Helpdesk Report

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Prevalence of health impacts related to exposure to poor air quality among children in Low and Lower Middle-Income Countries

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Question

What is the prevalence of health impacts related to exposure to poor air quality in low and lower middle income countries (LICs, LMICs), particularly focusing on children under 5 years old?

Contents

1. Summary

This rapid review provides an assessment of the contemporary health impacts arising from household (indoor) and ambient (outdoor) air pollution exposure in low income (LIC) and lower middle income countries (LMICs), with a specific focus upon children aged under 5 years. The review synthesises findings of key systematic reviews, as well as international and national reports, supported by relevant case studies and illustrative data from primary epidemiological studies. It is not intended to be exhaustive, but intends to highlight key areas of scientific knowledge and to identify notable gaps in the evidence base.

Air pollution is recognised as the largest global environmental risk to health contributing to an estimated 7 million premature deaths worldwide each year (WHO, 2018). Globally, an estimated 93% of children live in environments where outdoor air pollution levels exceeds World Health Organisation health-based air quality limit values, and more than one in four deaths of children aged under 5 years is directly or indirectly related to environmental risks (WHO, 2018). The economic costs of these losses is also significant; the World Bank estimated that globally air pollution led to USD 5.1 trillion in welfare losses and USD 225 billion in lost labour income globally in 2013 (World Bank and IHME, 2016).

The WHO estimates that urban air pollution levels increased by 8% from 2008-13 and 97% of cities in LICs and LMICs with over 100,000 inhabitants exceed WHO air quality guidelines; thereby contributing to global health inequity (WHO, 2018). The United Nations (UN) Sustainable Development Goals (SDGs) also recognise the critical importance of environmental factors as determinants of health, including ensuring healthy lives for all (SDG3), making cities inclusive, safe, resilient and sustainable (SDG11) and enabling access to clean energy (SDG13) by 2030.

Air pollution is recognised to exert adverse acute and chronic health effects throughout the human life course, from before birth, through childhood, adulthood and later life (RCP, 2016). Susceptible sub-groups include foetuses, young children (under 5 years), the elderly, persons with certain underlying diseases, groups exposed to other toxicants that interact with air pollutants and those with low socioeconomic status (WHO, 2004). Children are particularly susceptible to poor air quality; air pollutants inhaled during pregnancy can cross the placenta and affect the developing brain and typical childhood activity patterns result in higher duration of personal exposure to air pollution concentrated near ground level (UNICEF, 2017; RCP, 2016). The evidence suggests that the early years are also the best time to invest in a child's health, through action to improve their environment and reduce pollutant exposure (UN, 2017).

Although overall levels of air pollution have declined in High Income Countries (HICs) over the past 25 years, they have continued to increase in LIC and LMIC settings, notably the African, South-East Asia, Eastern Mediterranean and Western Pacific regions (WHO, 2018a). These contexts present the dual contemporary public health challenge of exposure to hazardous levels of both ambient and household air pollution, as a consequence of rapid industrialisation, urbanisation and ongoing reliance upon solid biomass fuels for basic domestic energy needs.

Actions taken to reduce exposure to air pollution, particularly among children who are among the most vulnerable, also offers an opportunity to reduce health, social and gender inequalities and therefore improve lifelong health, wellbeing and economic productivity (RCP, 2016). Reducing air pollution can also mitigate harmful climate change impacts as many air pollutants are atmospheric warming agents (IPCC, 2018).

Quantifying the association between pollutant exposure and distribution of specific disease outcomes, provides the best available information for policymakers and facilitates public communication concerning air pollution risks. However there exists a paucity of high quality, large scale epidemiological studies conducted in LIC and LMIC contexts, resulting in gaps in our current knowledge (Gall et al., 2013; Sun and Zhang, 2018). Specific challenges include the availability of vital statistics, access to health information management systems, inconsistency in clinical coding practices and limited public health research infrastructure.

Globally, using available health and demographic data sources it has been estimated that among children aged under 5 years in 2016 air pollution was responsible for 543,000 deaths, including 403,000 deaths from Acute Respiratory Lung Infections (ARLIs) and 37 million total Disability-Adjusted Life Years (DALYs) (WHO, 2018b). This reflects 9% of the total deaths arising from air pollution worldwide concentrated among LICs and LMICs in sub-Saharan Africa, south and south-east Asia and the western pacific regions.

2. Introduction

Sources of air pollution

When considered with regard to population health, air pollution typically refers to the airborne mixture of solid particles and gases arising from both natural and anthropogenic processes. Air pollution may be categorised by the dominant outdoor and indoor pollutant sources.

Ambient (outdoor) air pollution is derived mainly from fossil fuel combustion, industrial processes, vehicle emissions, waste incineration, agricultural practice and natural events such as wildfires, dust storms and volcanic eruptions. The main sources of ambient air pollution vary by season and context (such as between urban to rural areas). The main components of ambient air pollution which are recognised to be harmful for health include particulate matter (PM), nitrogen dioxide (NOx), sulphur oxides (SO_X) and ozone (O_3). Exposure to particulate pollution (PM) is recognised to be particularly harmful for human health.

Household (indoor) air pollution is produced from the incomplete combustion of solid fuels, consisting of complex mixtures of pollutants including PM and carbon monoxide (CO). Household air pollution is also an important source of ambient air pollution Overall, it is estimated that almost 3 billion people, use solid biomass fuels (e.g. wood, dung, straw) for domestic cooking and heating; with the greatest number of users in the global south (Bonjour et al., 2013).

Air pollutants

Particulate Matter (PM)

PM is a generic term used to describe a complex mixture of solid and liquid particles of varying size, shape and composition. PM arises from combustion of fuels and physical processes such as friction generated by brake and tyre wear. Natural sources include soil, dust, sea spray particles and vegetation wildfires. PM is usually classified by aerodynamic particle size:

- **Coarse particles** (PM_{10}); particles less than 10 µm in diameter
- **Fine particles** ($PM_{2.5}$); particles less than 2.5 µm in diameter
- **Ultrafine particles** ($PM_{0.1}$) particles less than 0.1 µm in diameter

Particle size and exposure duration are key determinants of health impacts and severity arising from PM exposure. Coarse particles (PM_{10}) are usually removed by ciliary and mucosal clearance processes in the nose and throat, however fine particles ($PM_{2.5}$) pose the greatest risk as they can be drawn into the lungs and penetrate into the cardiovascular system (Figure 1). This means $PM_{2.5}$ is distributed within the body therefore affect a wide range of organs (RCP, 2016).

See: Figure 1: Diagram of PM size compared to a human hair, https://www.blf.org.uk/support-for-you/air-pollution/types

There is consistent evidence for a quantitative relationship between exposure to high concentrations of particulates (both PM_{10} and $PM_{2.5}$) and increased risk of mortality or morbidity from cardiovascular and respiratory disease, on both a short-term (daily) and long-term basis. The strongest evidence is for $PM_{2.5}$, recognised to exert harmful effects at very low background concentrations (Kim et al., 2015) and for which no threshold has been identified below which there is no harm for health (Beelen et al., 2014). The PM component in outdoor air pollution is classified as a Group 1 carcinogen by the International Agency for Research on Cancer (IARC), due to consistent evidence for an association with increased cancer incidence, particularly lung cancer (Loomis et al., 2013). There is currently limited understanding of the health impacts arising from ultrafine particles, although this is increasingly a focus of epidemiological research.

Nitrogen Dioxide and Nitric Oxide: NO_2 and Nitric Oxide (NO) are gases collectively referred to as the oxides of nitrogen (NOx) emitted during agricultural and industrial activities, and combustion of fossil fuels and solid waste. NO_2 is also the source of nitrate aerosols, which form an important component of $PM_{2.5}$ and (in the presence of sunlight) ozone. Evidence from existing epidemiological studies is less consistent for NO_2 compared to PM, with limited knowledge of exposure patterns. However, it is recognised that long-term chronic exposure to NO_2 at typical concentrations in industrialised cities of Europe and North America is linked to increased risk of childhood asthma and impaired lung growth (Faustini et al., 2014; Atkinson et al., 2018).

