URBAN AIR POLLUTION AND CHILDREN IN LOW- AND MIDDLE-INCOME COUNTRIES

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SUMMARY

This evidence into action brief summarises the state of research on the topic of urban air pollution in low- and middle-income countries and its impacts on children, and proposes ideas for action.

Air pollution is a major global health challenge to which children are particularly vulnerable. In this briefing, the authors summarise the literature on this topic, focusing on low- and middle-income countries (LMICs). There are indoor and outdoor sources of air pollution and these pollutants can remain in the local area or be transported vast distances. Therefore, to reduce air pollution emissions and exposure to pollution, action is needed at local, national and international levels. In many cases, these actions can contribute to achieving multiple other sustainable development goals, including climate change mitigation. An integrated approach to action is needed, involving collaboration with community members, planners and policymakers.

- Invest in regulatory air pollution monitoring stations and provide training on data management and how to interpret the data. This will highlight the extent of pollution in places where monitoring is lacking.
- Support the development of air quality management systems (including air-quality regulations and standards on emissions) to monitor and reduce air pollution, particularly in urban areas.
- Develop citizen science monitoring programmes to fill the gaps in monitoring. Scientists and community members should work together to answer scientific questions, collect data and co-design awareness-raising campaigns at community level.
- Work with governments to integrate air pollution into climate change targets. Many sources of greenhouse gases are also sources of air pollutants. LMICS can increase their mitigation ambitions, meet international targets and achieve local development benefits through improved air quality.

CONTENTS

ACRONYMS

AIR Network	Air Pollution Interdisciplinary Research Network
LEAP-IBC	Low Emissions Analysis Platform – Integrated Benefits Calculator
LMIC	Low- and middle-income countries
LPG	Liquefied petroleum gas
NDCs	Nationally Determined Contributions
NGO	Non-governmental organisation
PM	Particulate matter
SEI	Stockholm Environment Institute
Unicef	United Nations Children's Fund
WHO	World Health Organization

1. INTRODUCTION

Air pollution is a global health issue. The World Health Organization (WHO) estimates that 9 out of 10 people breathe air that contains high levels of pollutants.[1] In 2019, air pollution contributed to nearly 500,000 deaths among infants in their first month of life.[2] Air pollution is classified as either outdoor (ambient) or indoor. However, outdoor air pollution levels can affect indoor air quality and vice versa.

In 2019, air pollution contributed to nearly 500,000 deaths among infants in their first month of life.

There are natural sources of air pollution, such as desert dust and sea salt, but air pollution is most often a result of human activity, including from incomplete combustion of fossil fuels and biomass, such as in transport, households, industries and to generate electricity. Other sources of air pollutant emissions include the (mis)-management of waste and agricultural processes, such as applying fertilisers, managing manure and burning crop residues. Sources of indoor air pollution include cooking practices, heating and lighting in the home, chemicals from cleaning fluids or other products, and smoking.

Air pollution is a mixture of gases and solid or liquid particles, emitted from natural and human-driven activities, the composition and concentration of which depends on the sources of pollution and meteorological conditions. Pollutants with health effects include nitrogen dioxide, sulphur dioxide, ozone, carbon monoxide, volatile organic compounds and particles. Some air pollutants also form from reactions between pollutants directly emitted from sources (called primary air pollutants) and reactions with other chemicals or with sunlight (these pollutants are called secondary air pollutants). Particles, or particulate matter, are themselves complex mixtures, including dusts (some of which have toxic properties, such as silica and asbestos) and particles formed from combustion or chemical reactions. Fine particulate matter, less than 2.5μm in diameter, can penetrate deep into the lungs and even enter the blood circulation.[3,4] Fine particulate matter has many sources, and can be composed of fine dusts, sea salt, secondary aerosols (formed from chemical reactions), and combustion (both natural and man-made processes). While all these particles have potential health impacts, combustion-source particles are of particular concern, due to their properties.[5,6,7] In addition to particles, air pollution includes a mixture of gases and vapours, and this combination likely also contributes to air pollution health impacts.

