



URBAN POLLUTION

SCIENCE AND MANAGEMENT

EDITED BY
SUSANNE M. CHARLESWORTH
AND COLIN A. BOOTH

WILEY Blackwell

Urban Pollution

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Science and Management

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WILEY Blackwell

This edition first published 2019
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Registered Office(s)

John Wiley & Sons, Inc., 111 River Street, Hoboken, NJ 07030, USA
John Wiley & Sons Ltd, The Atrium, Southern Gate, Chichester, West Sussex, PO19 8SQ, UK

Editorial Office

9600 Garsington Road, Oxford, OX4 2DQ, UK

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Library of Congress Cataloging-in-Publication Data

Names: Charlesworth, Susanne M., editor. | Booth, Colin (Colin A.), editor.

Title: Urban pollution : science and management / edited by Susanne

Charlesworth, Colin Booth.

Description: Hoboken, NJ : John Wiley & Sons, 2018. | Includes

bibliographical references and index. |

Identifiers: LCCN 2018014793 (print) | LCCN 2018028469 (ebook) | ISBN

9781119260462 (pdf) | ISBN 9781119260509 (epub) | ISBN 9781119260486

(cloth)

Subjects: LCSH: Urban pollution.

Classification: LCC TD177 (ebook) | LCC TD177 .U73 2018 (print) | DDC

628.509173/2--dc23

LC record available at <https://lcn.loc.gov/2018014793>

Cover Design: Wiley

Cover Image: © Melinda Nagy/Shutterstock

Set in 10/12pt WarnockPro by SPi Global, Chennai, India

For the future: our children (Ruth, Hugh, and Thomas; Esmée, Edryd, and Efren), and their children (Rónán, Ella-Rose, Aidan, and Douglas), and their children ...

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Insights and Issues into the Impacts of Urban Pollution

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1.1 Introduction

Urban pollution can be defined as the presence or introduction of contaminant material (solid, liquid, gas) or energy (heat, noise, light, radiation) into the built environment, either directly or indirectly, by natural sources and/or anthropogenic activities, which are likely to have harmful or poisonous effects on people, property, and/or the environment. This encompasses pollution of the air we breathe, pollution of the water we drink, pollution of the soil that grows the food we eat, pollution of plants we are reliant upon to perform photosynthesis, pollution of the buildings we live and work in and, ultimately, pollution that changes our weather/climatic systems.

Pollution events occur every day as a result of spills, accidents, negligence, or vandalism (Environment Agency, 2013). However, the effects can be devastating and long-lasting for both humans and the environment (e.g. radiation exposure from Chernobyl, Ukraine). Typically, some of the worst places to suffer from pollution are towns and cities (Table 1.1). Poor air quality is prevalent many days of the year in many cities around the world. For instance, Marylebone Road is a major arterial route (A501) for traffic and pedestrians in the City of Westminster, Central London, where the roadside buildings

create an asymmetric street canyon with a height-to-width ratio of ~ 0.8 (Charron *et al.*, 2007) and, as a consequence the area has consistently high daily mean PM₁₀ level that regularly exceeded the EU (1993/30/EC) Air Quality Directive (47 incidents in 2007; 29 in 2008; 36 in 2009; 15 in 2010; 34 in 2011; and 27 in 2012). These exceedances are attributed to high traffic flows, congestion, and vehicle combustion particulates (AQEG, 2005; Crosby *et al.*, 2014).

As much as 54% of the total global population was estimated to live in urban areas in 2014, which represents an increase of 20% since 1960, and this percentage is expected to grow to 66% by 2050, adding a further 2.5 billion people to urban populations (United Nations, 2014). Many cities are expanding at rates that exceed their capacity to accommodate their growing populations. This means some cities are experiencing a growth of informal settlements on their periphery where they lack services and infrastructure. The density of cities increases the chance that one source of pollution will affect a great many people (WHO, 2016a).

Intensive urbanisation brings with it increased pollution from a variety of sources including industry, traffic, domestic heating, coal and oil combustion, incineration, construction activities, road weathering, and

Table 1.1 The world's ten most polluted cities.