Ozone: Ozone at ground level is formed by the reaction with sunlight (photochemical reaction) of NOx and volatile organic compounds (VOCs) emitted by vehicles, solvents and industry. As a result, the highest levels of ozone pollution occur during warm, sunny periods. Excessive levels of ozone are recognised to have a marked effect on human health, including an association with increased levels of asthma and risk of chronic lung diseases (Bell et al., 2014; Zhao et al., 2018)

Sulphur Dioxide: Sulphur dioxide (SO_2) is a colourless gas produced from coal and oil combustion and mineral smelting. SO_2 also combines with water to form sulphuric acid, a major component of acid rain. SO_2 is known to cause inflammation and irritation of the respiratory tract and eyes, aggravating chronic conditions and increasing susceptibility to infectious pathogens. Short-term impacts also include increased risk of cardiovascular morbidity and mortality (Liu et al., 2019).

However, much less is known about air pollution exposure and associated health risks in LIC and LMIC settings where annual average pollutant exposures are higher and population level vulnerabilities limit extrapolation of findings from HIC settings (Coker & Kizito, 2018). These notable gaps in the evidence base must be considered when undertaking assessment of the health impacts in LIC and LMIC contexts, which are most reliably undertaken using PM only, which is the primary focus of this review.

Air quality guidelines

The *WHO Air quality guidelines* (WHO Global Update, 2005) provides guidance on thresholds and limits for key harmful air pollutants (Table 1). The Guidelines apply worldwide and are based on expert evaluation of current scientific evidence for $PM_{2.5}$, PM_{10}, Ozone, NO_2 and SO_2. In addition, a series of Interim Targets for annual PM2.5 concentrations have been developed to enable international tracking of progress towards WHO PM limit values.

Table 1: WHO Air Quality Guidelines (2005)

Pollutant	Concentration	Averaging Period
Particulate Matter ($PM_{2.5}$)	10 µgm^{-3} 25 µgm^{-3}	1 year 24 hours
Particulate Matter (PM_{10})	20 µgm^{-3} 50 µgm^{-3}	1 year 24 hour
Ozone	100 µgm^{-3}	8 hour
Nitrogen dioxide (NO_2)	40 µgm^{-3} 200 µgm^{-3}	1 year 1 hour
Sulphur dioxide (SO_2)	20 µgm^{-3} 500 µgm^{-3}	24 hour 10 minute

Source: WHO Air quality guidelines. Global update 2005. (2005, p. 9,14,16,18), licensed under CC BY-NC-SA 3.0 IGO

More recently, the WHO developed indoor air quality guidelines for household $PM_{2.5}$ and CO concentrations. These values are based upon emission rates from household fuel combustion necessary to meet WHO guideline limits, thereby providing a basis for testing and selecting appropriate devices and fuels (Table 2).

Table 2 WHO indoor air quality guidelines: household fuel combustion (2014)

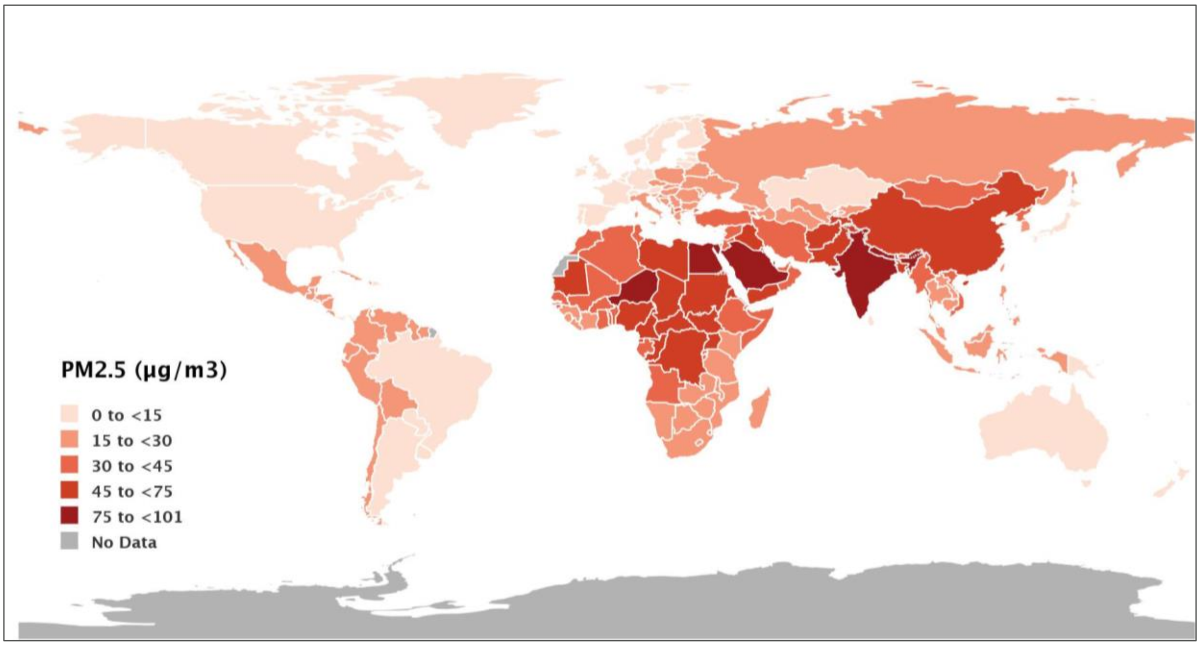
Pollutant	Concentration	Household conditions
Particulate Matter ($PM_{2.5}$)	0.23 mgmin^{-1} 0.80 mgmin^{-1}	Unvented Vented
Carbon Monoxide (CO)	0.16 gmin^{-1} 0.59 gmin^{-1}	Unvented Vented

Source: WHO indoor air quality guidelines: household fuel combustion (2014, p. 101), licensed under CC BY-NC-SA 3.0 IGO

3. Global Burden of Air Pollution

The sources responsible to air pollution vary within and between countries and countries, with the mix and magnitude of different sources change over time. Global comparisons of air pollution exposure use population-weighted annual concentrations to reflect where most people live. Applying this approach, it is evident that the highest average ambient $PM_{2.5}$ exposures occur in south Asia and sub-Saharan Africa (Figure 2).

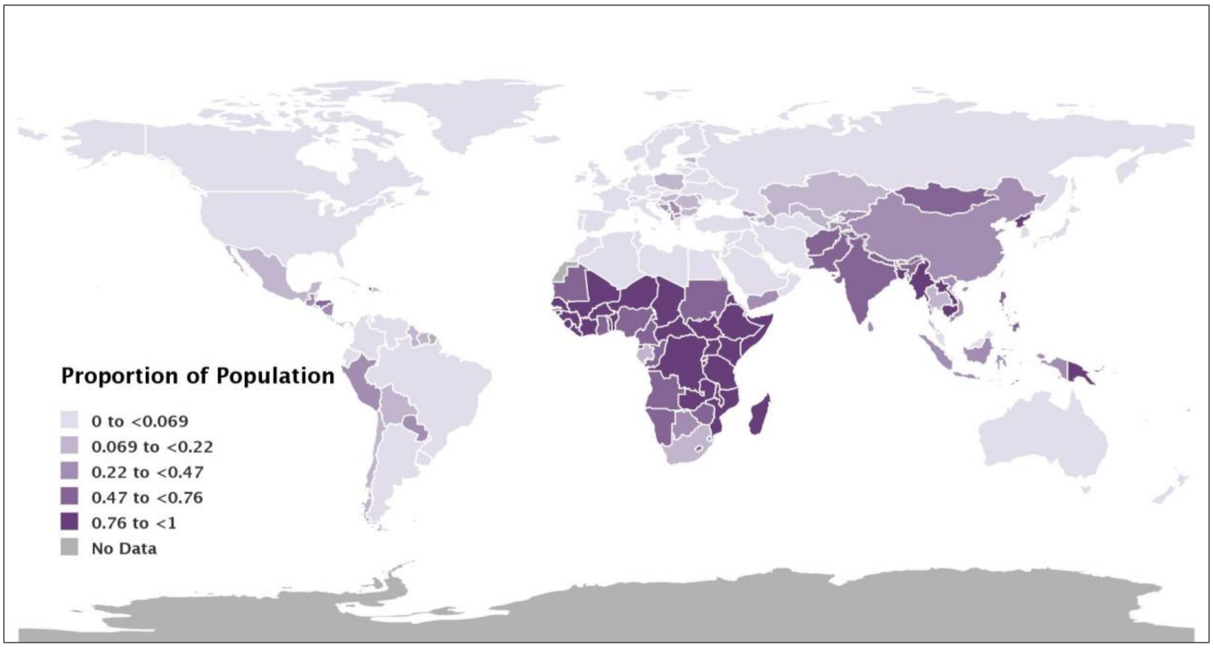
Figure 2 Average annual population-weighted PM2.5 concentrations in 2017 (Health Effects Institute, 2017)