According to the WHO, every day around 93 per cent of the world's children under 19 years breathe air that is so polluted it puts their health and development at risk.[1] Children are exposed to potentially high levels of pollutants through ambient air pollution in urban areas and pollution indoors at home and school. In developing countries especially, household air pollution resulting from the use of biomass or coal in overcrowded and poorly ventilated housing contribute to high rates of respiratory illness, particularly in young children.[8,9]

Both peaks in air pollution and long-term chronic exposure are linked to increased deaths and hospital admissions from respiratory and cardiovascular diseases. Children, the elderly and those with pre-existing cardiovascular diseases are particularly vulnerable.[10,11] For children, this is because their bodies are still developing and they inhale more air per unit of body weight than adults.[12,13] In childhood, air pollution exposure can impair lung growth,[14] increase the risk of asthma exacerbation and incidence, increase risk of acute lower respiratory infections, and neuro-cognitive effects.[15]

In this briefing, we give an overview of the sources of air pollution, its effects on children and young people, and work that is being done to address this issue. We draw on key lessons from the literature and case studies, particularly focusing on low- and middle-income countries.

2. LITERATURE REVIEW

2.1 Sources of air pollution

There are many sources of air pollution, including electricity generation, industry, vehicles, open burning of waste, agricultural fires, fertiliser application and management of manure, dust and household cooking and heating.[16,17] The drivers of these vary across the world. In urban areas, vehicles are a major source of local air pollution.[18] In developing countries, localised sources such as burning of rubbish, industries, cooking, dust, and tobacco smoke also contribute significantly to exposure.[19,20,21,22] On top of these local sources, some air pollutants can be transported long distances, including between countries and continents, meaning that people can be exposed to air pollution that is the result of emissions emitted hundreds or thousands of kilometres from where they live.[23,24] Agricultural burning can be an important contributor to this long-range transport of pollutants.

The indoor environment can be a significant source of air pollution exposure in both urban and rural areas. Household air pollution in developing countries has been singled out as a particular contributor to the global burden of disease from air pollution.[2,9] Approximately 3 billion households are dependent on primarily wood, dung and other solid fuels for heating and cooking.[1] Inefficient combustion of these fuels and lack of ventilation can lead to high exposures. Women and children are particularly vulnerable as they spend a disproportionate amount of time cooking.[27] Providing cleaner and more efficient stove and fuel alternatives would reduce air pollution-related diseases,[28] as well as produce a range of other benefits, including saving a significant amount of time spent collecting fuel and cooking, which could be used for education or paid work.[29]

Household air pollution in developing countries has been singled out as a particular contributor to the global burden of disease from air pollution.

2.2 Air pollution and climate change

Air pollution and climate change are closely linked because many of the sources of greenhouse gases responsible for climate change are also major sources of air pollutants (e.g. burning of fossil fuels, forest fires), and because a subset of pollutants directly contribute to both impacts. The 2015 Paris Agreement aims to limit global temperature increases to no more than 2°C, and to take all possible actions to limit increases to 1.5°C above pre-industrial levels. Countries are required to submit and update their Nationally Determined Contributions (NDCs) to achieving these targets every five years. However, the NDCs stated in 2015 would not achieve the Paris Agreement goals, so more ambitious targets are needed.

Integrating air pollution and human health is one way that countries can increase their climate change mitigation ambition, meet international targets and achieve local development benefits through improved air quality.[30] For example, Chile has set a target to reduce black carbon emissions by 25% in 2030 compared to 2016 levels. Black carbon is a component of fine particulate matter that is emitted when fuels are not burned efficiently, and is a short-lived climate pollutant (SLCP) absorbing sunlight and warming the atmosphere. This commitment will address two of Chile's most pressing problems – energy poverty and environmental inequality – as a major source of black carbon is the burning of wood and other biomass for fuel to heat homes, which disproportionately impacts lower-income families who are exposed to the air pollution emissions from these sources.[31] Taking action to reduce black carbon by facilitating families to use cleaner and more sustainable forms of energy for heating and cooking will reduce air pollution exposure particularly of women and children. Integrating actions that simultaneously mitigate climate change and improve air quality in climate change commitments like this can increase their chances of implementation due to the ability to access climate change finance (including the Green Climate Fund).

Air pollution and climate change are closely linked because many of the sources of greenhouse gases responsible for climate change are also major sources of air pollutants.

