Review

Pollution and health: a progress update

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The *Lancet* Commission on pollution and health reported that pollution was responsible for 9 million premature deaths in 2015, making it the world's largest environmental risk factor for disease and premature death. We have now updated this estimate using data from the Global Burden of Diseases, Injuries, and Risk Factors Study 2019. We find that pollution remains responsible for approximately 9 million deaths per year, corresponding to one in six deaths worldwide. Reductions have occurred in the number of deaths attributable to the types of pollution associated with extreme poverty. However, these reductions in deaths from household air pollution and water pollution are offset by increased deaths attributable to ambient air pollution and toxic chemical pollution (ie, lead). Deaths from these modern pollution risk factors, which are the unintended consequence of industrialisation and urbanisation, have risen by 7% since 2015 and by over 66% since 2000. Despite ongoing efforts by UN agencies, committed groups, committed individuals, and some national governments (mostly in high-income countries), little real progress against pollution can be identified overall, particularly in the low-income and middle-income countries, where pollution is most severe. Urgent attention is needed to control pollution and prevent pollution-related disease, with an emphasis on air pollution and lead poisoning, and a stronger focus on hazardous chemical pollution. Pollution, climate change, and biodiversity loss are closely linked. Successful control of these conjoined threats requires a globally supported, formal science–policy interface to inform intervention, influence research, and guide funding. Pollution has typically been viewed as a local issue to be addressed through subnational and national regulation or, occasionally, using regional policy in higher-income countries. Now, however, it is increasingly clear that pollution is a planetary threat, and that its drivers, its dispersion, and its effects on health transcend local boundaries and demand a global response. Global action on all major modern pollutants is needed. Global efforts can synergise with other global environmental policy programmes, especially as a large-scale, rapid transition away from all fossil fuels to clean, renewable energy is an effective strategy for preventing pollution while also slowing down climate change, and thus achieves a double benefit for planetary health.

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Commission findings on pollution and health

Pollution— ie, unwanted waste of human origin released to air, land, water, and the ocean without regard for cost or consequence—is an existential threat to human health and planetary health, and jeopardises the sustainability of modern societies. Pollution includes contamination of air by fine particulate matter ($PM_{2·5}$); ozone; oxides of sulphur and nitrogen; freshwater pollution; contamination of the ocean by mercury, nitrogen, phosphorus, plastic, and petroleum waste; and poisoning of the land by lead, mercury, pesticides, industrial chemicals, electronic waste, and radioactive waste.

The 2017 *Lancet* Commission on pollution and health, which used data from the Global Burden of Diseases, Injuries, and Risk Factors Study (GBD) 2015, found that pollution was responsible for an estimated 9 million deaths (16% of all deaths globally) and for economic losses totalling US$ 4·6 trillion (6·2% of global economic output) in 2015.[1] The Commission noted pollution's deep inequity: 92% of pollution-related deaths, and the greatest burden of pollution's economic losses, occur in low-income and middle-income countries (LMICs).

This report presents an updated estimate of the effects of pollution on health, made on the basis of the GBD 2019 data, and also makes an assessment of trends since 2000. These data show that the situation has not improved, and that pollution remains a major global threat to health and prosperity, particularly in LMICs. Since 2000, the steady decline in the number of deaths from the ancient scourges of household air pollution,

Key messages

- Over the past two decades, deaths caused by the modern forms of pollution (eg, ambient air pollution and toxic chemical pollution) have increased by 66%, driven by industrialisation, uncontrolled urbanisation, population growth, fossil fuel combustion, and an absence of adequate national or international chemical policy.
- Despite declines in deaths from household air and water pollution, pollution still causes more than 9 million deaths each year globally. This number has not changed since 2015.
- More than 90% of pollution-related deaths occur in low-income and middle-income countries.
- Key areas in which focus is needed include air pollution, lead poisoning, and chemical pollution. Air pollution causes over 6·5 million deaths each year globally, and this number is increasing. Lead and other chemicals are responsible for 1·8 million deaths each year globally, which is probably an undercounted figure.
- Most countries have done little to deal with this enormous public health problem. Although high-income countries have controlled their worst forms of pollution and linked pollution control to climate change mitigation, only a few low-income and middle-income countries have been able to make pollution a priority, devoted resources to pollution control, or made progress. Likewise, pollution control receives little attention in either official development assistance or global philanthropy.
- 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.
- We cannot continue to ignore pollution. We are going backwards.

	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 (0·07–0·25)	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.

Table: **Global estimated pollution-attributable deaths (millions) by type of pollution and sex, 2019**

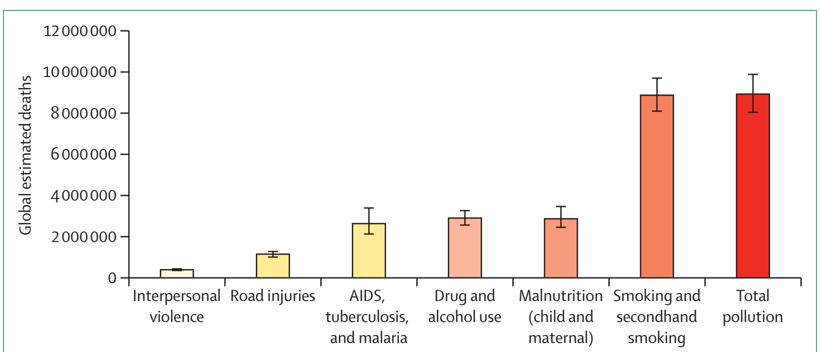

Figure 1: **Global estimated deaths by major risk factor or cause**
Data from Institute for Health Metrics and Evaluation and Global Burden of Diseases, Injuries, and Risk Factors Study 2019.[6] Error bars are 95% CI.

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unsafe drinking water, and inadequate sanitation are offset by increasing deaths attributable to the more modern forms of pollution. These modern forms of pollution—eg, ambient air pollution, lead pollution, and chemical pollution—require major increases in mitigation and prevention.