Data Source: Global Burden of Disease Study 2017. IHME, 2018, licensed under CC BY-NC-ND 4.0

Due to limited routine monitoring data in many LIC and LMIC settings, it is challenging to estimate the contribution of total pollution arising from ambient and household sources respectively. However, the proportion of population using solid fuels provides a proxy measure for pollution arising from domestic fuel combustion (Figure 3).

Figure 3 Proportion of population using solid fuels in 2017 (Health Effects Institute, 2017)

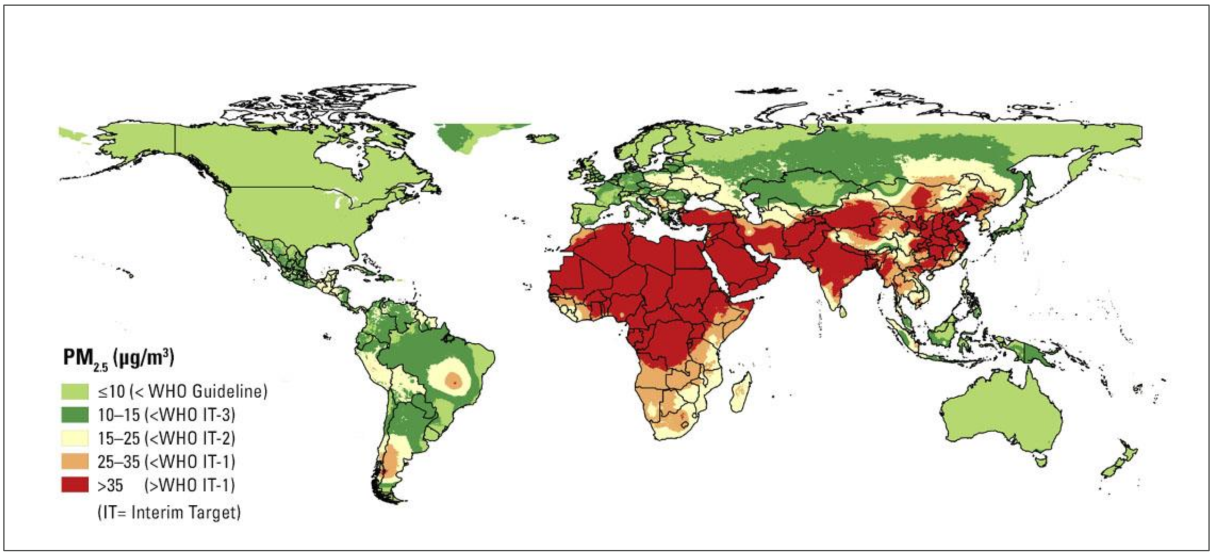


Source: Global Burden of Disease Study 2017. IHME, 2018, licensed under CC BY-NC-ND 4.0

Comparison to WHO Air Quality Guidelines

The WHO Air Quality Guidelines an Interim Targets may be used to track progress towards health-based limit values. It was estimated that in 2017 a total of 92% of the world's population lived in areas that exceeded the WHO Guideline for $PM_{2.5}$ (10 µg/m^3) and 82% lived in areas exceeding Interim Target 3 (15 µg/m^3) (Figure 4).

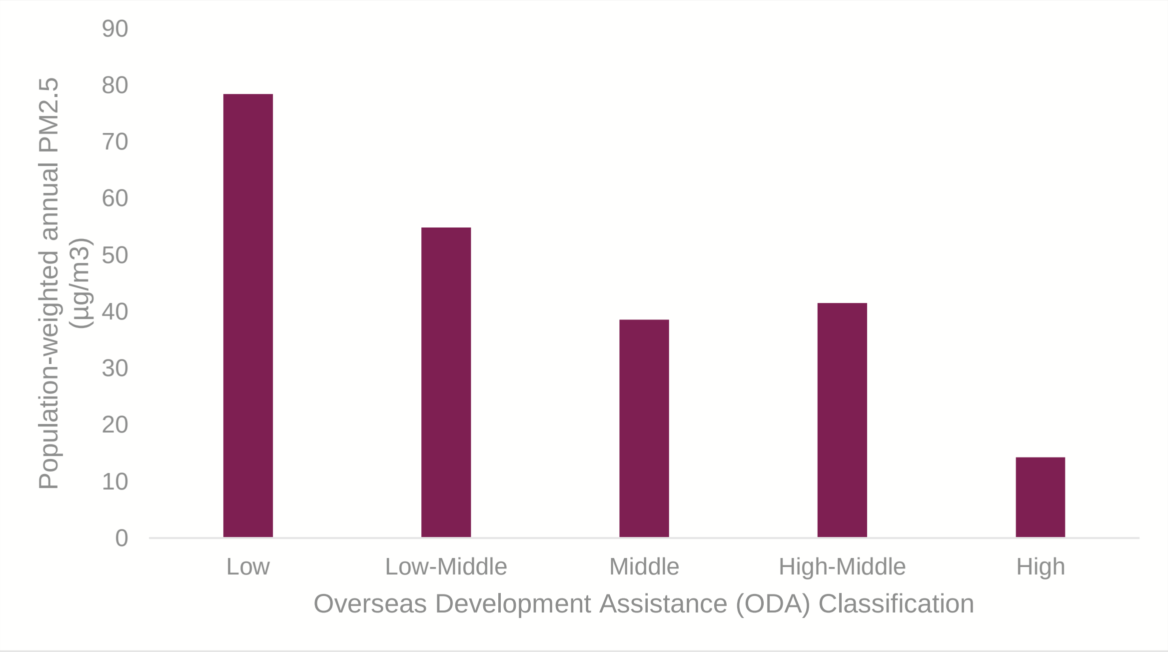
Figure 4 Global map comparing 2017 fine particle concentrations to WHO air quality guidelines and interim targets (IT-1, 2, and 3)



Source: Global Burden of Disease Study 2017. IHME, 2018, licensed under CC BY-NC-ND 4.0

Between 1990 and 2017 the largest reductions in $PM_{2.5}$ levels relative to the WHO Guideline of 10 µg/m^3 were experienced within the European Union, Russia, Japan, Brazil and the United States. Overall, LIC and LMIC countries experience average $PM_{2.5}$ concentrations of 78 µg/m^3 and 55 µg/m^3; four to five times higher than the HIC average exposure (14 µg/m^3) (Figure 5).

