards are set for the most hazardous high-volume pollutants, called the criteria pollutants that include

- Airborne Particles (PM).
- Sulphur oxides (SO\textsubscript{x}).
- Carbon monoxide (CO).
- Nitrogen oxides (NO\textsubscript{x}).
- Ozone (O\textsubscript{3}).
- Lead (Pb).

Developed countries have systems to report the levels of the criterion pollutants in the air, air quality index, warning systems and the prediction systems to report levels of pollution and assess the impacts they have on the health and well-being of their populations. Most developing countries however have been slower to establish laws and formal governmental structures to address the serious impacts of air pollution issues. Chinnaswamy [31] stated there are major factors that hinder addressing air pollution issues in developing countries that include monitoring-related issues, lack of data, low budgets, lack of knowledge, lack of government support and the lack of an integrated approach.

4 Monitoring Air Pollution

To identify sources of pollution and locate areas of high concern, air pollution is widely monitored; this is then benchmarked against national or international guidelines and reported. Monitoring depends on the pollutant and the resources available, and most countries use relatively low sampling density, i.e. one sampling site for every 100 km\textsuperscript{2}. Gaseous pollutants such as ozone cover large areas but some pollutants such as particulate matter may only be detectable within a few metres from their sources, hence, it is vital to choose the appropriate sampling and measurement methods to achieve the optimum measurements.
Brauer et al. [32] state that effective air quality management includes three main components:

1. identification and quantification of major sources;
2. regulatory and non-regulatory approaches to reduce source contributions; and
3. measurement and monitoring of air quality to support source identification and to evaluate progress in achieving ambient air quality targets.

Air quality monitoring methods have traditionally employed the use of fixed monitors in select locations that record either hourly or daily data and report the levels. Methods may include passive sampling using diffusion-based methods and active sampling with pumps. Most methods for regulated gas pollutants such as CO, NO₂, ozone and SO₂ use in situ continuous monitors for hourly averaged concentrations. Airborne particles are sampled mostly using integrated sampling systems over a 24 h period with defined inlets, sampler surfaces, filter substrates/holders, pumps and flow controllers [33].

In the USA, more than 4000 monitoring stations track 6 types of air pollution to not only report the levels but to also provide warnings [34]. The primary purpose of a systematic air quality monitoring network assesses if levels of air pollution exceed the guidance as higher levels may result in adverse impacts on human health. Any exceedances in levels require interventions from the government or relevant regulatory bodies.

Data is reported via publicly accessible Internet portals that also employ air quality forecasting tools as well as spatial models that highlight the variation within urban areas. The costs of establishing individual stations are very high, in addition, the spatial variability in pollutant concentrations is poorly characterised with these methods, especially in urban areas (Brauer 2010). Chinnaswamy [12] employed the use of mobile monitors to record the exposure of pollution by outdoor workers in select drive-through selections across the UK to provide a more accurate representation of levels of pollution at the point of exposure of the workers. Adopting newer technologies is imperative in measuring, combatting and mitigating the harmful effects of high levels of pollution.

5 Smart Cities and Air Pollution

UNEP [35] states that by 2050, 66% of the global population will be residing in cities, increasing steeply from the current 54%. This increase in populations is going to increase the environmental pressures in addition to infrastructure needs [36]. Planning cities then becomes essential to provide services and a decent quality of life to citizens [37]. Quality of life includes several dimensions including the air that populations breathe, accessible food, clean water, safe streets, efficient and reliable transportation and many other services [37] [36].

Smart cities use digital technologies and the data they collect to improve the quality of life. A report by McKinsey [36] states that the key quality of life indicators can be