City/country	Type of pollution
1. Linfen, China	Coal
2. Tianying, China	Heavy metals
3. Sukinda, India	Hexavalent chromium
4. Vapi, India	Chemicals and metals
5. La Oroya, Peru	Sulphur dioxide, lead, copper, and zinc
6. Dzerzhinsk, Russia	Chemicals and toxic by-products, such as sarin and VX gas
7. Norilsk, Russia	Air pollution, such as particulates and sulphur dioxide
8. Chernobyl, Ukraine	Radiation
9. Sumgayit, Azerbaijan	Organic chemicals, heavy metals, and oil
10. Kabwe, Zambia	Cadmium and lead

Derived from <http://www.blacksmithinstitute.org/>

maintenance activities such as street sweeping and gully emptying. Inevitably, this leads to increased release of polluted particulates, dissolved contaminants, nutrients, new and emerging pollutants (such as hormones and personal care products), as well as inhalable and respirable particles, among others.

Air pollution is a major risk for many people, as it can cause cardiovascular diseases, strokes, chronic obstructive pulmonary disease, lung cancer, and acute respiratory infections. Moreover, an estimated 3.0 million deaths in 2012 were caused by exposure to outdoor pollution, specifically ambient air pollution, and an estimated 4.3 million deaths were caused by household air pollution. These mortality rates vary regionally – with Georgia, North Korea, Bosnia and Herzegovina, Bulgaria, Albania, China, and Sierra Leone among the highest per 100,000 of their population (WHO, 2016b).

Most global cities lack adequate wastewater management, such that unsafe water, sanitation,

and hygiene were responsible for an estimated 871,000 deaths in 2012. Most of these deaths were linked to diarrhoeal diseases, together with malnutrition, intestinal nematode infections, and schistosomiasis, caused mainly by contamination of drinking water, waterbodies, and soil. Sanitation for urban populations in the world's least developed regions is limited. As a consequence, mortality rates are greatest in Africa – with Angola, Congo, Somalia, Chad, Sierra Leone, Niger, and Burundi among the highest per 100,000 of their population (WHO, 2016b).

With urban pollution being responsible for so many deaths annually, and with an estimated one in every three people expected to be living in cities with at least half a million inhabitants by 2030 (United Nations Human Settlements Programme, 2016), there is a pressing need to explore, understand, expose, and address pollution sources, pathways, and receptors in the urban setting and identify how best to manage and police the issues and impacts associated with them. The next section provides some notable examples of urban pollution that have taught some harsh lessons enabling changes to be made in management and policy.

1.2 Examples of Urban Pollution

There has been a plethora of pollution disasters around the world that have diseased populations, infected landscapes, and contaminated resources above and below ground. As a means of introducing the severity of urban pollution around the world, detailed in the following is an array of examples where air pollution, water pollution, and soil pollution has been devastating and long-lasting for those affected.

1.2.1 Air Pollution in London, United Kingdom

Air quality in towns and cities has been a global problem for many centuries (Brimblecombe,

1998). One of the most widely reported examples of urban air pollution is the 'Great Smog' of London. On 4 December 1952, an anticyclone descended over a windless London, causing a temperature inversion with cold, stagnant air trapped under a layer of warm air. The period of cold weather meant the residents of London burned more coal than usual so they could stay warm. The resultant chimney smoke, mixed with fog, culminated in a blanket of smog forming over the city. However, as concentrations of air pollutants built up in the air, this aided the condensation of water and thus decreased temperatures causing concomitant increases in demands for further heating. As a consequence, air quality quickly deteriorated alongside the health of vulnerable groups (the very young and elderly) or those with pre-existing respiratory problems. By the time the weather changed on 9 December 1952, it was estimated the event had caused (or advanced) the death of 4,000 people, mainly due to respiratory tract infections from hypoxia (low oxygen levels in blood) and due to mechanical obstruction of the air passage from lung infections caused by the smog (Logan, 1953). Similar international examples include the 1930 Meuse Valley fog in Belgium, which killed 60 people (Nemery *et al.*, 2001); the 1948 Donora smog in Pennsylvania, United States, which killed 20 people (Snyder, 1994); the 1966 New York City smog in the United States, which killed 168 people; the 2013 Harbin smog in China (Nunez, 2013); and the 2013 Shanghai smog in China. Unfortunately, in many cases, it takes fatalities attributed to extreme pollution disasters before policies and regulations are even initiated or updated (e.g. the Great Smog (1952) led to the creation of the Clean Air Act (1956) in the United Kingdom).