Figure 5 Global patterns in average annual PM2.5 exposures by national income status (Health Effects Institute, 2017)



Data Source: Global Burden of Disease Study 2017. IHME, 2018, licensed under CC BY-NC-ND 4.0

The proportions of children exposed to levels of fine particulate matter ($PM_{2.5}$) higher than the WHO air quality guidelines are as follows (WHO, 2018b):

- 93% of all children, and about 630 million children aged under 5 years worldwide
- in LMICs, 98% of all children under 5 years;
- in HICs, 52% of children under 5 years;
- in the WHO African and Eastern Mediterranean regions, 100% of all children under 5 years;
- in LMICs in the South-East Asia Region, 99% of all children under 5 years;
- in LMICs in the Western Pacific Region, 98% of all children under 5 years; and
- in LMICs in the Region of the Americas, 87% of all children under 5 years

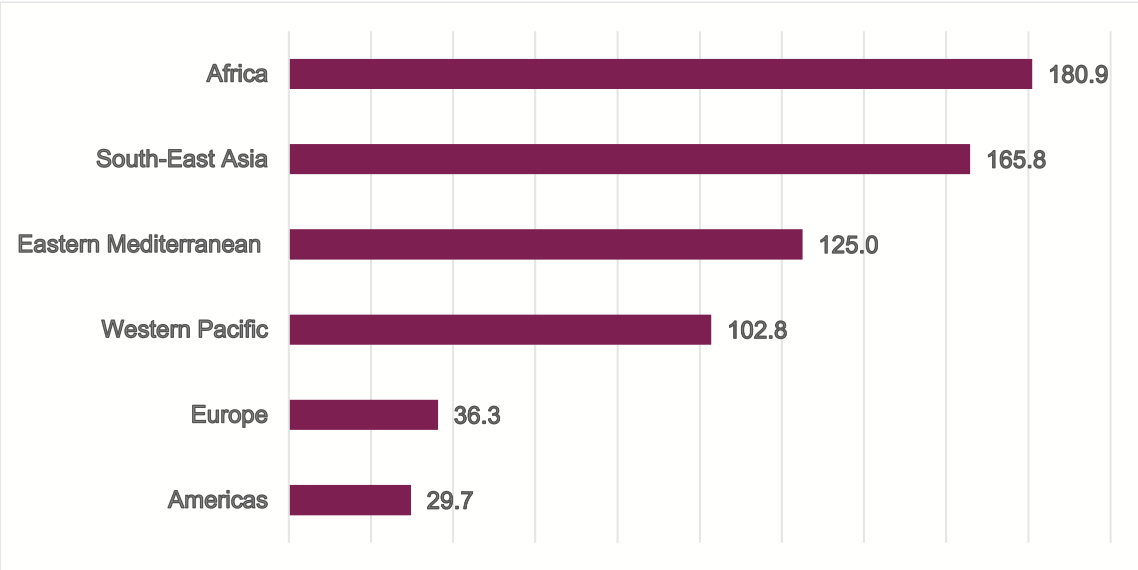
Mortality attributable to air pollution

Ambient air pollution: Overall ambient air pollution was estimated in 2016 to be responsible for 4.2 million premature deaths worldwide, with 91% occurring in LMIC settings and the greatest burden in the South-East Asia and Western Pacific regions. Over half of these deaths (58%) were due to ischaemic heart disease and strokes, while 18% of deaths were due to chronic obstructive pulmonary disease and acute lower respiratory infections respectively, and 6% of due to lung cancer (WHO, 2018).

Household air pollution: is estimated to cause 3.8 million premature deaths each year of which it is estimated over one quarter are due to pneumonia (27%), 18% from stroke, 27% from ischaemic heart disease (IHD), 20% from chronic obstructive pulmonary disease (COPD) and 8% from lung cancer. These deaths include 45% of all those arising from pneumonia in those aged up to 5 years old.

Overall, air pollution exposure contributed to 9% of deaths worldwide in 2017; a proportion which varies from 2% in many high-income countries to 15% across many countries, notably in South East Asia (WHO, 2018). After standardisation for age profile differences, the highest mortality burden arising from total ambient and household pollution is experienced within Africa and South-East Asia (Figure 6).

Figure 6 Ambient and household air pollution attributable age-standardised mortality rate by WHO world region



Data Source: WHO Global Ambient Air Quality Database, 2018, licensed under CC BY-NC-SA 3.0 IGO

4. Health impacts of air pollution

Understanding the distribution of health impacts associated with poor air quality is critically important to inform a public health approach to air quality management, specifically to enable:

(i) **Assessment** of country-specific disease burden associated with poor air quality

(ii) **Planning and prioritisation** of targeted public health measures to mitigate air pollution impacts among vulnerable groups

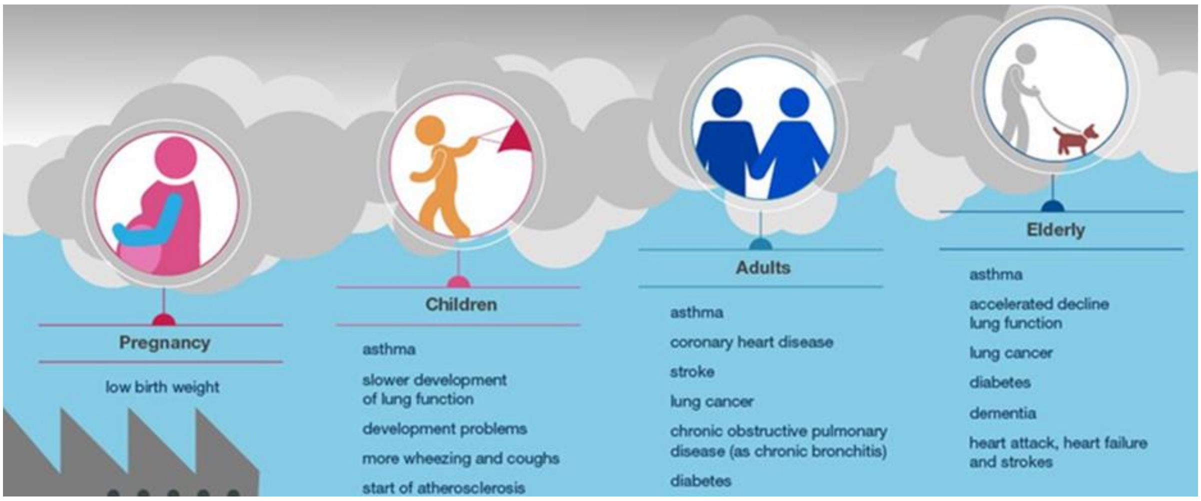
(iii) **Predictive modelling** of future co and dis-benefits arising from specific air quality management scenarios

Life course approach

There is consistent and compelling evidence that air pollutant exposure is harmful to human health throughout the human life course, from before birth to later life. Exposure to air pollution early in prenatal or early life can impair lung development, reduce lung function and increase the risk of chronic lung and cardiovascular disease in adulthood due to adverse effects at critical periods of organ development and maturation (RCP, 2016; UNICEF, 2017).

Adopting a ‘whole life course’ approach to air pollution exposure assessment provides a more accurate assessment of long-term and cumulative impacts (Figure 7). Knowledge and understanding of specific disease risks has been obtained from extensive epidemiological studies, predominantly conducted among healthy populations in Europe and North America. There is more limited knowledge about these risks in LIC and LMIC populations; however this is an emerging focus of research for high-quality large-scale observational studies.

Figure 7 Health impacts of air pollution through the human life course



Source: PHE, 2018, licensed under Open Government Licence v3.0

Vulnerability and susceptibility to air pollution

Children are at greater risk than adults from many of the adverse health effects of air pollution, due to a combination of behavioural, environmental and physiological factors. They are particularly vulnerable during the early pre-school aged years, when organs are still undergoing maturation. Children also have a higher breathing rate than adults and they breathe air located closer to the ground, where some pollutants are at higher concentrations (RCP, 2016). Children also spend more time outside playing and engaging in physical activity (compared to adults, and new-born and young children who spend most time indoors, where in LIC and LMIC settings they are vulnerable to impacts of household air pollution. Children also have a longer life expectancy than adults, and exposure during critical periods of early life may have influences upon latent disease mechanisms and predisposition to ill health in later life (RCP, 2016).

Vulnerability to air pollution may also be compounded by factors including adaptive capacity (i.e. the ability to protect oneself from harm including access to materials, technology, knowledge, information and social protection); location; the extent of assistance and support, including services, resources and technical expertise, that society can provide. Three dimensions of vulnerability are thereby commonly identified (Howe et al., 2013):

- **Exposure -** the degree to which the subjects or areas could be effected by air pollution.
- **Susceptibility** - the likelihood or being harmed by air pollution.