Death and disease due to pollution in 2019

The analysis of disease and premature death due to pollution that we present uses GBD methodology that was developed in the 1990s by WHO, which was expanded by the Institute for Health Metrics and Evaluation (IHME).[2] Similar to earlier iterations of the GBD study, the 2019 study included new input data and several methodological updates.[3] Given the large number of chemical pollutants and their ubiquity in the modern environment, the disease burden attributable to chemical pollution is likely to be substantially greater than current estimates.[4]

Pollution-related death

In 2019, pollution was responsible for approximately 9·0 million premature deaths. Air pollution (both household and ambient air pollution) remains responsible for the greatest number of deaths, causing 6·7 million deaths in 2019. Water pollution was responsible for 1·4 million premature deaths. Lead was responsible 900 000 premature deaths. Toxic occupational hazards, excluding workplace fatalities due to safety hazards, were responsible for 870 000 deaths (table). The total effects of pollution on health would undoubtedly be larger if more comprehensive health data could be generated, especially if all pathways for chemicals in the environment were identified and analysed.[5]

The GBD 2019 data show that the effect of pollution on disease and disability varies by sex. Men are more likely to die from exposure to ambient air pollution, lead pollution, and occupational pollutants than women. Women and children are more likely to die from exposure to water pollution than men.

A comparison of the effects of pollution on morbidity and mortality with those of other risk factors on morbidity and mortality shows that pollution continues to be one of the largest risk factors for disease and premature death globally. The impact of pollution on health remains much greater than that of war, terrorism, malaria, HIV, tuberculosis, drugs, and alcohol, and the number of deaths caused by pollution are on par with those caused by smoking (figure 1).[6]

Trends in pollution and pollution-related death and disease: 2000–19 and 2015–19

The decline in deaths from traditional pollution (ie, household air pollution from solid fuels and unsafe water, sanitation, and hand washing) is most evident in Africa, where improvements in water supply, sanitation, antibiotics, treatments, and cleaner fuels have made measurable inroads in mortality statistics (figure 2).[6]

Deaths from the modern forms of pollution (ie, ambient particulate matter air pollution, ambient ozone pollution, lead exposure, occupational carcinogens, occupational particulate matter, gases, fumes, and environmental chemical pollution) have increased substantially over the past 20 years on a global scale. Ambient air pollution was responsible for 4·5 million deaths in 2019. This proportion is an increase from 2015, when ambient air pollution was responsible for 4·2 million deaths, and 2000, when it was responsible for 2·9 million deaths. These increases were due to increases in ambient air pollution and in the incidence of non-communicable diseases (NCDs) linked to air pollution.

Increases in deaths from the more modern forms of pollution are particularly evident in south Asia, east Asia, and southeast Asia (figure 3).[6] Rising ambient air pollution, rising chemical pollution, ageing populations, and increased numbers of people exposed to pollution are the factors responsible for these increased numbers of deaths.[3]

In Africa, household air pollution and water pollution are still the predominant causes of pollution-related disease and death, but the amount of ambient air pollution and the number of deaths from air-pollution-related NCDs have begun to increase as African countries develop economically, industrialise, build infrastructure, and become increasingly urbanised.[7,8] Increases are most marked in the most rapidly emerging African economies. Data show that there has been improvement in the morality rate (number of deaths per 100 000 population) attributable to $PM_{2·5}$ in some cities in Africa.[9]

Pollution issues of growing concern

The persistence of lead pollution

With the decision made by the Government of Algeria, in 2021, to remove lead from its gasoline supply, lead has now been removed from automotive fuel in every country in the world. This decision represents a major triumph for public health and has resulted in a worldwide reduction of lead blood concentrations in children and a reduction in the prevalence of lead poisoning. However, despite these advances, lead remains a major threat to health.

The GBD 2019 estimated that lead exposure is annually responsible for 0·9 million deaths (95% CI 0·55–1·29) worldwide but this estimate is probably a substantial undercount, because new data from long-term studies of American adults suggest that the cardiovascular and renal toxicity of lead could extend down to much lower blood lead concentrations than previously recognised and that there might be no threshold for these effects.[10–12]

Furthermore, analyses have documented that elevated blood lead concentrations and lead poisoning in children, especially in LMICs, are much more widely prevalent than previously recognised (figure 4).[13,14] More than 800 million children are estimated to have blood lead concentrations that exceed 5·0 μg/dL, which was, until 2021, the concentration for intervention established by the US Centers for Disease Control and Prevention. This concentration has now been reduced to 3·5 μg/dL.[14] The implications of this finding for children's intellectual impairment are staggering. Children with blood lead concentrations higher than, or equal to, 5·0 μg/dL could score 3–5 points lower on intelligence tests than children with blood lead concentrations lower than 5·0 μg/dL. Furthermore, higher blood lead concentrations are associated with serious losses of cognitive function.[15] Lead-related IQ losses are associated with increased rates of school failure, behavioural disorders, diminished economic productivity, and global economic losses of almost $1 trillion annually. In Africa, the economic losses from lead-related IQ loss are equivalent to about 4% of gross domestic product (GDP) and in Asia, these losses are equivalent to 2% of GDP.[14]

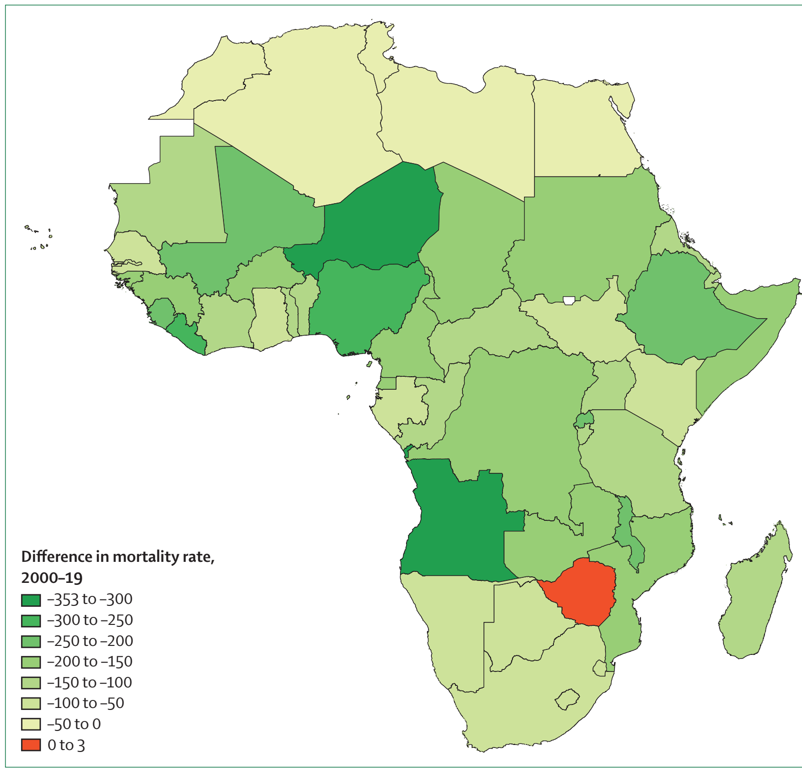

Figure 2: **Downward trend in mortality rate from traditional pollution in Africa, 2000–19**
Mortality rate is deaths per 100 000 population. Data from Institute for Health Metrics and Evaluation and Global Burden of Diseases, Injuries, and Risk Factors Study 2019.[6]