2.3 Differences between countries

The Global Burden of Disease project quantifies the health burden at national scale from exposure to a range of different risk factors, including exposure to ambient and household air pollution across the world.[32] Globally in 2019, 691,000 deaths of children under five (from respiratory infections and adverse pregnancy outcomes such as preterm births) were estimated as attributable to exposure to air pollution.[32] In 2019, air pollution was estimated to contribute 30% of lower respiratory infections and 20% of infant mortality in the first month of life.[2] The majority of the health burden of air pollution on adults is estimated to occur in Asia (due to high $PM_{2.5}$ exposures and large populations, where $PM_{2.5}$ refers to particles that have a diameter of less than 2.5 micrometres that are formed as a result of burning fuel and chemical reactions in the atmosphere). However, over half (54%) of infant deaths from air pollution exposure were estimated to occur in sub-Saharan Africa (compared to 14% of global premature deaths from air pollution for all ages).[32] The larger fraction of infant air pollution-attributable deaths occurring in Africa is a result of relatively high $PM_{2.5}$ exposure, but also the substantially higher infant mortality rates of African infants (<5 years, 1,616 deaths per 100,000 in 2019) compared with other regions (global infant mortality rates was 761 deaths per 100,000 in 2019).[32,33] In fact, nearly 1 in 5 child deaths from air pollution were estimated to occur in one country, Nigeria. This highlights the importance of not just focusing on reducing air pollution but on also improving pre- and post -natal care and strengthening health systems in countries such as Nigeria. This can also be effective at reducing the susceptibility of infants to respiratory diseases exacerbated by air pollution.[2,32] Infant deaths due to air pollution have reduced over recent decades (a 62% reduction in annual infant deaths attributable to air pollution between 1990 and 2019) because of reductions in overall infant mortality, but this reduction was only 27% across sub-Saharan Africa.[2,32]

Over half (54%) of infant deaths from air pollution exposure were estimated to occur in sub-Saharan Africa.

While infant deaths attributable to air pollution exposure result in the largest burden of disease from air pollution among children, there are also substantial effects of exposure to air pollution on morbidity. For example, asthma is one of the main causes of ill health among children, and exposure to air pollution (ozone, particulate matter and nitrogen oxides) has been associated with increased exacerbation of asthma, and incidence of new cases of asthma. Globally, it has been estimated that exposure to nitrogen dioxide has been estimated to result in 4 million childhood asthma cases per year.[34]

2.4 Air-quality data

National air-quality standards are a key tool used by governments to reduce air pollution and protect human health. Assessing whether these standards are being met, or exceeded, requires monitoring the levels of air pollutants. Unfortunately, many low- and middle-income countries do not have air-quality standards, with 44% of countries identified as not having ambient air-quality standards or air-quality legislation.[35] In addition, regions still lack effective programmes to systematically measure the levels of air pollution that their citizens are being exposed to, to understand the magnitude of the problem or develop strategies to address it. Official monitoring stations are expensive to establish and maintain. The WHO maintains a database of particulate matter measurements made in 2,603 cities, called the Global Ambient Air Quality Database.[36] Last updated in 2018, only 16%

of these cities are in Asia, 3% are in Latin America and less than 1% are in Africa, with the majority in North America and Europe. The United Nations Children's Fund (Unicef) recently estimated that only 6% of children in Africa live near reliable monitoring of air quality.[37] Some data is available through non-official sources, and this can be seen on the OpenAQ website.[38] But again, there is limited LMIC data. Therefore, in those locations where air pollution health impacts are estimated to be the most severe, there is a critical lack of monitoring infrastructure to track air pollution levels in situ over time.

UNICEF recently estimated that only 6% of children in Africa live near reliable monitoring of air quality.

There are other options to understand the magnitude and variation in air pollution concentrations and exposure, in addition to ground-based monitoring stations. Atmospheric chemistry transport models simulate how emissions of pollutants disperse and react in the atmosphere, to produce estimates of air pollution levels in a particular location.[39,40] In addition, satellite observations can be used, in combination with modelling, to estimate air pollution concentrations in regions where there are no ground measurements of pollution.[41,42] For example, this method was used to estimate air pollution values for all countries in the Global Burden of Disease analysis, including those without monitoring data.[42] A combination of remotely sensed data with calibration from ground-level measurements has potential to improve monitoring in urban areas in LMICs.[43]

Citizen science, where scientists and community members work together to answer scientific questions, often through collecting data, is increasingly being used as a way of both obtaining much-needed data about air pollution and raising awareness of the issue. This has been aided by the rapid rise in the availability of low-cost sensors for monitoring air pollution (including particulate matter, nitrogenous pollutants and carbon monoxide, among others). There are concerns about data quality with these instruments as they require careful calibration and can degrade over time, and it is often not possible to compare their data to regulatory monitors. Nonetheless, they can give important information about the relative levels of air pollution across a city, and through carrying monitors, the invisible threat of air pollution is made visible to participants.[44] This has the potential to encourage individual and collective action, including lobbying governments for change. Practitioners could work with researchers to co-design low-cost monitoring campaigns, particularly focusing on Africa and Latin America, which have limited official monitoring.