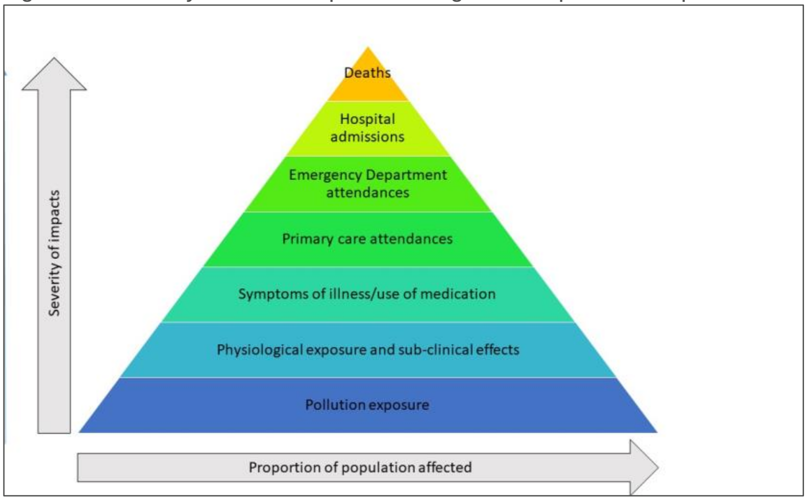
- **Adaptive capacity** - the ability to take actions to either reduce or avoid risk. This includes treatment information and access to healthcare resources (Avis and Khaemba, 2018).

The inequitable distribution of environmental pollutant exposures, pre-existing susceptibility, and adaptive capacity to reduce air pollutant derived health risks, all also contribute to prevailing health, social and economic inequalities in LIC and LMIC settings.

Health outcome measures

Health impacts may be measured using different levels, ranging from sub-clinical effects, disease symptoms, disease diagnoses, healthcare service utilisation (primary care consultations, emergency room attendances and hospital admissions), disability and death (Figure 8).

Figure 8 Hierarchy of health impacts arising from air pollutant exposure



Source: Author’s Own

Pregnancy and delivery

Adverse birth outcomes

Pregnancy is recognised as a highly vulnerable time to the toxicological impacts of air pollutant exposure and there is an expanding body of evidencing linking air pollutant exposure with a range of adverse birth outcomes, many of which have enduring lifelong consequences. There is robust evidence that exposure to ambient PM is associated with low birth weight, reflected by a two systematic reviews which identified consistent positive associations between $PM_{2.5}$ exposure during pregnancy and low birth weight, suggesting that the final trimester of pregnancy may be a particularly vulnerable time (Shah et al., 2011; Steib et al;, 2016). Ambient air pollution exposure, particularly fine PM has robust evidence for an association with risk of preterm birth and suggestive evidence for a link with infants born Small for Gestational Age (SGA); however this review was restricted to studies conducted in China (Jacobs et al., 2017).

Early life and childhood (up to 5 years)

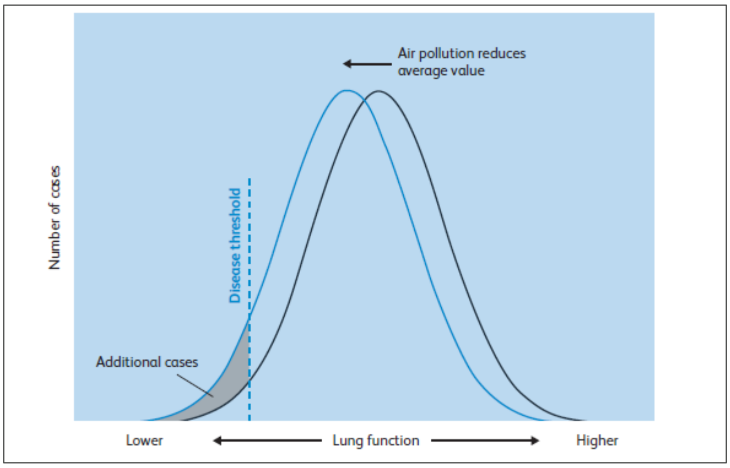
Infant mortality

Infant mortality refers to death which occurs in the first year of life. There are relatively few studies which have investigated a link with air pollution exposure, however those which have been completed suggest an association with PM exposure. Most studies have focused on acute (short-term) ambient pollutant exposure immediately before an infant's death, suggesting that as pollutant levels increase so does the risk of mortality, particularly from PM and toxic gases (Son et al, 2011) However, few studies have investigated the impact of household air pollution exposure and risk of infant mortality.

Lung function

There is consistent and robust evidence that exposure to air pollution damages children's lung function and impedes lung growth, even at low exposure levels. Studies have also indicated that prenatal exposure to air pollution is associated with impairment of lung development and lung function in childhood. Conversely, there is evidence that children experience better lung function growth in areas in which ambient air quality is improved (Gehring et al., 2013; Korten et al., 2017). Changes in lung function may be sub-clinical, however even a small reduction in lung function will result in a large number of children falling below the disease threshold at a population level (Figure 9).

Figure 9 Relationship between average lung function and disease threshold at population level



Source: reproduced with permission from RCP (2016, p 45)

Acute Lower Respiratory Infections (including pneumonia)

Numerous studies offer compelling evidence that exposure to ambient and household air pollution increases the risk of Acute Lower Respiratory Tract Infection (ALRI) in children (Dherani et al., 2008; Misra et al., 2012). However, few studies have independently investigated the independent effect of specific air pollutants on pneumonia in children aged under 5 years.

Exposure to household air pollution is considered to almost double the risk for childhood pneumonia and is responsible for 45% of all pneumonia deaths in children under 5 years old (WHO, 2016). A recent systematic review which used fuel type as a proxy measure for $PM_{2.5}$ exposure identified the need to standardise measurement of exposure and outcome variables and to account for different pollutants (Adaji et al., 2019) There is some limited evidence for an association between household air pollution and ALRI risk among adults (Jary et al., 2016), however many existing studies are of low methodological quality.

Childhood asthma

Asthma is the most common chronic illness of childhood worldwide. There is consistent evidence that exposure to ambient and household air pollution increases the risk of children for developing and exacerbating asthma (Fan et al., 2016; Zheng et al., 2015) and also influences asthma morbidity (Burbank et al., 2018). Asthma in early life is also recognised to be underreported and diagnosed in many countries, particularly in the global south (WHO 2018b).

Middle ear infections (Otitis media)

Otitis media (inflammation of the middle ear) is a common childhood infection which causes pain, poor sleep and can lead to chronic ear conditions if recurrent. A systematic review of 24 studies found limited but increasing evidence of a link between exposure to ambient air pollution and risk of otitis media in children. All the studies found a positive association, but results were inconsistent for most pollutants except NO_2 (Bowatte et al., 2018).

Neurodevelopment

A growing body of research suggests that both prenatal and postnatal exposure to air pollution can negatively influence neurodevelopment, leading to lower cognitive text outcomes and influencing the development of behavioural disorders such as autistic spectrum disorder and attention deficit hyperactivity disorder (ADHD). There is strong evidence that exposure to ambient air pollution can negatively affect children's mental and motor development, especially pollutants emitted from vehicles (Sunyer et al., 2015) however most primary studies have been conducted in HIC settings.

Childhood stunting

Childhood stunting is impaired growth and development that children experience from inadequate nutrition, repeat infections, and environmental influences in early life. Children are defined as stunted if they have a height-for-age more than two standard deviations below the WHO Child Growth Standards median value.[1] Stunting in early life has long-term functional consequences, including poor cognition, reduced educational performance, lost productivity and an increased risk of nutrition related chronic diseases in later life. A recent review and meta-analyses of 27 studies representing 18 LMIC countries and more than 1 million study participants, identified up to a 13% and 90% increased risk of stunting in children exposed to increased levels of AAP and HAP respectively Pun et al., 2019).