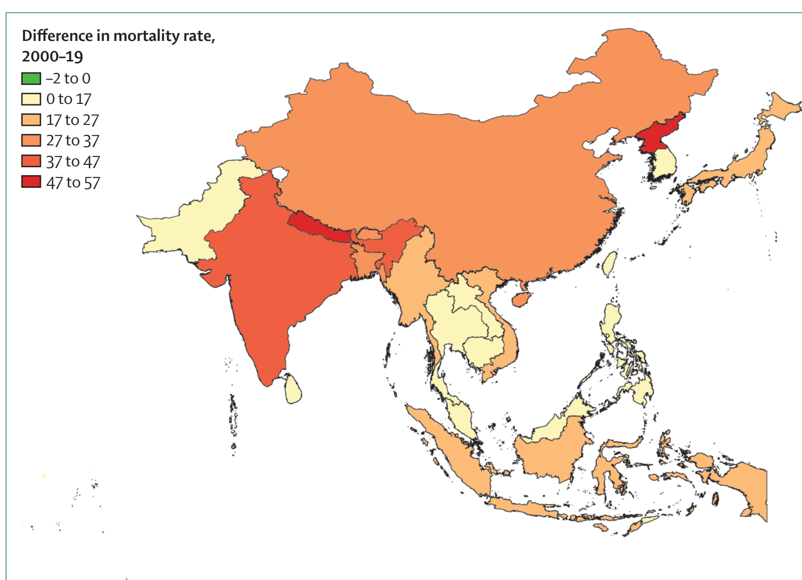

Figure 3: **Upward trend in mortality from modern pollution in south Asia and southeast Asia, 2000–19**
Mortality rate is deaths per 100 000 population. Data from Institute for Health Metrics and Evaluation and Global Burden of Diseases, Injuries, and Risk Factors Study 2019.[6]

Today, the principal sources of lead exposure include unsound recycling of lead–acid batteries and e-waste without pollution controls;[16–18] spices that are contaminated

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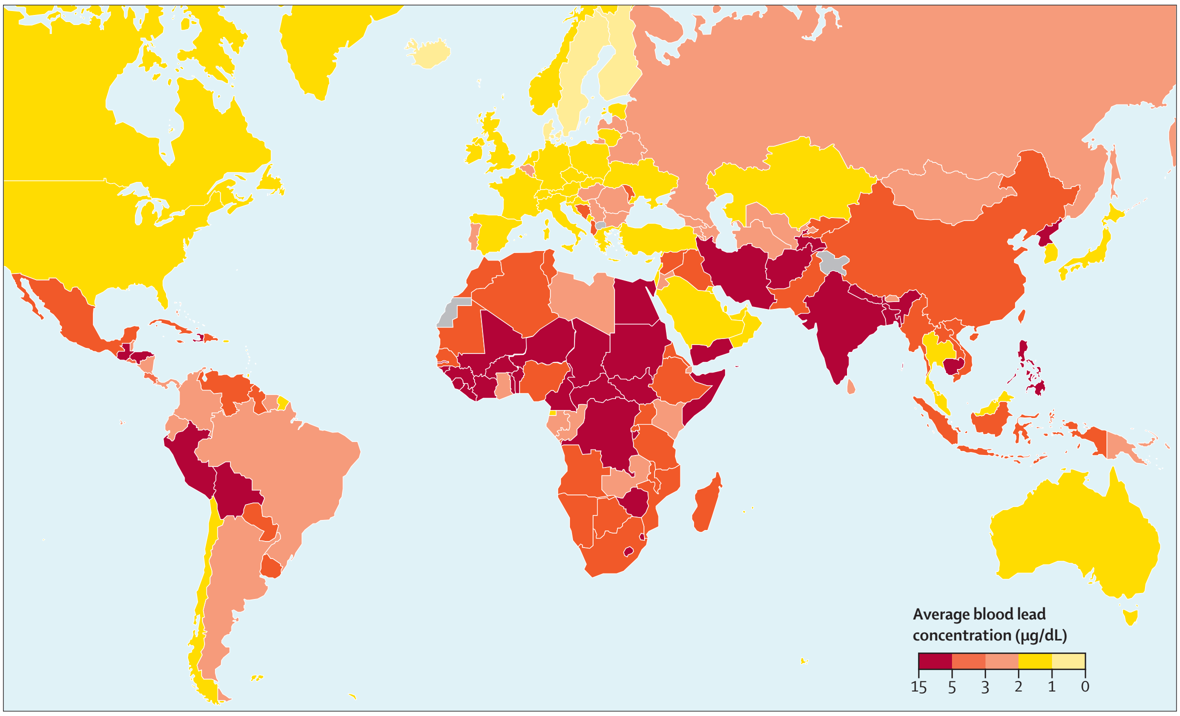

Figure 4: **Global distribution of childhood lead exposures in 2019**
Childhood lead exposures represented by average blood lead concentration (µg/dL). This figure is reproduced from a previous report[14] by permission of UNICEF and Pure Earth.

with lead;[19,20] pottery glazed with lead salts, which leach out into acidic foods;[21,22] and lead in paint and other consumer products.[23] The full extent of population exposure to each of these sources varies by country and is often unknown.