A comprehensive review by the World Meteorological Organization (WMO) on the current state of low-cost sensor technology emphasises the potential usefulness of these sensors for identifying hotspots and spatial variation of pollutant concentrations, especially in the absence of higher-grade instruments.[45] However, they caution against their use for other applications, in particular for comparison against legislated air-quality standards, or assessing long-term trends in pollutant concentrations. In short, careful consideration must be given to the purpose of deploying low-cost sensors to ensure their use is appropriate and robust.

2.5 Air pollution and informal settlements

More than half of the global population live in cities, with 83% of the global urban population living in LMICs.[46] Air quality tends to be worse in urban areas, is multifactorial and is linked to the location and proximity of air pollution sources. Rapid industrialisation and urbanisation in developing countries in recent years, often poorly regulated and lacking in air quality legislation, has resulted in increased air pollution-related burdens when compared to developed countries.[47]

Nearly 1 billion urban poor live in informal settlements. Settlement dwellers suffer multiple deprivations, including poor housing and sanitation, job insecurity and inadequate access to health services. Health data from informal settlements is patchy, with some cities dominating the evidence base (Mumbai, Dhaka and Nairobi in particular),[48] either because data are not collected from informal settlements, or it is not disaggregated to that level.[49] However, the location and nature of informal settlements means that residents are at particularly high risk of being affected by infectious and non-communicable respiratory diseases, many of which are linked to air pollution.[50] A study of cities in India found that children living in slums had negative health effects from air pollution three times that of children living outside slums.[51]

Informal settlements are often located in close proximity to 'dirty' industrial zones and busy congested roads, which are often unpaved and therefore dusty. Poor waste-management infrastructure results in local burning of plastic waste and e-waste (electrical or electronic equipment waste). Consequently, residents of informal settlements are exposed to extremely high levels of outdoor air pollution.[52] In addition, indoor air quality is poor. Informal settlement dwellers live in cramped, poorly ventilated homes and more than three million people worldwide use kerosene, charcoal or wood for cooking, lighting and heating.[53] These fuels are often supplemented by plastic or textile fragments which emit toxic fumes. In Pondicherry, India, women cooking with biofuels had more respiratory symptoms than those using kerosene, with liquefied petroleum gas (LPG) giving lowest levels of symptoms.[54] Women and young children spend more time in the home when cooking and are disproportionately affected by indoor air pollution, and young children are especially vulnerable to the adverse health effects of indoor air pollution. The specific pollutants that children in informal settlements are exposed to vary considerably, depending on the location. For example, in Mexico City, children living in the north are exposed to high levels of PM and its constituents, whereas children living in the south are exposed to high ozone concentrations, resulting in different health problems.[55]

Informal settlement dwellers live in cramped, poorly ventilated homes and more than three million people worldwide use kerosene, charcoal or wood for cooking, lighting and heating.

Much of the research around exposure of informal-settlement residents to air pollution comes from Indian cities and Nairobi, Kenya. Studies in the Nairobi settlements of Korogocho and Viwandani found that there was a high prevalence of respiratory illness, asthma and acute respiratory infections in these areas, as well as $PM_{2.5}$ levels well above WHO guidelines.[52,56,57] Kerosene is used by most households for cooking, followed by charcoal, and then gas or electricity.[58] About 18% of households showed high levels (above 100 μg/m^3) of $PM_{2.5}$ with only 14% of households showing levels below 25 μg/m^3 (the WHO guideline for 24-hour average exposure). If windows were present, they were not always opened during cooking, meaning pollution was trapped indoors. Mobile PM monitors in Mukuru informal settlement have shown that both indoor and outdoor levels are high.[44]

2.6 How does air pollution affect children?

An estimated 237,000 excess child deaths each year are due to ambient air pollution-induced respiratory tract infections.[16] Children are particularly vulnerable to the health impacts of air pollution because their bodies are still growing. They also inhale a greater volume of air per unit of body weight than adults, and therefore may inhale more pollutants.[12,13,59] Children are vulnerable from the time they are in the womb. Stresses experienced by the mother and foetus can lead to negative health for the child and future adult.[60] Air pollution exposure during pregnancy could similarly affect health, although the magnitude of that effect is uncertain. Studies have found associations between in utero pollution exposures and foetal growth, birthweight and development of lung function in childhood.[61,62,63,64] Cognitive development may also be impacted by in utero and early life exposures.[15,65,66] Malley et al. 2017 found that ~18% of global preterm births were associated with maternal PM2.5 exposure. Preterm birth increases the chances of infant mortality, as well as a range of physical and neurological health impacts in survivors and long-term economic effects.[67] There is also a link between air pollution and child stunting.[68,69]