1.2.2 Air Pollution in Bhopal, India

On 3 December 1984, the world's worst industrial disaster occurred when a toxic gas plume leaked from the Union Carbide Corporation (now Dow Chemical) pesticide

plant in Bhopal, in the state of Madhya Pradesh, India, and descended on the residents of the surrounding urban area, as they slept in their beds (Agarwal and Narain, 1985; Labib and Champaneri, 2012). More than 40 tons of methyl isocyanate gas fumes drifted into the city. People woke with burning eyes and lungs. The incident directly caused at least 3,800 deaths with significant morbidity and premature death for many thousands more (Broughton, 2005). After almost 20 years of legal haggling, compensation was awarded to 554,895 people for injuries received and 15,310 surviving relatives of those killed. The average amount paid to victims was a paltry 25,000 rupees (£300; US\$390; 360 euros), with a shameful 100,000 rupees (£1,200; US\$1,560; 1,440 euros) to families of the dead (Kumar, 2004). It was only following the event that the Indian Government created the Environment Protection Act (1986), which gave powers to the Ministry of Environment and Forests for administering and enforcing environmental laws and policies (Broughton, 2005).

1.2.3 Water Pollution in London, United Kingdom

Claimed by many as the first epidemiological study, Dr John Snow, a public health worker, investigated a severe cholera outbreak in Soho, London, in 1854, that was responsible for killing 616 people (Newsom, 2006; Tulodziecki, 2011). Around this time, London had already suffered incapacitating outbreaks of cholera (1832 and 1849), which had killed thousands of people. To unearth the evidence he needed, he set about mapping the location of those people who contracted the deadly disease and was able to link their movements and activities to those who drank from a water well on Broad Street (now Broadwick Street). Dr Snow was convinced that contaminated water (and not foul air) was responsible for spreading the infectious disease. Conclusive by modern-day standards, it took the removal of the pump handle and subsequent abatement of

the outbreak to convince some officials that the disease was waterborne. In fact, further investigation revealed the well was sited close to a cesspit that was discharging into groundwater and, by doing so, highlighted that faecal waste was somehow responsible for the contamination of the drinking water and for the original cholera outbreak. Other international modern-day examples of cholera outbreaks include those in Iraq (2007), in Congo and Zimbabwe (both 2008), in Haiti (2010), and 2012 in Sierra Leone (Mason, 2009; Nguyen *et al.*, 2014; Piarroux *et al.*, 2011).

1.2.4 Water Pollution in Minamata, Japan

Toxic discharges of industrial wastewater effluent (since 1932) from a petrochemical factory (owned by the Chisso Corporation) in the city of Minamata, Japan, contained methylmercury, which bioaccumulated in shellfish and fish that were then eaten by local residents (D'itra, 1991; Harada, 1995). By 1956, it was observed that many of these people had developed Minamata disease (or Itai-Itai disease, Japanese for 'ouch-ouch') – a neurological syndrome that causes dysfunctional muscle movement together with hearing and speech loss, instigated by severe mercury poisoning. Sadly, the disease was responsible for 21 fatalities over the next two years and, despite accumulating evidence indicating the point source of the pollution, no controls were ever imposed on production and processes at the factory until it ceased operating in 1968. By 1975, there were 800 verified victims of this long-term pollution event, of which 107 were fatalities, and a further 2800 possible additional victims (Mance, 1987).