The intersection of climate change and air pollution

Air pollution is entwined with climate change because the emissions driving both development problems come largely from the same sources (eg, fossil fuel or biofuel burning). Burning fuels results in fine and ultrafine particulates (eg, $PM_{2·5}$ and others), long-lived greenhouse gases, and short-lived climate pollutants (SLCPs). SLCPs are simultaneously air pollutants and climate warmers. The primary SLCPs are methane, black carbon (ie, soot), and hydrofluorocarbons.[24] Methane emissions emitted up to and including 2019 account for approximately a third of the warming effect of all well mixed greenhouse gas emissions and for 45% of the net warming effect of all anthropogenic activities.[25,26] Methane emission is one of the main precursors to ground level ozone, which is a major source of premature death. Black carbon is a component of $PM_{2·5}$ and is also a SLCP with a global warming potential that is 460–1500 times higher than that of carbon dioxide. Black carbon emissions emitted up to and including 2019 account for approximately 8% of the net warming effect of all anthropogenic activities.[24] Solid fuels that are used for domestic purposes contribute to 58% of global black carbon emissions.[27] Some air pollutants (eg, sulphates, nitrates, and some types of $PM_{2·5}$) lead to climate cooling. Policies that do not simultaneously optimise climate change mitigation and air quality run the risk of causing unanticipated trade-offs or so-called win–lose outcomes, but policies that do can result in synergies that benefit both climate and health.[28–30] SLCPs have a relatively short residence time in the atmosphere (ie, less than approximately 15 years); for this reason, SLCP reductions are the strongest lever available to slow the rate of warming and the mounting toll of climate change events in the next few decades.

The silent threat of chemical pollution

Chemicals have become widely disseminated in the global environment. Global chemical manufacturing is increasing at a rate of about 3·5% per year and is on track to double by 2030.[4] Approximately two-thirds of current chemical production is in LMICs.

Undercounting of the disease burden attributable to chemical pollution is probably substantial, because only a small fraction of the many thousands of manufactured chemicals in commerce have been adequately tested for safety or toxicity, and the disease burdens attributable to these chemicals cannot be quantified. Three particularly worrisome, and inadequately charted, consequences of chemical pollution are developmental neurotoxicity, reproductive toxicity, and immunotoxicity.

Developmental neurotoxicity of chemicals

Over 200 chemicals, including lead, methylmercury, polychlorinated biphenyls, arsenic, organochlorine and organophosphate pesticides, organic solvents, and brominated flame retardants are neurotoxic to humans,[31] and many of these chemicals are widespread in the modern environment.[4] Children are particularly susceptible to their effects: even low-dose exposures to neurotoxic chemicals during key periods of developmental vulnerability in fetal and postnatal life have more serious effects on health than high-dose exposures to the same chemicals in adults.[32,33]

Reproductive toxicity of chemicals

Evidence is strong and growing that exposure to particular manufactured chemicals, even at low doses, can have adverse effects on fertility and pregnancy. Pesticides, industrial chemicals (eg, halogenated flame-retardants, plasticisers, and dioxins), environmental chemicals of pharmaceutical origin, and toxic metals have been linked to a range of reproductive problems.[4,34] Prenatal and early postnatal exposure to chemicals also appear to be linked to an increased incidence of reproductive diseases later in life, including endometriosis, breast cancer, cervical cancer, uterine cancer, and testicular cancer.[4]

Immunotoxicity of chemicals and implications for communicable disease control

Some pollutants are toxic to the immune system. For example, perfluoroalkyl acids have been associated with reduced antibody responses to vaccines,[35] increased risk in children for hospitalisation with infectious disease,[36] and increased severity of COVID-19 infections.[37] Exposure to traffic-related air pollution[38] has been associated with increased mortality from COVID-19 and exposure to cadmium[39] has been associated with increased mortality from influenza. Many other chemical exposures have been shown to be toxic to the immune system in laboratory studies;[40] although research on the clinical consequences of exposure is still scarce.

Transboundary pollution

Although most pollution remains near pollution sources in countries of origin, a growing body of evidence shows that transboundary pollutants can travel long distances in wind, in water, through the food chain, and in consumer products. Global winds transport air pollution from east Asia to North America, from North America to Europe, and from Europe to the Arctic and central Asia.[41] A substantial portion of air pollution exposure in Europe originates from non-European sources.[42] Industrial activity in China has increased airborne pollutants in places as near as Japan, South Korea, and Taiwan, and as far away as California, USA.[43,44]

The drivers of pollution also extend across less tangible boundaries. Wealthier countries displace their pollution footprints overseas, whereas lower-income countries experience increasing pollution domestically.[45] China has both problems. As China successfully reduced $PM_{2·5}$ emissions from household and domestic factories, emissions generated by export production rose, with more than 60% of this increase associated with the manufacture of goods destined for use in Organisation for Economic Co-operation and Development (OECD) countries.[46]

It is not just air pollution that moves globally. The contamination of cereals, seafood, chocolate, and vegetables produced in LMICs for export increasingly threatens global food safety. This contamination is a consequence of soil and water in LMICs that are polluted with lead, arsenic, cadmium, mercury, and pesticides.[47–49] Toxic metals found in infant formulas and baby foods are of particular concern.[50–53] There have been few studies on this issue in LMICs, although turmeric contaminated by lead has been identified in several locations in Bangladesh, a problem that is likely to be widespread.[19]

Economic impacts of pollution

The economic losses associated with deaths due to pollution can be valued by the output lost when a person dies prematurely (ie, the human capital approach), or by using the value per statistical life (ie, what people would pay for small risk reductions that sum up to one statistical life), which we refer to as welfare losses. The 2017 *Lancet* Commission on pollution and health, which used the value per statistical life approach, found that welfare economic losses associated with 2015 pollution were equal to 6·2% of world GDP, and 82% of these economic losses were attributed to ambient air pollution and household air pollution. A World Bank study on health costs of $PM_{2·5}$ air pollution using GBD 2019 data showed that, in 2019, the global economic welfare losses attributable to household air pollution and ambient $PM_{2·5}$ air pollution amounted to 6·1% of global economic output.[54] The economic effects of air pollution are especially severe in regions of east Asia and the Pacific, where losses are equivalent to 9·3% of GDP, and south Asia, where losses are equivalent to 10·3% of GDP.[54]

For this Review, instead of repeating global calculations, we used the human capital approach to evaluate the cost of modern pollution on a subset of countries' prospects for economic growth and societal development.[55] Specifically, we estimated the present value of future output lost when a person dies prematurely due to pollution. Six countries or regions were chosen: India and China, which are the two most populous countries globally; Nigeria and Ethiopia, which are the two most populous countries in Africa; the USA, which has the world's largest economy; and EU15, which is a large economic entity with common pollution standards across member states (figure 5).[6,56,57]