In childhood, air pollution exposure is linked to poor respiratory health, greater risk of respiratory infections, lower lung function and asthma exacerbation and incidence. Household air pollution from biomass fuel burning indoors has been linked with acute lower respiratory infections, including pneumonia, with much of the burden occurring in Africa and Asia.[16] Traffic-related pollution has been linked with airway inflammation and asthma. For both of these types of sources, fine particulate matter ($PM_{2.5}$) is the issue, although other pollutants, such as nitrogen dioxide from traffic, may also play a role in health effects. Deprivation and stresses related to insecurity, including exposure to violence, may increase the impacts of air pollution exposure on health, and this is of concern considering that often more-deprived communities may not only have higher air pollution exposure but also co-morbidities that increase their susceptibility to these exposures.[70] Studies have also found an association between PM exposure and neurocognitive outcomes such as autism spectrum disorders and attention deficit hyperactivity disorder.[15,66,71,72]

An estimated 237,000 excess child deaths each year are due to ambient air pollution-induced respiratory tract infections.

Much of the research into air pollution exposure in developing countries tends to focus on indoor air pollution, primarily because of the burden of health impacts from inefficient fuels and stoves used for cooking and heating.[8] Indeed, due to the amount of time spent at home and the high levels of pollution emitted from these sources, they contribute greatly to children's total personal exposure. Children, especially infants, spend most of their time indoors and much of this is at home, at least in developed countries.[73,74,75] Infants tend to spend most of the time with the mother therefore exposure related to the mother (e.g. near cooking fires in developing countries) would also affect the child. However, relatively few studies have assessed total personal-level exposure to air pollution of children in low- and middle-income countries.[76] Several studies have assessed air pollution exposure in Accra, Ghana. Arku *et al*. 2015 measured the personal exposure to air pollution of 56 students in different neighbourhoods in Accra.[77] The average exposure to fine particulate matter ($PM_{2.5}$) across the students was 56ug m^{-3}, which is more than five times higher than the WHO guidelines for the protection of human health (10μg m^{-3} annual average exposure to outdoor $PM_{2.5}$).[18] There was significant variation between students, with exposure ranging from 10 to 150 ug m^{-3} due to whether the school was located in an area where biomass fuels were widely used for cooking, and whether their own household used biomass fuel for cooking. Lower-income neighbourhoods with substantial use of biomass for cooking have much higher concentrations of $PM_{2.5}$ compared to higher-income neighbourhoods in Accra.[22,78] The average exposure to female students to $PM_{2.5}$ was higher than for boys (67 ug m^{-3} vs 44 ug m^{-3}).[77] One explanation for this is that girls tend to spend a larger proportion of time helping with domestic cooking compared with boys, with girls aged 10–17 years spending 155 minutes a day doing unpaid domestic work, including cooking, compared to 87 minutes for boys, according to Ghana's 2009 time use survey.[79] Malley *et al*. 2020 modelled the consequences of these differences on the $PM_{2.5}$ exposure of girls and boys in Accra, and estimated that for those households cooking using charcoal (used by approximately half of households in Accra), the exposure for girls was approximately 65% higher than the exposure for boys.[80] When less-polluting fuels such as LPG are used for cooking, the exposure of both boys and girls drops substantially, and the difference in exposure between boys and girls almost disappears. There is also an association between malnutrition and air pollution, with anaemic children with higher pollution exposure being hospitalised more than non-anaemic children.[81]

2.7 Interventions to improve air quality or reduce exposure

To minimise the health burden from children's exposure to air pollution, interventions need to reduce the source of the air pollutant emissions. This is a complex and multi-faceted problem because of the number and variety of sources that contribute to air pollution in different locations, and because in many locations a large fraction of the air pollution that people are exposed to is not emitted in the location in which people are being exposed. Interventions are therefore required at all scales, from household, community, city and country to regional and global levels, if children's air pollution exposure is to be reduced to levels that are below WHO guidelines for the protection of human health. Case studies 1 and 2 give some examples of interventions across these scales.

In Europe and North America (and other regions), over the past 40 years, interventions to improve air quality have substantially reduced outdoor air pollution exposure. Archibald *et al.* 2017 estimated that over 500,000 premature deaths (all ages) per year have been avoided as a result of interventions to reduce air pollution in Europe and North America since the 1970s.[82] This reduction in exposure and increased health benefits have resulted from technology improvements, and the implementation of effective air quality management systems in both regions, which include air-quality standards, extensive and comprehensive air quality-monitoring systems to assess compliance, and regulations and standards on emissions to control emissions from particular sectors (e.g. exhaust-emission limits for vehicles).