Childhood obesity

A limited number of studies have identified a potential association between exposure to ambient air pollution and certain adverse metabolic outcomes in children. The findings include positive associations between exposure to near-roadway air pollution and increased rate of change of childhood BMI at age 10 years (Kim et al., 2018)

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[1] WHO Growth references height-for-age (5-19 years). Available at: https://www.who.int/growthref/who2007_height_for_age/en/ (Accessed 15 March 2020)

Childhood leukaemia

Several studies have identified associations between prenatal exposure to ambient air pollution and higher risks of retinoblastomas and leukaemia in children (RCP, 2016). Relatively few studies have focused on household air pollution and cancer risk in children, however in adults household air pollution has been strongly associated with several types of cancer and typically contains substances classified as carcinogens. A recent systematic review, identified an association between leukaemia incidence and exposure to motorised traffic or modelled air pollutant levels, however, the majority of eligible studies were undertaken in Europe and North America (Filippini et al., 2019). Few longitudinal or retrospective studies have investigated this relationship in LMIC and LIC settings.

Adult life

Exposure to poor air quality in early life is also recognised to increase Non Communicable Disease (NCD) predisposition and risk in late life (WHO, 2018a) including heart disease, stroke, lung disease and cancers.[2] Air pollution is the second leading cause of deaths from NCDs after tobacco smoking and worldwide, with 24% cases of stroke, 25% of IHD 28% of lung cancer and 43% of COPD attributable to ambient and household air pollution in 2016 (WHO, 2018a).

Chronic Respiratory Disease

COPD

COPD is an umbrella term for progressive lung diseases including emphysema, chronic bronchitis, and refractory (non-reversible) asthma. In a review of evidence on the role of air pollution in the development of COPD, Schikowski et al, (2014) commented that the overall evidence of chronic effects of air pollution on the prevalence and incidence of COPD among adults was suggestive but not conclusive, despite plausible biological mechanisms and good evidence that air pollution affects lung development in childhood and triggers exacerbations in COPD patients. In a more recent systematic review exploring impacts upon disease exacerbations, short-term exposure to air pollutants was observed to significantly increase the risk of COPD acute exacerbations (Li et al., 2016). Further detailed source specific assessments in longitudinal studies are required in LIC and LMIC settings.

Asthma

In relation to asthma, the literature highlights issues with reporting and identification of cases across the global south and thus a corresponding paucity of data. Studies that have explored asthma cases in Africa from 1990-2010 suggest an increasing prevalence of asthma in over the past two decades (Adeloye et al., 2013). The authors, however, caution that given the paucity of

[2] Many NCDs such as IHD and stroke are also influenced by risk factors such as high blood pressure, unhealthy diets, lack of physical activity and smoking. Some other risks for childhood pneumonia include suboptimal breastfeeding, underweight and second-hand smoke. For lung cancer and chronic obstructive pulmonary disease, active smoking and second-hand tobacco smoke exposure are also main risk.

data, the true prevalence of asthma may be significantly under-estimated. They assert that there is a need for national governments in Africa to consider the implications of this increasing disease burden and to investigate the relative importance of underlying risk factors, such as rising urbanisation and population aging in their policy and health planning responses to this challenge.

Ischaemic Heart Disease (IHD)

IHD the most common NCD worldwide related to the gradual build-up of fatty material within arterial walls. Identified risk factors include high blood pressure, smoking, diabetes, physical inactivity obesity, high blood cholesterol, poor diet, depression, and alcohol excess (WHO, 2011). Air pollution exposure has consistently been linked to IHD risk, including myocardial infarction (Luo et al, 2015), out of hospital cardiac arrest (Zhao et al., 2017) and cardiovascular mortality (Pranata et al., 2020). Approximately 11% of all deaths due to IHD, accounting for over a million premature deaths annually, can be attributed to exposure to HAP (WHO, 2018).

Stroke

Stroke remains the second most common cause of death and third most important cause of disability worldwide accounting for over 118.6 million Disability Adjusted Life Years (DALYs) each year. The epidemiological evidence base suggests link between air pollution exposure and risk of ischaemic stroke. The Global Burden of Diseases study estimated that in 2015, air pollution accounted for 21% of deaths due to stroke (Lancet, 2016) with the WHO (2018a) placing the figure at closer to 25%.

Metabolic Disease

Air pollution has been hypothesised to be a risk factor for Type II Diabetes, however the epidemiological evidence has been inconsistent. A systematic review conducted in 2015, suggested an increased risk of Type II Diabetes associated with $PM_{2.5}$ and NO_2; although there was a high risk of bias among eligible studies which were based in Europe and North America (Eze et al., 2015). Future high quality epidemiological studies which assess pollutant dose-response effects are required.

Cancer

Approximately 17% of lung cancer deaths in adults are attributable to exposure to carcinogens from HAP caused by cooking with kerosene or solid fuels like wood, charcoal or coal (Raspanti et al., 2016). The risk for women is higher, due to their role in food preparation particularly in LICs and LMICS. However, few studies have comprehensively investigated the risk of lung cancer associated with HAP in contexts where biomass usage is the norm.

Later life

Lung function

Lung function in adulthood slowly declines with age. Longitudinal studies conducted in the US and Europe among older adults indicate that this decline accelerates among those exposed to higher levels of traffic-derived air pollution (Lepeule et al., 2014; Adam et al., 2015)

Cognitive decline and dementia

There is also emerging evidence that air pollution affects both the developing and the emerging brain. A systematic review undertaken in 2019 identified an increased risk of dementia among those exposed to higher levels of $PM_{2.5}$, NOx and CO (Peters et al., 2019). However, all of these studies were conducted in high income settings (USA, Taiwan, Sweden, UK) and there remains a paucity of high quality epidemiology research on this topic in the global south.

Functional decline and frailty

It has been hypothesised that air pollution exposure is associated with risk of frailty, comprising multiple components of physiological decline in later life. Emerging data and literature from South Korea support this relationship suggest an adverse impact upon self-reported quality of life and increased healthcare per-patient expenditure (An et al., 2019). Understanding these relationships is challenging as older populations are heterogeneous and individuals may have a wide variety of health conditions which influence their vulnerability to the health effects of air pollutants. It is also unclear if conventional analyses for air pollutant impacts can distinguish between the effects of air pollution and natural ageing processes.

5. Approaches to estimating health impacts of air pollution

Demographic data sources

Accurate assessment of the health impacts arising from air pollution and tracking of progress towards policy goals requires actionable data integrated within a health information system. The key sources of health information routinely available within LIC and LMIC settings comprise:

Civil registration systems: the continuous and universal recording of vital events (live births, deaths, foetal deaths, marriages and divorces) and other civil events in accordance with national legal requirements. Civic registration information systems provide information on population structure, including among districts and sub-district units. If medical certification of cause of death is used according to standards of the International Statistical Classification of Diseases and Related Health Problems (ICD) it will generate accurate and timely data on cause of death, therefore enabling construction of life tables and mortality estimates by age and sex. Similarly, information on live births enables understanding of fertility patterns, reproductive dynamics and provides the basis for population projections. However, coverage of birth registration typically remains low among LIC and LMIC settings.

Population census: The UN recognises a modern census as ‘individual enumeration, universality within a defined territory, simultaneity and defined periodicity. In the global south coverage of civil registration systems is incomplete, the census is a key data source for fertility, mortality and population dynamics. The counts provide a denominator for health indicators and comparisons may be used to infer trends about the growth or decline of a population. The census may also be used indirectly to estimate mortality, by asking people about the survival of their children, parents, siblings or spouses. This may be combined with the enumerated population, to produce mortality estimates by age and sex.

Household surveys: In the global south, population-based surveys are the most important sources of health information, given the limited development of routine health information systems. Surveys provide information on direct health indicators, as well as individual behavioural and lifestyle risk factors. They can also be used as a mechanism for collection of clinical and biological measurements, therefore generating more accurate and reliable information on health status in comparison to self-report. The gold standard survey is integrated within a national health and statistical information system, enabling generation of health statistics on a routine basis.