Traditional pollution

In 2000, output losses due to traditional pollution were 6·4% of GDP in Ethiopia, 5·2% of GDP in Nigeria, and

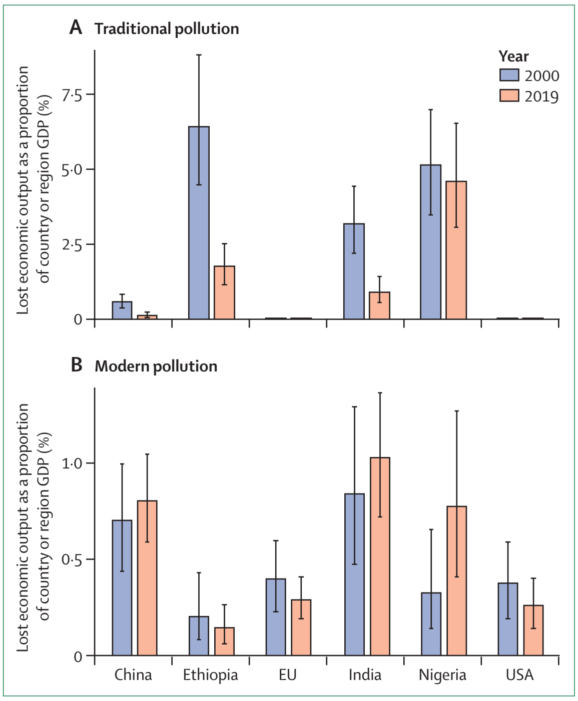

Figure 5: **Lost economic output as a proportion of country GDP due to deaths from modern and traditional pollution in 2000 and 2019**
(A) Traditional pollution includes deaths from household air pollution from solid fuels and unsafe water, sanitation, and hand washing.[6,56,57] (B) Modern pollution includes deaths from ambient ozone pollution, ambient particulate matter pollution, lead exposure, occupational carcinogens, occupational particulate matter, gases, and fumes.[6,56,57] GDP=gross domestic product.

3·2% of GDP in India. These output losses were huge burdens on the economies of these countries. By 2019, death rates due to traditional pollution were a third of the death rate in 2000 in Ethiopia and Nigeria, and less than half of the death rate in 2000 in India. Consequently, pollution-related economic losses as a proportion of GDP fell substantially. Nonetheless, economic losses due to traditional pollution are still approximately 1·0% of GDP in India and 2% of GDP in Ethiopia. In Nigeria, economic losses from traditional pollution are more than 4·6% of GDP, due to the increase in the value of workers' output in Nigeria over the past 20 years.

See Online for appendix

Modern pollution

Economic losses due to modern forms of pollution have increased as a proportion of GDP between 2000 and 2019 in India, China, and Nigeria, and are now conservatively estimated to amount to approximately 1·0% of GDP in each of these countries. The full economic losses, if the full health impacts of pollution were to be counted and the effects of pollution on informal sectors and environmental damage were to be fully detailed, are likely to be greater. By contrast, economic losses due to modern forms of pollution have fallen as a proportion of GDP in the USA and in EU15 countries. The reduction of economic losses in these countries reflects pollution control, the outsourcing of polluting industries, and reductions in death rates.

Progress in addressing pollution and pollution related disease

The *Lancet* Commission on pollution and health made science-based recommendations in 2017 for action against pollution on the basis of data from the GBD 2015.[1] Since 2017, there has been strikingly little effort in most countries to act on these recommendations or to prioritise action against pollution. For example, although GBD 2019 calculates that lead currently contributes to over 900 000 premature deaths each year,[6] international attention and funding on chemical pollution is more focused on emerging issues such as perfluorinated and polyfluorinated alkyl substances and endocrine disruptors, for which the global burden of disease is less clear than on lead. Likewise, ministries of health continue to prioritise infectious diseases and disease treatment, leaving pollution prevention to the ministries of environment, which usually have less power and less funding than ministries of health. The powerful ministries of finance, urban development, and energy, which make the key investment decisions that shape options in energy choices and development pathways, are seldom involved in pollution control. Despite strong and growing evidence for pollution's contribution to NCD morbidity and mortality, international and national NCD control programmes focus almost exclusively on behavioural and metabolic risk factors such as tobacco use, exercise, and obesity, while ignoring pollution.[58]

As health improvements typically occur several years after changes in policy, major reductions in the burden of disease attributable to pollution could not reasonably be expected to be visible in this 4-year review of IHME data. However, our review of pollution policies in countries around the world finds little substantive progress in the development of pollution-control policies, even in the most severely affected countries, which are mostly LMICs. High-income countries with active programmes to control air pollution and chemical pollution continue to show advances, but only a handful of LMICs show measurable advances (appendix pp 1–4). The absence of quantitative data on pollution rates and population exposures, particularly for chemical pollution, means that assessment of progress for most issues relies largely on specialist knowledge and opinion.

We summarise responses to the *Lancet* Commission's recommendations in the following paragraphs. In general, responses have been weak and have been overwhelmed within national development agendas by a focus on climate change and COVID-19.

Prioritise pollution prevention and health protection nationally and internationally

International attention to pollution reduction has been growing, albeit slowly and unevenly. Most notably, the

UN Environment Programme has identified pollution as one of three key pillars of its 2022–25 strategy, alongside climate change and biodiversity loss.[59] WHO has substantially tightened its health-based global air quality guidelines, lowering the guideline value for $PM_{2·5}$ from 10 μg/m³ to 5 μg/m³.[60] WHO has also issued new guidance on medical management of lead exposure, and has linked air pollution reduction to climate change mitigation and NCDs.[61]

In national programmes, China has incorporated pollution-control targets into its most recent 5-year plan, and has begun to reduce air pollution in several large urban areas.[62,63] Mexico City, Bangkok, and other major cities have had some success against ambient air pollution.[64] India has made efforts against household air pollution, most notably through the Pradhan Mantri Ujjwala Yojana programme, but in 2019 still had the world's largest estimated number of air pollution-related deaths.[55] The EU has a domestic Zero Pollution Action Plan as part of the European Green Deal, which also includes a small international component.[65] These initiatives are all important steps, but much more is needed.