A large fraction of the air pollution that people are exposed to are not emitted in the location in which people are being exposed. Interventions are therefore required at all scales.

A review of interventions to improve outdoor air quality in the UK found a number of principles were needed to guide interventions.[83] These principles are all relevant for LMIC contexts, the additional challenge being lack of data quantifying air pollution:

- Different air pollutants should be tackled together as they tend to be interdependent.
- Local authorities must work together as the problem crosses boundaries.
- A coherent approach is needed between different actors (e.g. local authorities, civil society organisations, the private sector, members of the public).
- It is better to reduce the sources of pollution than to mitigate the consequences.
- Improving air quality can also have economic benefits.
- Some actions may disproportionately affect different groups in society, who will need different forms of support (e.g. financial incentives).

In the context of LMICs, a 2019 report for the United States Agency for International Development (USAID) about LMIC urban air pollution strategies noted that solutions to mitigate air pollution are also most effectively developed and implemented within the context of an overall Air Quality Management System (AQMS).[84] This report summarises five solutions to reduce emissions in LMICs:

- Household cooking with cleaner fuels
- Reduced trash burning
- Cleaner industrial technologies (including brick kilns)
- Cleaner vehicles and fuels, and
- Reduced agriculture burning.

In Asia and the Pacific, a 2019 United Nations Environment Programme (UNEP) report identified the top 25 clean air measures.[85] These measures demonstrate the multi-scale and multi-sectoral approach required to achieve this level of air pollution reductions. The measures include three categories:

- **Conventional clean air measures:** These include mostly controls after combustion of power stations, industry and vehicles to reduce emissions.
- **Next-stages air-quality measures that are not commonly part of clean air plans:** These include stopping the burning of agricultural waste and forests, managing livestock manure and fertiliser application, and controlling emissions from international shipping.
- **Air-quality measures that contribute to development priorities:** These include switching to low-polluting fuels for cooking and heating; energy efficiency standards for industry, services and households; improving public transport and switching to electric vehicles; and increasing the use of renewables for power generation.

The full implementation of these measures was estimated to reduce air pollution exposure to below WHO guidelines for 1 billion people, reduce outdoor air pollution health impacts by 31–37%, and reduce premature deaths from indoor air pollution by 1 million people per year, the majority of whom are women and children.[49]

At the household level, reducing emissions from cooking and heating is the most important intervention to reduce exposure by switching to cooking and heating using more efficient biomass stoves or using lower-polluting fuels, such as gas or electricity.[85,86] Several systematic reviews have been conducted on the efficacy of interventions to reduce household air pollution in LMIC settings, mainly involving improved cookstoves that still use biomass, but which burn more efficiently.[87] These reviews have found that, when well-designed, stove interventions can have positive effects on reducing particulate matter, but that levels tend to remain above the WHO guidelines. Transitioning to clean household fuels (including LPG, biogas, ethanol, biomass pellets and electricity) is required. It is also important that any solutions are developed in consultation with local stakeholders and users, as otherwise uptake of improved fuels or cooking/heating methods may not be adopted to the extent they need to be to reduce air pollution exposure. Additionally, housing stock and ventilation is an important determinant of indoor air quality which should also be considered alongside source emission reduction.

3. CASE STUDY: NATIONAL TARGETS FOR AIR POLLUTION IN MONGOLIA

Air pollution in Ulaanbaatar, the capital of Mongolia, reaches dangerous levels every winter, primarily through the use of coal for heating, as temperatures drop to -30°C. Weather patterns trap this pollution in the city, leading to concentrations of particulate matter that can be 10 times higher than WHO air-quality guidelines for the protection of human health. In Mongolia's 2019 Voluntary National Review of their progress in achieving the Sustainable Development Goals, Prime Minister Khurelsukh Ukhnaa described air pollution as 'a complex, multifaceted development challenge that would benefit from cross-sectoral coordination and multi-stakeholder partnerships'.[88] According to research by Unicef, children living in central Ulaanbaatar have 40% lower lung function than children living in unpolluted rural areas of Mongolia.[89,90]

Different interventions have been taken in Mongolia to improve air quality, and in particular to reduce children's exposure to air pollution. These interventions include activities that aim to directly reduce personal exposure. Examples include providing some schools with air filters and children using facemasks when outside (e.g. travelling to and from school), although the effectiveness of this for reducing exposure is uncertain. However, these interventions do not target the source of the pollution impacting children's health in Ulaanbaatar, which is primarily the use of coal for heating, followed by coal power stations and transportation.