1.2.5 Soil Pollution in Missouri, United States

A dioxin disaster forced the resident of Times Beach, in Missouri, United States, to abandon their homes and town forever (since

1982) (Belli *et al.*, 1989; Lower *et al.*, 1990). The United States Environmental Protection Agency (EPA) found high levels of a toxic chemical called dioxin (unwanted by-products of industrial and combustion processes) had contaminated many parts of the town. The roads in this suburban town were unpaved and dusty so, in 1972, in an effort of control the dust, the town employed the services of a waste oil haulier to spray its dirt roads with oil. Unfortunately, the haulier, who normally applied used motor vehicle oil for spraying, had been subcontracted to remove oily residues from the processing activities of a pharmaceutical and chemical company (NEPACCO) in Verona. The chemical waste (heavily contaminated with dioxin) was then mixed with waste motor vehicle oil, stored in tanks before being sold or, in the case of Times Beach, being applied as a dust control (Hites, 2011). It is estimated that ~160,000 gallons of waste oil was sprayed over a four-year period. It was almost a decade later that the EPA investigated and found contaminated soils along the network of roads surrounding the homes of the entire community. In the interests of safety, officials were forced to evacuate the town and opted to buy out the 800 residential properties and 30 businesses at an estimated cost of US\$36.7 million (£28.5 million; 33.8 million euros).

1.3 Structure of This Book

This book comprises five sections, which are collated into 31 chapters. The first part of the book provides *An Introduction* that offers some initial insights into the impacts and issues associated with urban pollution (Chapter 1). Since many nations now have legislation and policies in place for their designated environmental protection bodies to control and manage pollution to regulated and permitted guidelines, Section 2 exposes *Policy and Pollution* through chapters that take a historical view of pollution and offer insight into relevant air policies, water policies, and soil policies (Chapters 2–5), and demonstrate a

range of types of pollution (Chapters 6–12). Section 3 assembles options for *Monitoring, Remediation, and Management* through a collection of chapters concentrating on river ecology, urban hay meadows, ecosystems, waste disposal sites, building materials, zeolites, bioremediation, environmental impact assessment, and citizen science (Chapters 13–22). Section 4 contextualises *International Case Studies* with examples from the United States, China, India, Brazil, Hungary, Ghana, Nigeria, and Lebanon (Chapters 23–30). Finally, Section 5 converges with a *Summary of the Book* that distils lessons that can be learned to protect people and property in the built environment.

1.4 Conclusions

This edited book aims to develop an appreciation of the diverse, complex, and current themes of the urban pollution debate across

the built environment, urban development, and management continuum. While it cannot cover every type of pollutant and revisit every notable pollution incident in every country, it does offer an integration of physical and environmental sciences, combined with social, economic, and political sciences and the use of case studies to provide a unique resource, useful to policy experts, scientists, engineers, and subject enthusiasts. Many of these chapters have been written by academics with expertise in the field, but this book also contains chapters authored or co-authored by practitioners with a wealth of practical experience. It is, therefore, of interest to those involved in the impacts and management of urban pollution issues worldwide, such as environmental toxicologists, chemists, and health experts working in government agencies, academia, and commercial consultancies.

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2

Historical Urban Pollution

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2.1 Introduction

Pollution released from anthropogenic activities is a major environmental concern at global, regional and local scales. The natural environment has been contaminated by human activity for thousands of years; however, modern industrial development, advancements in transport technologies, population increases and the subsequent urban sprawl have led to unprecedented levels of pollution experienced since the twentieth century. A changing complexity of contaminants has been released to land, waterways, and air, from industry, transport and residential sources within built environments over time, especially since the Industrial Revolution post 1800 in Europe and the United States (Brimblecombe, 2005). Urban populations residing in close proximity to industrial complexes and transport infrastructure are most at risk to the long- and short-term health effects of exposure to toxic pollutants. Air pollution is ubiquitous within the urban environment and comprises principally noxious gases and particulate matter (PM). Exposure is unavoidable and dangerous even at low levels (Shi *et al.*, 2016). Air pollution is recognized as the single largest global environmental health risk, responsible for 7 million annual global deaths (Silva

et al., 2013; Austen, 2015), making it the focus of this chapter.

Much of what we understand about past urban air pollution is derived from documented historical evidence of known industrial and urban activities and only relatively recent (post 1960) pollution monitoring programmes. Environmental archives such as lakes, peat bogs and ice sheets therefore provide invaluable evidence of pollution emissions. Natural sinks for atmospheric contaminants, they allow the reconstruction of past pollution trends beyond what is possible with conventional monitored data. Records from sediment archives reveal intricate relationships between technological advancements and air pollution since ancient times (Brännvall *et al.*, 1999). As new technologies and industries have emerged and expanded, so too have new types of pollutants, especially post WWII.