There are a range of survey instruments used, with the most common being the USAID-supported Demographic and Household Survey (DHS) (USAID, 2019) followed by the UNICEF Multiple Indicator Cluster Survey. These internationally sponsored surveys provide a population based sample and generally utilise electronic data entry to tablets by trained fieldworkers. . There are inherent response biases in questionnaires, resulting in inaccuracies in the data; in addition, to questionnaires being country specific, reducing the breadth of comparison that can be undertaken between countries. However, DHS survey modules generate a valuable data repository for exploring symptoms and health outcomes with regard to household air pollution, such as by analyses to explore associations with fuel type and to explore establish trends to gauge progress with health programs.

However, reliance upon surveys for health indicators does have disadvantages; the information is inherently retrospective and relates to historical events. Recall bias may be a problem if questions are asked about past events, such as previous births and sampling methodology can generate uncertainty. Furthermore, large-scale surveys are often reliant upon external technical and financial support

Health service statistics

Health statistics obtained from healthcare facilities of relevance for air pollution typically relate to:

Health status

- Admissions and discharge by diagnosis
- Case fatality rates
- Outpatient attendances
- Maternal deliveries/maternal deaths

Health service provision

- Type and utilisation of services
- Supplies and human resources.

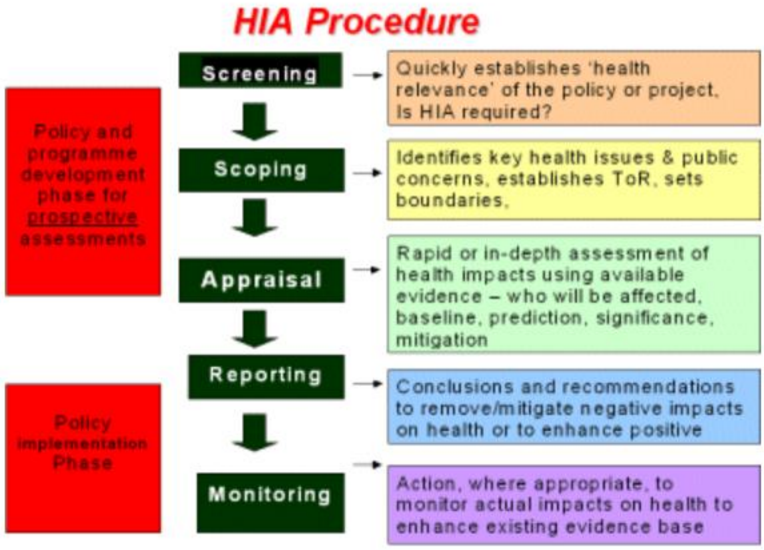
It is widely recognised that routine datasets generated through routine health management information systems (such as health facility assessments, vaccination programmes, routine health checks) are often under-analysed and under-utilised for air quality and health research Furthermore, such data sources may be biased for population-based studies as they relate to those using health services. The greatest value of integrated data systems for health impact assessment is by comparison of routine health statistics with survey data, enabling an

All of the above data sources are important for understanding the health impacts of a population, but yield greatest value when integrated together enable assessment of data quality, validity and completeness and an assessment of bias, ideally within an electronic management system.

Health impact assessment

Health impact assessment (HIA) is a combination of practical procedures and methods, which are used to evaluate the existing health effects of an exposure or the potential consequences of a policy or programme. HIA comprises a series of defined steps, comprising a development phase (screening, scoping and appraisal) followed by an intervention phase (reporting, monitoring) whereby evidence is used to develop and apply relevant policy measures (Figure 10).

Figure 10: The process of a Health Impact Assessment



Source: WHO (n.d.), https://www.who.int/teams/environment-climate-change-and-health/air-quality-and-health/hia-tools-and-methods, reproduced with permission from WHO

With regard to air quality, HIA is undertaken to assess the morbidity and mortality rates due to current air pollution levels and to quantify the public health benefits if levels would change to a certain extent, thereby providing decision-makers with choices about the best available alternatives. HIA for air pollution was originally conducted in Europe and has since been used for large collaborative studies, notably including the Global Burden of Disease (GBD study) and future emissions scenarios.

HIAs typically apply exposure-response relationships for specified health conditions based on published risk estimates in the scientific literature. Health impacts can be quantified using different metrics (also called' health endpoints'), reflecting morbidity (e.g. an increase in the number of hospitalisations, working days lost) or mortality (e.g. number of premature deaths). Application of these recognised relationships to the baseline health status of a selected population, enables the excess health risks associated with specific pollutant exposure to be quantified and risks may be further aggregated to give an overall impact (such as premature mortality) at a population level.

Health Impact Assessment: Methodology

The natural (and most common) metric for measuring a health impact is the portion of the observed occurrence, which is attributable to PM exposure. Although the biological mechanism of action of this heterogeneous pollutant is not yet fully understood, the association between PM and health is generally regarded as causal, and a non-threshold relationship has been observed in a wide range of settings.

To calculate the attributable risk due to PM in a HIA framework, one needs to understand the distribution of the exposure in the population, such as the average ambient PM concentration measured in the city or area where the population of interest live, which may be obtained from air quality observations or extrapolated by modelling techniques. Typically everyone living in an area is assumed to be exposed to the PM concentration measured by a central monitoring station. If the observed rates of disease or mortality occurrence in the population are known, it is then possible to calculate the attributable risk (to PM) as a proportion of all cases. TPM is often used as a summary indicator of overall air quality, enabling the question "what are the health gains potentially obtainable adopting specific abatement policies?" A series of steps are then followed (Box 1) to calculate the quantitative answer.

Figure 11 Steps for impact assessment of PM exposure

Step 1	Establish a set of health endpoints known to be associated with PM exposure
Step 2	Identify concentration-response coefficient and its confidence interval (CI) using published evidence
Step 3	Estimate proportion of events in the study population attributable to PM concentration

Source: Author's Own

Health Impact Assessment: Strengths and Limitations

Although the methodological process for conducting health impact assessment is straightforward, there are several issues which may lead to inaccurate estimates. Measures of PM concentrations across large populations and averaged over long time durations are used which do not reflect individual level pollutant exposure or reflect fluctuations in magnitude over short time periods. In addition, most long-term epidemiological studies have been conducted in high income studies with differences in terms of vulnerability to poor air quality and contextual differences such as climatic conditions, housing which would result in different exposures at the same ambient level. Ideally, concentration-response coefficients would be derived from the same population for which the impact is performed; however the cost and resource requirements for long-term population-based longitudinal studies prohibits this. In addition, PM is often used as an indicator for a mix of pollutants, which overlooks potential differences in exposure-response relationships for different urban pollutants (such as Nitrogen Oxides, Ozone, carbon monoxide). Finally, HIA is limited in consideration for different impacts among population subsets (by age, social class, area of residence or other factors).