Mobilise, increase, and focus funding and international technical support for pollution control

The international funding response for pollution prevention has been meagre. Only a small number of bilateral and multilateral agencies and organisations are promoting the health and pollution agenda, and even those efforts receive only little support.

An analysis of available OECD figures for 2016 on official development assistance (ODA) concluded that donor countries have not responded to the global crisis of pollution-related disease and death through expanded investment in pollution control.[66] A 2019 study of ODA from bilateral and UN agencies allocated to reducing modern pollution found that support fluctuated from year to year and that there was no overall upward trend.[66] ODA contributions to international conventions and frameworks concerning pollutants and chemicals amounted to $860 million in 2016–18, which is inadequate for the size and scope of the problem. Private philanthropic funding for pollution control also remains scarce.[67,68]

Establish systems to monitor and control pollution

Monitor air pollution and its effects on health

China and India, countries with massive pollution challenges, have been making substantial investments in monitoring and planning to support pollution reduction efforts. Extensive efforts in China to control the burning of solid fuels under National Air Quality Action Plans have resulted in marked decreases in the amount of pollution. In the Beijing region, mean ambient $PM_{2·5}$ concentrations have dropped by nearly 40%.[69] Nationally, population-weighted $PM_{2·5}$ exposures fell to 48 μg/m³ in 2019, from 63 μg/m³ in 2013.[70] India has developed instruments and regulatory powers to mitigate pollution sources but there is no centralised system to drive pollution control efforts and achieve substantial improvements.[71] In 93% of India, the amount of pollution remains well above WHO guidelines.[72] International organisations have supported various databases to monitor air quality.

In Europe and North America, most urban areas have one or more reference-grade ambient air quality monitoring stations, which represents about one monitor per 100 000–600 000 residents. By contrast, across sub-Saharan Africa, there is just one ground-level monitor per 15·9 million people.[73,74] Only seven of 54 African countries currently have reliable real-time air quality monitoring. Although improved satellite imaging and analysis are helping to fill gaps,[75] satellite estimates of surface $PM_{2·5}$ concentration could have errors in the range of 22–85% if they are not calibrated by ground-level monitoring data.[76] South Africa has continuous air quality monitoring systems. Other countries, including Ghana, Nigeria, and Senegal, have carried out monitoring programmes at intervals, although funding for maintenance and quality control is sporadic.

Monitor lead pollution

Monitoring lead exposures requires population-wide blood lead testing, especially in pregnant women and in children, because of the neurological effects of lead on brain development early in life. Outside of high-income countries these monitoring programmes are almost non-existent. Pilot studies in Mexico have catalysed a national programme to identify and control lead exposure in children and pregnant women.[77] UNICEF has initiated a baseline programme in Georgia,[78] and the Philippines is planning to incorporate lead testing in its next country survey. China has also made initial efforts to determine baseline lead exposures.[79]

Most LMICs do not have population-wide blood lead or environmental lead monitoring systems in place.[80] A multistakeholder approach to addressing lead exposure—ie, Protecting Every Child's Potential—has been initiated with UNICEF and others.[81]

Monitor water, sanitation, and hygiene

Despite continued efforts over many decades and continuing improvements, inadequate water, sanitation, and hygiene (WASH) remains a major global risk factor for disease and premature death and has serious health and socioeconomic consequences, particularly for women and girls living in LMICs.[82]

Considerable expansion of access to clean water and sanitation services has been achieved in the past 50 years, but a 2018 review of progress towards the achievement of the targets set under the Sustainable Development Goals (SDGs) concluded that it would be an enormous challenge to close existing gaps in coverage by 2030.[83] A fundamental problem is that rapidly growing populations in LMICs often outstrip efforts to provide clean water and sanitation, with the result that the number of people worldwide who do not have adequate access to these services remains high despite valiant efforts.[84] According to UN estimates, 2·2 billion people still do not have access to safe drinking water and 4·2 billion do not have access to safely managed sanitation services.[85]

Monitor chemical pollution

For most of the thousands of manufactured chemicals now in commerce there are no reliable data on developmental toxicity, reproductive toxicity, immunotoxicity, the effects of long-term low-level exposures, or the health risks of chemical mixtures.[86] Despite substantial progress in the international arena since the 1990s to establish multilateral agreements regulating some chemicals in waste, "the global goal of sound chemicals and waste management in ways that lead to minimized adverse effects on human health and the environment" has not been achieved.[87]

A process to establish a science–policy interface (SPI) for chemicals and wastes[88] has been launched at the UN Environment Assembly in 2022. Such a programme mirrors the Intergovernmental Panel on Climate Change and the Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services. It will be important for WHO to be fully involved in launching the process, and the scope of this programme should preferably span all forms of pollution. The SPI would need to receive broad governmental and multilateral support (including funding), and should draw on existing knowledge and expertise from a wide range of stakeholders.

Build multisectoral partnerships for pollution control

Pollution is rarely highlighted in multilateral bank or UN Development Programme country planning strategies, and only a handful of countries have begun the process of integrating pollution responses into their development strategies, in the context of many other competing demands. A useful approach to helping governments prioritise pollution issues on the basis of their health impacts is the Health and Pollution Action Plan (HPAP) or similar processes. The HPAP is a prioritisation process designed to assist governments of LMICs to identify their most important pollution problems and to develop and implement solutions.[89] Although ambient air pollution might already be on the agenda, the HPAP process often brings up serious problems with toxic chemicals and metals. Currently about a dozen countries have done such processes, with support from donors and UN agencies (appendix p 23). The HPAP is led by a government agency and is structured to bring together agencies and parties who usually do not interact. Although the HPAP process ensures strong local ownership and prioritised programmes, it is challenging to find funding for the process itself and for HPAP programme implementation.

For the **European Exposome Network** see https://www.humanexposome.eu/about/

International policy efforts to combat pollution remain fragmented and uncoordinated. Air pollution is dealt with regionally, with the UN Economic Commission for Europe Convention on Long Range Transboundary Air Pollution providing the most comprehensive set of agreements and monitoring arrangements. Water pollution is dealt with at the level of river basins or through Regional Seas Conventions. The major health effort is the UN Water, Sanitation and Hygiene programme. Industrial pollution of water receives little international attention and 6 years after the adoption of Agenda 2030, which established suitable indicators for tracking chemical pollution of waterways, this information is still not being collected.