In 2019, to combat winter air pollution, the Mongolian government decided to ban the use of raw coal for heating in Ulaanbaatar. This ban was enforced through fines and alternatives to raw coal were provided, such as coal briquettes, which burn more efficiently and produce lower emissions. This intervention has been a success, with early indications showing that air pollution in winter 2019–2020 was substantially lower than previous years.[91]

There are tools available to support governments in decision-making around which interventions to adopt to tackle air pollution. One is the Low Emissions Analysis Platform – Integrated Benefits Calculator (LEAP-IBC) developed by the Stockholm Environment Institute (SEI), which has thousands of users from governments, academic organisations and non-profit organisations.[92] The application of LEAP-IBC has supported the development of plans and strategies that include priority mitigation actions to improve air quality and mitigate climate change that have been endorsed at ministerial or cabinet level in at least six countries.[93–98] The LEAP-IBC tool is used by national planners to explore how to reduce greenhouse gas emissions and air pollution emissions from different mitigation actions, policies and strategies, and supports users to develop quantitative evidence on the benefits to human and environmental health that could be achieved from the implementation of these actions.[99]

4. CASE STUDY: KENYA AIR QUALITY NETWORK – USING BOTTOM-UP APPROACHES

The United Nations 2030 Sustainable Development Agenda has pledged to 'leave no one behind'.[100] This drive towards a more equitable, inclusive and people-centred framework requires that all voices are listened to. Interventions to reduce air pollution exposure by changing people's behaviours have not always proved successful. Interventions need to be socially and culturally appropriate, affordable and acceptable to the recipients. For this reason, it is important to have meaningful consultations with stakeholders, working *with* individuals and communities who are affected, and building capacity within communities to identify, understand and help to create solutions to problems such as air pollution.

Recognising this, the SEI Africa and SEI York centres worked with the Muungano Alliance[101] and local residents to monitor air pollution using low-cost portable monitors in Mukuru informal settlement, Nairobi (Kenya).[102] This citizen-science project led to the creation of the Kenya Air Quality Network to tackle air quality, coordinated by SEI Africa. The network is composed of researchers, policymakers and community representatives. Building on this work, the AIR Network (Air Pollution Interdisciplinary Research Network, funded by the Medical Research Council and the Arts and Humanities Research Council through Global Challenges Research Fund) explored the issue of air pollution in Mukuru and began to develop solutions to it. Details of the project activities can be seen on the project website.[103] The project used creative participatory methods including theatre and storytelling to explore people's lived experiences of air pollution, and raised awareness of air pollution via a 'Hood2Hood' music festival attended by over 1,500 local people. This work uncovered contrasting definitions of air pollution, differing perceptions of responsibilities, unexpected solutions, and the understanding that air pollution cannot be seen in isolation from other issues faced by settlement residents. Information from the project fed into the Kenya Air Quality Network.

Following on from this work, the Tupumue project, led by Liverpool School of Tropical Medicine and Kenya Medical Research Institute, is currently exploring the determinants of lung health in young people in Mukuru and the neighbouring wealthier community of Buru Buru. Again, they are using creative and participatory methods, this time alongside a much larger quantitative health study.[104] This project is working with local lung health champions and community artists to raise awareness of the project, of air pollution and lung health, using techniques including puppetry, music and comics. These techniques are reaching very large audiences of local schoolchildren and families and raising awareness of the issue of air pollution, and have helped recruit over 900 families to the project. Using arts-based participatory methods like these can help facilitate multiway dialogue, break down hierarchies and reveal unexpected perspectives and insights. Creative methods can be especially useful when working with children and young people, who may have wide-ranging levels of literacy and who can be difficult to engage.

5. IMPLICATIONS FOR PRACTICE – RESEARCH INTO ACTION

5.1 Design interventions that consider multiple key issues

Air pollution should not be considered in isolation from other issues. For example, Clasen and Smith (2019) argue that when tackled in isolation, neither air pollution nor water, sanitation and hygiene (WASH) interventions are as successful as they could be. However, both air pollution and WASH interventions use similar approaches and methods and work in the same areas, and could be improved through greater integration.[105] This should take place at the project level, with projects considering both sets of issues together in a holistic way and developing and evaluating interventions that address both. Opiyo *et al.* (2020) argue that informal-settlement dwellers are exposed to multiple risks that cumulatively affect residents, including air pollution, poor waste management and environmental contamination.[106] Open dumpsites, for example, contain solid waste and faeces which is a potential source of ammonia, but burning also takes place here to reduce the waste volume, contributing to high levels of particulate matter in the settlement. The Climate and Clean Air Coalition Waste Initiative is providing tools and resources to help governments reduce open waste burning, such as the Solid Waste Emissions Estimation Tool (SWEET), which assesses emissions along the solid waste value chain.[107] Successful interventions to improve air pollution exposures will likely need to address numerous factors, as these are generally not independent of the overall socioeconomic and infrastructure/environmental context.