6. Childhood burden of disease related to air pollution exposure in LICs and LMICs

Mortality burden

Globally, by undertaking HIA using available data sources it has been estimated that 543,000 deaths in children aged under 5 years and 52,000 deaths among children were attributable to the joint effects of ambient and household air pollution in 2016 (WHO, 2018a)

Investigating this breakdown by world region, it is evident that the greatest impacts were experienced among low and middle-income countries in the African region, with the highest death rate among children under 5 years (184.1 per 100,0000) and 5-14 years (12.9 per 100.000), compared to equivalent European country rates of 8.8 per 100,000 and 0.3 per 100,000 respectively (Table 4)100.000), compared to equivalent European country rates of 8.8 per 100,000 and 0.3 per 100,000 respectively (Table 4)

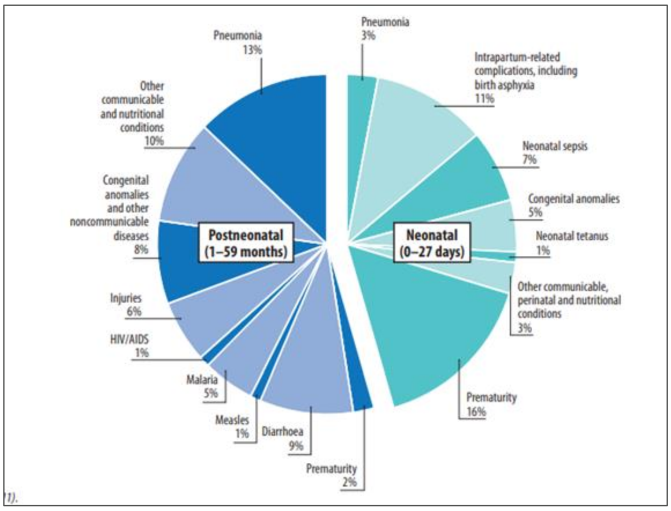
Table 3: Death rate per 100 000 children attributable to the joint effects of Household and Ambient Air Pollution

WHO Region	Income Level	Children < 5 years	Children 5-14 years
African	LMIC	184.1	12.9
	HIC	4.3	1.4
Americas	LMIC	14.2	0.7
	HIC	0.3	0.0
South-East Asia	LMIC	75.0	2.5
European	LMIC	98.6	3.6
	HIC	0.3	0.0
Eastern Mediterranean	LMIC	98.6	3.6
	HIC	5.3	0.4
Western Pacific	LMIC	20.5	1.0
	HIC	0.3	0.0
All	LMIC	88.7	4.5
	HIC	0.6	0.1
World		**80.5**	**4.1**

Source: adapted from WHO (2018a), licensed under CC BY-NC-SA 3.0 IGO

Among children aged under 5 years, the five leading global causes of death are prematurity, ARI, intrapartum complications, other group one conditions and congenital anomalies (Figure 10). In the African Region, acute respiratory infection is the leading cause of death in this age group.

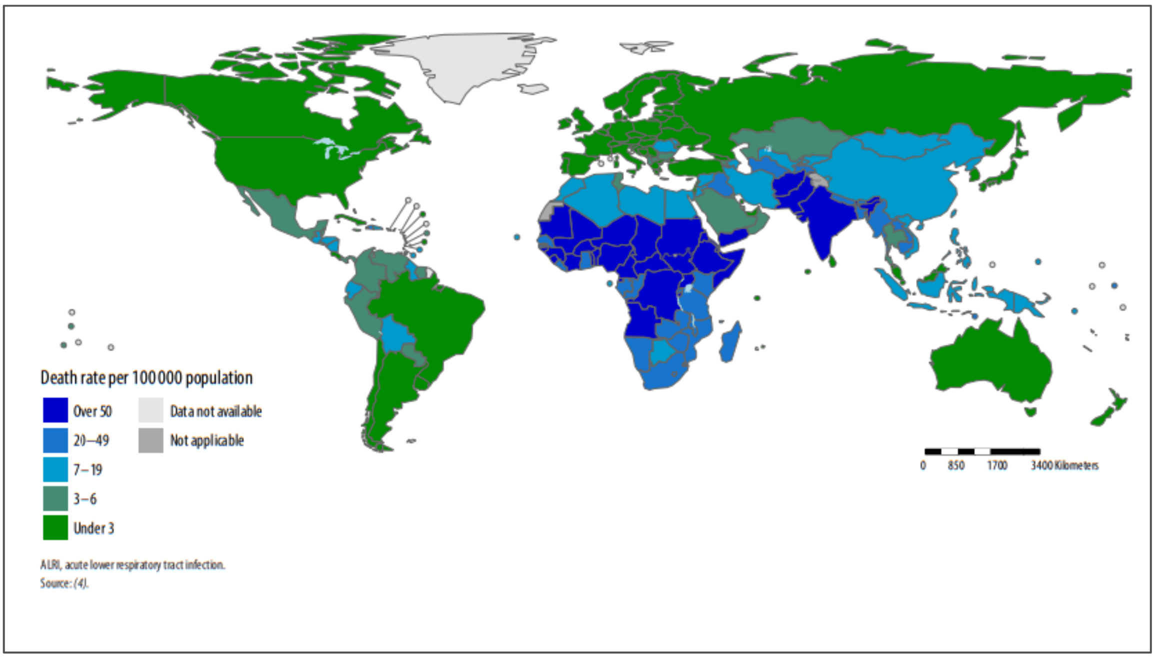
Figure 12: Causes of death among children aged under 5 years worldwide



Source: WHO, 2018, licensed under CC BY-NC-SA 3.0 IGO

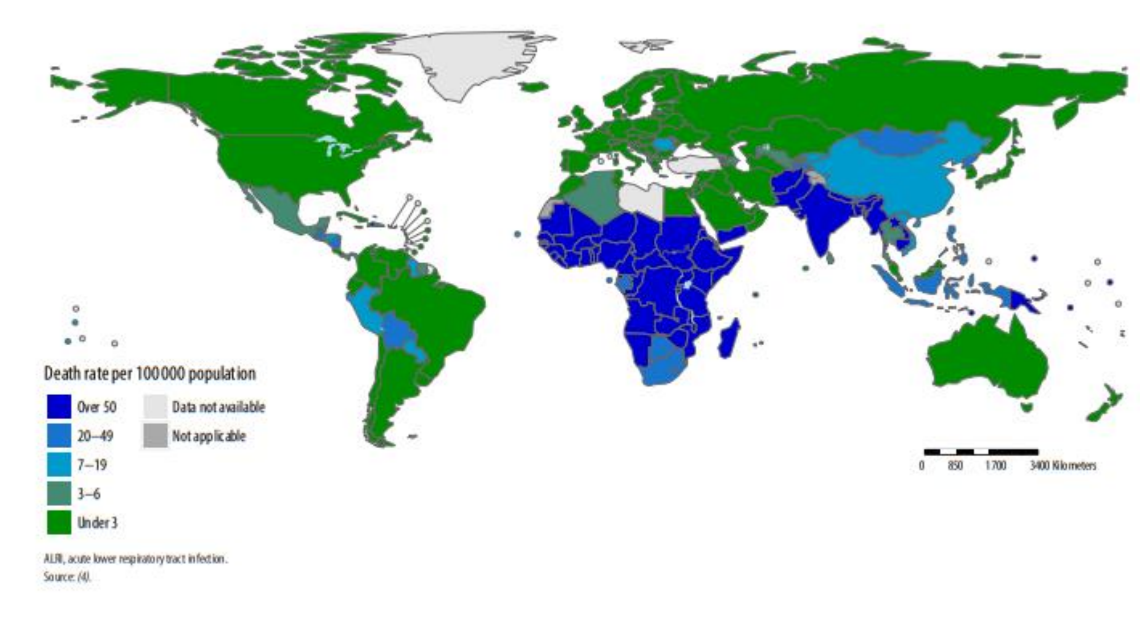
Reviewing the global distribution of deaths due to ALRI in children aged under 5 years, these are concentrated in sub-Saharan Africa, south and south-east Asia and the western pacific region for both ambient and household air pollution (Figs 13 & 14).

Figure 13 Death rate per 100,000 from ALRI due to ambient air pollution in children under 5 years in 2016.



Source WHO, 2018b, licensed under CC BY-NC-SA 3.0 IGO

Figure 14 Death rate per 100,000 from ALRI due to household air pollution in children (<5 years) in 2016. Source: WHO, 2018



Similar patterning is observed by reviewing the population attributable fraction of child mortality due to ALRI as a joint effect of household and ambient air pollution (Table 5).

Table 5 Population attributable fractions of child mortality due to ALRI as a joint effect of household and ambient air pollution (2016) by WHO region and income level

WHO Region	Income Level	Children < 5 years	Children 5-14 years
African	LMIC	66	66
	HIC	25	24
Americas	LMIC	34	34
	HIC	8	7
South-East Asia	LMIC	63	62
European	LMIC	27	27
	HIC	13	14
Eastern Mediterranean	LMIC	58	55
	HIC	40	40
Western Pacific	LMIC	53	52
	HIC	12	11
All	LMIC	62	62
	HIC	18	15
World		**62**	**62**

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