Control of chemical and hazardous waste pollution is especially fragmented. The Strategic Approach to International Chemicals Management is the only comprehensive process that targets this issue, and it is entirely voluntary and has a very small budget. The UN Environment Programme is currently the only UN agency to prioritise addressing all types of pollution. UNICEF has taken up air pollution and is just beginning to add lead to its country portfolios.

Integrate pollution mitigation into planning processes for NCDs

Pollution is a major risk factor for NCDs. In 2018, air pollution (household and ambient) was recognised by WHO as one of five major risk factors for NCDs, alongside unhealthy diets, smoking, harmful use of alcohol, and physical inactivity.[90] The NCD Alliance has advocated for pollution's inclusion on the list of major risk factors. So far, however, little action has occurred in terms of funding or coordination with pollution agencies in programmes in the field, and no targets or timetables have been set.

Research pollution and pollution control

There has been growing attention paid to pollution in the research community, with some funding successes. Funded through the EU, the European Human Exposome Network is the largest research group in the world studying the effect of environmental risk factors, including pollution, on human health. In the USA, the Superfund Research Program has made valuable contributions and has extended its reach globally through the Pacific Basin Consortium for Environment and Health. However, there is little comparable work in LMICs and more sharing of relevant research and results is needed.

Highlight pollution control in the SDGs

The SDGs were adopted by the UN General Assembly in 2015 as part of the Agenda 2030 action plan. The 17 goals are supported by 169 targets measured through 231 indicators. Although none of the goals is exclusively devoted to pollution or its effects on health, there are targets and indicators of relevance to pollution control scattered throughout the goals. These goals aim to provide globally agreed information on the drivers of pollution, the amount of pollution, and on institutional responses to pollution. However, the relevant targets are less concrete than for some other challenges and are therefore unlikely to attract adequate political attention and resources.

The agreed Target 3.9 indicators for ambient air pollution, household air pollution, unsafe sanitation, and unsafe water sources are derived from the sex-disaggregated GBD mortality data. However, the chosen indicator for chemical pollution is deficient because it relates to deaths from accidental poisonings, which is not an adequate proxy for morbidity from NCDs due to chronic chemical pollution. The indicator should rely on the various forms of chemical pollution tracked by the GBD study.

Tracking awareness of pollution and health

Continued tracking of plans, expenditures, and action on pollution by national and local governments is essential. However, it is also important to track public attention to issues of pollution and health because the public demand for more effective action against pollution by governments can be powerfully catalytic.

Two metrics that can be tracked over time as proxies for public awareness of pollution and health are: the inclusion of pollution prevention in development strategy frameworks; and media attention to topics relating to pollution and health.

Inclusion of modern pollution prevention in multilateral development institutions' country strategy frameworks

To assess the frequency of support for pollution control programmes in Country Partnership Frameworks and equivalent documents developed by the World Bank, regional development banks, and the UN Development Programme, a text analysis was performed across these reports for the years 1995–2020, covering a period when new efforts could be expected to begin emerging (appendix p 28). The results show that from 1995 to 2020, discussions of pollution and biodiversity remained relatively constant, whereas discussion of climate change increased. Further, between 2015 and 2020, the terms "household air pollution" and "water pollution" were mentioned more often than "ambient air pollution" or "chemical pollution", suggesting a greater focus on traditional pollution than modern pollution (figure 6).[91–95]

These findings mirror the results of a 2017 review conducted by the World Bank's Independent Evaluation Group.[96] This review found that only 28% of World Bank Group country strategies referenced pollution concerns. Most strategy documents (56%) did not mention pollution.

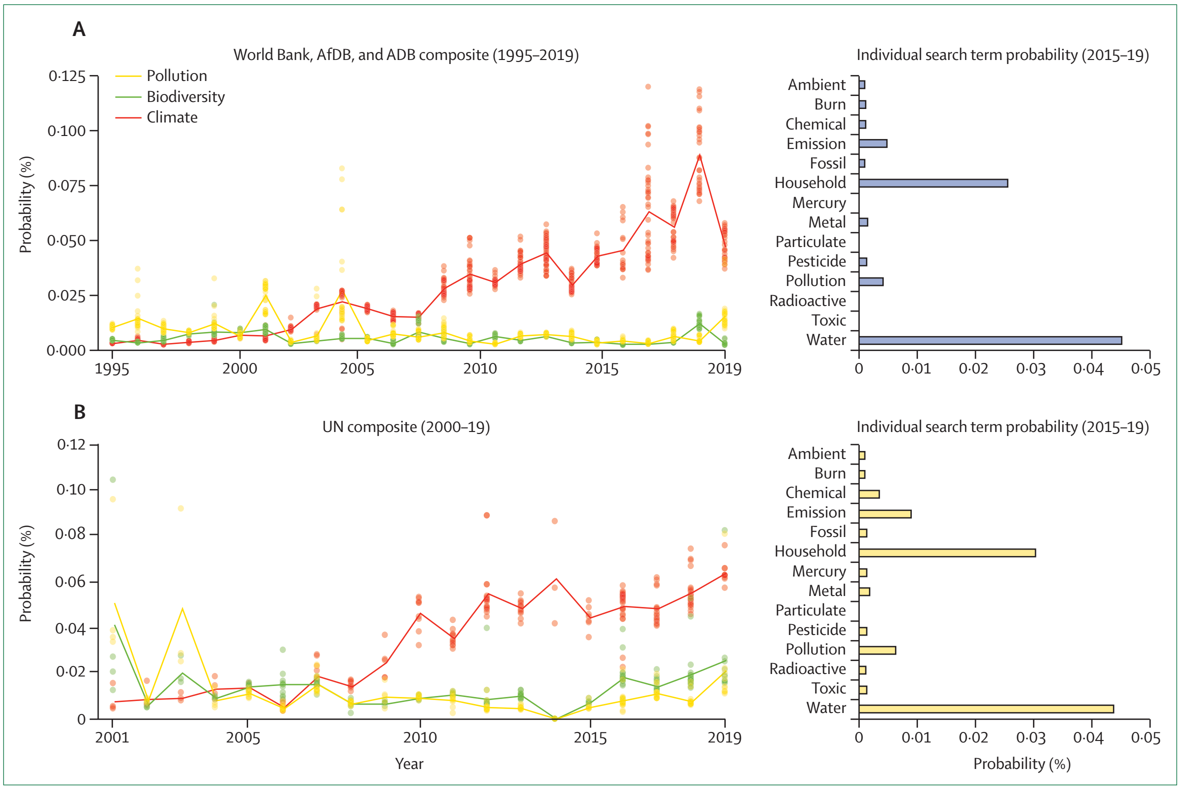

Figure 6: **Probability of subject matter coverage of pollution, biodiversity, and climate change (composite terms and key phrases) in country framework documents**

(A) Composite data are from the World Bank, the AfDB, and the ADB (1995–2019); data for individual search terms are from the World Bank (2015–19).[91–94] (B) Composite data are from UN (2000–19); data for individual search terms are from UN (2015–19).[95] AfDB=African Development Bank. ADB=Asian Development Bank.