Urban pollution varies from place to place, depending on specific past urban and industrial activities experienced in countries and cities. Sedimentary archives record local, regional and global pollution signals. In this chapter, case studies of urban pollution are presented that focus primarily on UK cities since Britain is renowned for its extensive industrial and urban past. A general history of urban air pollution is presented, supported by evidence

from sedimentary archives and key events that span ancient civilizations, the Industrial Revolution and the twentieth century.

2.2 Historical Pollution Monitoring using Environmental Archives

Once emitted into the environment, pollutants are transported via air or water and eventually can settle in natural archives, such as ice sheets, estuaries, lakes, and peat bogs (MARC, 1985) (Figure 2.1). A robust record of pollution deposition can be preserved within naturally accumulating sediments, inferred from a range of environmental proxies and atmospheric contaminants stored within extracted sediment/ice cores (Figure 2.1, Table 2.1). These records allow the reconstruction of spatially specific, long-term pollution histories spanning decades to millennia. Lake and peat bog records from around the world have revealed local, regional and global impacts of industry and urbanization on pollutant emissions. Contamination detected in archives from even the most remote, ‘pristine’ regions (e.g. the Arctic) demonstrates the long-range transport and far-reaching impacts of air pollution (Rose *et al.*, 2004).

2.3 Ancient Air Pollution

Urban pollution is not a recent phenomenon. Palaeolithic cave dwellings would have been polluted with smoke from wood burning, particularly from 300,000 to 400,000 years ago when fire became a common hominin technology (Boros *et al.*, 2003; Roebroeks and Villa, 2011). As early settlements were established, domestic activities would have caused deterioration of air quality at a very localized scale. The earliest significant regional air pollution caused by pre-historic anthropogenic activities is detected in Swiss lake sediments. Enhancements in Pb flux occur during the Neolithic (3800 BC) due to

the release of Pb from soil due to early agriculture and Bronze Age (2500 BC) metallurgy (Thevenon *et al.*, 2011).

A 7000-year metal history reconstructed from Chinese lake sediments detects emissions from the start of the Bronze Age at ~3000 BC (+/- 328) and identifies a period of rapid metal enhancement in the late Bronze Age (475 BC–220 AD) from the production of weapons, vessels, and tools (Lee *et al.*, 2008). Temporal shifts in the metallic characteristics of lake stratigraphies also distinguish between early Bronze Age technology (Cu) and later (1100–1300 AD) silver mining activity (Cd, Ag, Pb, and Zn) in China (Hillman *et al.*, 2015).

Air pollution increased as a consequence of the rise of ancient civilizations. Peaks in airborne Pb recorded in European (Swiss and Swedish) sediment records are attributed to the Greek (800–146 BC) and Roman (300 BC–100 AD) empires from Pb and Sn smelting (Brännvall *et al.*, 1999; Thevenon *et al.*, 2011). Mining regions in central Spain, exploited for gold and silver during the past 2000 years, are also highlighted as a potential ancient source of atmospheric Pb and Hg releases (Thevenon *et al.*, 2011).

Permanent increases in Pb deposition are observed during the medieval period (900–600 AD) in Europe, reflecting population increases and the expansion of mining activities (Brännvall *et al.*, 1997). Periods of relatively low anthropogenic emissions reflect episodes of reduced economic and industrial activity due to population declines during the Great Famine (1315–1321 AD) and Black Plague (1346–1383 AD) (Brännvall *et al.*, 1999; Thevenon *et al.*, 2011). Further Pb reductions ~1600 AD are attributed to the relocation of metal exploitation from Europe to America. This is reflected in Peruvian environmental archives, which reveal localized, low-scale metallurgical activity during the Inca Empire (1400–1533 AD), with regional metal enhancement due to intensified extensive silver exploitation during the onset of the colonial period (post 1540 AD) (Uglietti *et al.*, 2015).