5.2 Identify the dominant sources of air pollution first

Before identifying solutions, it is crucial to understand the dominant sources of air pollution. These vary between places. For example, in Indonesia, a major component of air pollution in the region is peat and forest fires for the palm oil industry. Non-governmental organisation (NGOs) should support research to understand the sources of pollution, either using a combination of remote-sensed and groundtruthed data, or by supporting governments to establish official monitoring stations. This includes building the capacity of local researchers and government agencies to do source attribution, monitoring and exposure studies. Partnerships with established experts in other countries and training programmes for local scientists as well as resource instrumentation and computing capabilities will be important. This work must be sustainable over the long term, therefore NGOs should work with communities (see below) to continue to advocate and encourage government activity on pollution.

5.3 Make interventions realistic

For interventions to work, they must be realistic. Advising people to open windows when cooking may not be possible in informal settlements where there are either no windows or they cannot be opened due to concerns about mosquitoes or theft. NGOs can support the development of realistic interventions by conducting or commissioning research into the viability of different interventions, starting with a review of the literature, and supplementing this with local on-the-ground research to take account of cultural contexts. Once this research has been conducted, NGOs can support campaigns to promote interventions.

5.4 Collaborate with local communities

This is essential for gaining a holistic understanding of the issues and co-designing realistic solutions. NGOs can use creative approaches such as those used by the AIR Network and Tupumue to explore perceptions of air pollution and local sources of air pollution, and to develop solutions to the issues.[108] NGOs can also act as a broker or communication channel between this community-level work and government and other decision makers, advocating for solutions derived from community members.

5.5 Understand who has the power to reduce emissions

As stated above, air pollution is emitted from a wide range of sources and exposure is determined by emissions across a range of geographic scales. The ability to reduce exposure for a particular population therefore requires that the individual or organisation with the ability to reduce emissions is clearly identified. For example, a national government is usually responsible for electricity production and vehicle import restrictions, while city officials may be responsible for waste management and public transport. Understanding institutional, regulatory and governance of key air pollution-emitting sectors allows interventions to be properly directed to those who are best able to take action.

5.6 Embed air pollution into climate change commitments

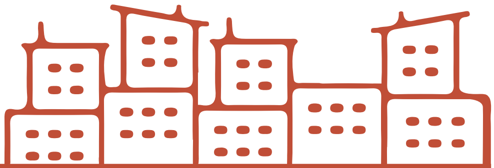
This can be a win-win solution. NGOs can encourage governments to incorporate air pollution into climate change commitments such as NDCs. They can use tools such as LEAP-IBC to demonstrate the benefits of this approach, explore options for reducing emissions and quantify the benefits to human and environmental health. For example, Colombia and Chile recently both enhanced their climate change mitigation ambition by including targets to reduce black carbon, a component of particulate matter that contributes to its impact on health, but also contributes to global temperature increases.[109]

5.7 Improve maternal and post-natal healthcare

Alleviating the health burden of air pollution on children and infants requires that the emissions they are exposed to are reduced. However, the impact of air pollution on children is exacerbated in those countries where infant mortality is high and childhood healthcare is limited. In these cases, strengthening health systems to reduce overall incidences of infant mortality and childhood respiratory and other diseases exacerbated by air pollution exposure will also be effective in reducing the impact of air pollution exposure on children.

6. CONCLUSIONS

Children in urban areas in LMICs are particularly affected by poor air quality, arising from cooking and heating homes, transport and other sources. Air pollution is a major cause of premature death, and it also impacts children's developmental trajectories and their quality of life, both as children but also into adulthood, limiting life chances. However, much is still unknown about exactly what pollutants children and young people are exposed to, where this occurs and the impacts on their health. Governments in LMICs need support to create air quality management systems to conduct monitoring of air pollution, particularly in urban areas. This data then needs to reach both policymakers and community members for top-down and bottom-up action. Developing and enforcing emissions regulations from local to national and regional levels are also necessary for reducing exposure to and related health impacts from air pollution. Practitioners and researchers should work together to implement new monitoring schemes and to bring together all stakeholders to take action based on data emerging from monitoring schemes.



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