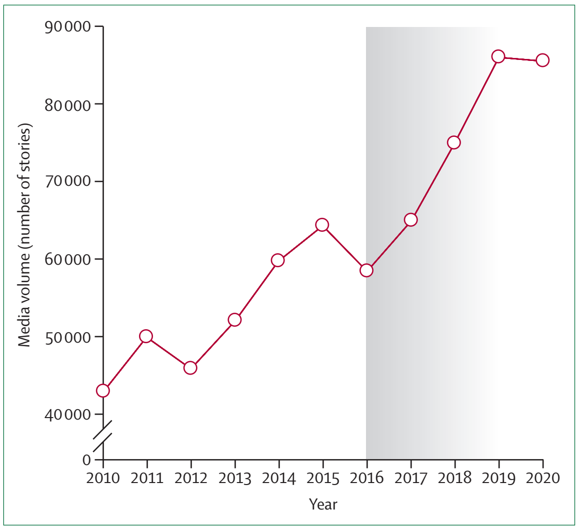

Figure 7: **Coverage of modern pollution topics in major media outlets in 2020**
Data obtained through a search of the Factiva database from Jan 1, 2010, to Dec 31, 2020.

Number of stories in major media covering pollution issues

We conducted an analysis focused on coverage of modern pollution in English language media since 2010 (appendix p 30). For traditional media (ie, in print, online, and broadcasted), a search of the Factiva database yielded 1794 677 articles dealing with topics on pollution. A breakdown of this search by year reveals a steadily rising trend in coverage (figure 7). The largest annual increases were seen in the years 2017–19, following publication of the report of the *Lancet* Commission on pollution and health in 2017. Clearly, public interest in pollution is strong and growing.

Conclusion and recommendations

Despite its substantial effects on health, societies, and economies, pollution prevention is largely overlooked in the international development agenda, with attention and funding only minimally increasing since 2015, despite well documented increases in public concern about pollution and its effects on health.

The 2017 *Lancet* Commission on pollution and health documented that pollution control is highly cost-effective and, because pollution, climate change, and biodiversity loss are closely linked, actions taken to control pollution have a high potential to also mitigate the effects of those other planetary threats, thus producing a double or even a triple benefit.

We present specific recommendations for pollution and health, building on the earlier recommendations in the *Lancet* Commission on pollution and health.

International organisations and national governments need to continue expanding the focus on pollution as one of the triumvirate of global environmental issues, alongside climate change and biodiversity. We encourage the use of the health dimension as a key driver in policy and investment decisions, using available GBD information.

Affected countries must focus resources on addressing air pollution, lead pollution, and chemical pollution, which are the key issues in modern pollution. A massive rapid transition to wind and solar energy will reduce ambient air pollution in addition to slowing down climate change.

Private and government donors need to allocate funding for pollution management to support HPAP prioritisation processes, monitoring, and programme implementation. ODA support should involve LMICs in setting priorities through these processes.

All sectors need to integrate pollution control into plans to address other key threats such as climate, biodiversity, food, and agriculture. All sectors need to support a stronger stand on pollution in planetary health, OneHealth, and energy transition work.

International organisations need to establish an SPI for pollution, similar to those for climate and biodiversity, initially for chemicals, waste, and air pollution.

International organisations need to revise pollution tracking for the SDGs to correctly represent the effect of chemicals pollution including heavy metals. The reporting systems should allow burden of disease estimates to be used in the absence of national data.

International organisations and national governments need to invest in generating data and analytics to underpin evidence-based interventions to address environmental health risks. Priority investments should include the establishment of reliable ground-level air quality monitoring networks, along with lead baseline and monitoring systems, and other chemical monitoring systems.

International organisations and national governments need to use uniform and appropriate sampling protocols to collect evidence on exposure to hazardous chemicals such as lead, mercury, or chromium, which can be compared or generalised across LMICs.

Contributors
RF and PJL developed the concept and objectives for the Review. All authors contributed to the identification of key issues and writing of the Review.

Declaration of interests
MB reports institutional support from the Bill & Melinda Gates Foundation; JH also reports consulting fees from the German Ministry of Environment to develop ideas for advancing the Strategic Approach to Chemicals Management process; and JH reports fees from the UK Department for Environment, Food & Rural Affairs for teaching workshops. HH reports grants from the US National Institutes of Health for neuro-epidemiological research on the developmental neurotoxicity of pollutants; HH also reports consultant fees to law firms on cases related to the developmental neurotoxicity of pollutants; and HH serves as Chair of the Scientific Advisory Board of the Marilyn Brachman Hoffman Foundation and is a member of the Advisory Board for Physicians for Human Rights. PJL reports grants and contracts from the Centre Scientifique de Monaco, UN Environment, and the Barr Foundation, and consulting fees from the Centre Scientifique de Monaco; and PJL serves as President of the Collegium

Ramazzini, Chair of the Scientific Advisory Board of the Collegium Ramazzini, and Treasurer for the Consortium of Universities for Global Health. BL reports grants from the US National Institutes of Health, Canadian Institutes of Health, and US Department of Housing and Urban Development for research projects and personal consulting to study the effects of toxic chemicals on human health; BL also served as an expert witness in cases related to lead and fluoride poisoning in the USA and Canada but received no personal compensation for these services; and his expert witness fees are deposited in a research and training fund at Simon Fraser University (Burnaby, BC, Canada). All other authors declare no competing interests.

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