Science of the Total Environment 650 (2019) 2389–2394

Contents lists available at ScienceDirect

Science of the Total Environment

journal homepage: www.elsevier.com/locate/scitotenv

Pollution and children's health

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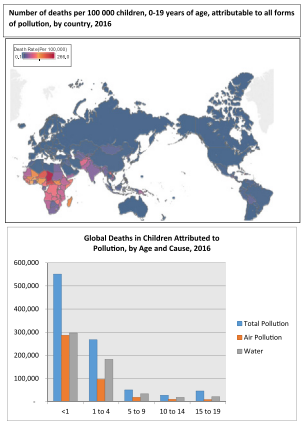
HIGHLIGHTS

- Pollution was responsible in 2016 for 940,000 deaths in children, two-thirds under age 5.
- 92% of pollution-related deaths in children occur in low- and middle-income countries.
- Most are due to respiratory and gastrointestinal diseases caused by polluted air and water.
- Pollution is linked also to multiple NCDs in children. These diseases are on the rise.
- Pollution prevention is a major opportunity to prevent disease and improve children's health.

GRAPHICAL ABSTRACT



ARTICLE INFO

Article history:
Received 10 July 2018
Received in revised form 10 September 2018
Accepted 29 September 2018
Available online 2 October 2018

Editor: Pavlos Kassomenos

Keywords:
Pollution;
Children's environmental health;
Non-communicable diseases;
Global health;
Prevention

ABSTRACT

Findings: The *Lancet* Commission on Pollution and Health found that pollution – air, water, soil, and chemical pollution - was responsible in 2016 for 940,000 deaths in children worldwide, two-thirds of them in children under the age of 5. Pollution is inequitably distributed, and the overwhelming majority of pollution-related deaths in children occurred in low- and middle-income countries (LMICs). Most were due to respiratory and gastrointestinal diseases caused by polluted air and water.

Pollution is linked also to multiple non-communicable diseases (NCDs) in children including low birth weight, asthma, cancer and neurodevelopmental disorders, and these diseases are on the rise. The full impact of pollution, especially chemical pollution on the global burden of pediatric disease is not yet known, but almost certainly is undercounted because patterns of chemical exposure are not well charted and the potential toxicity of many chemical pollutants has not been characterized. The list of pediatric NCDs attributed to pollution will likely expand as the health effects of newer chemical pollutants are better defined and additional associations between pollution and disease are discovered.

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[1] were co-chairs of the *Lancet* Commission on Pollution and Health and Drs. Suk, Sly and Chiles were members of the Commission.

https://doi.org/10.1016/j.scitotenv.2018.09.375

Conclusion: Pollution prevention presents a major, largely unexploited opportunity to improve children's health and prevent NCDs, especially in LMICs. Failure to incorporate pollution prevention into NCD control programs is a major missed opportunity for disease prevention.

1. Introduction

Pollution is the world's largest environmental cause of disease and premature death. It is responsible for an estimated 9 million deaths per year—16% of all deaths worldwide— three times more deaths than AIDS, tuberculosis, and malaria combined (Landrigan et al., 2017). In the most severely affected countries, pollution is responsible for more than one death in four. Children are exquisitely sensitive to pollution (Suk et al., 2016).

Despite the great magnitude of the problem, pollution has been neglected in the international development and global health agendas.

To end this neglect, raise awareness of pollution's impacts, and mobilize the resources, political leadership and civic will needed to control pollution and prevent pollution-related disease, the *Lancet* Commission on Pollution and Health was formed in 2015. This Commission undertook a comprehensive analysis of pollution and its effects on human health and the global economy and disseminated its findings in October 2017 (Landrigan et al., 2017). This review is based on the *Lancet* Commission report and highlights pollution's impacts on the health of children.

2. Findings of the *Lancet* Commission on Pollution and Health

2.1. The global burden of pollution-related disease

Using data from the Global Burden of Disease study (Forouzanfar et al., 2015a and 2015b), the *Lancet* Commission found that air pollution is the largest cause of pollution-related disease. Air pollution is responsible for an estimated 6.4 million deaths per year - 4.2 million from ambient air pollution (HEI/IHME, n.d.) and 2.8 million from household air pollution (Smith et al., 2014; Yadama, 2013). Water pollution is responsible for an estimated 1.8 million deaths annually. Occupational pollutants – dusts and carcinogens kill an estimated 800,000 people. Lead is responsible for approximately 500,000 deaths each year and additionally causes widespread, but inadequately quantified impairment of cognitive function and behavior.

The *Lancet* Commission found that in many places and especially in the growing cities of rapidly developing low- and middle-income countries, pollution – especially, ambient air pollution and chemical pollution - is getting worse. The numbers of deaths due to pollution-related disease are projected to rise still further in coming decades unless aggressive interventions are undertaken (Lelieveld et al., 2015). Key drivers of these increases are the uncontrolled growth of cities; rising demands for energy; mining; smelting; deforestation; the global spread of toxic chemicals; increasingly heavy applications of toxic insecticides and herbicides; and the growing global use of petroleum-powered cars, trucks, and buses.

2.2. Pollution and non-communicable disease

The *Lancet* Commission noted that pollution is a major cause of non-communicable diseases (NCDs) in persons of all ages - responsible for 16% of all NCD deaths globally. The impact of pollution on NCD mortality is especially strong in heavily polluted low- and middle-income countries where it exceeds the impacts of tobacco, alcohol and obesity (Landrigan et al., 2017; Fuller et al., 2018). In 2015, all forms of pollution combined were responsible for 21% of all deaths from cardiovascular disease, 26% of deaths due to ischemic heart disease, 23% of deaths due to stroke, 51% of deaths due to chronic obstructive pulmonary disease, and 43% of deaths due to lung cancer (Landrigan et al., 2017).

2.3. Toxic chemical pollution

The Commission considered chemical pollution to be a great and growing threat to children's health. An estimated 140,000 new chemicals and pesticides have been invented and manufactured since 1950, and many have become widely disseminated in the earth's environment (Landrigan and Goldman, 2011; Prüss-Ustün et al., 2011). Patterns of exposure to manufactured chemicals are poorly mapped in most countries, and the toxicity of the majority of chemicals in commerce has never been evaluated.

2.4. Pollution, poverty and human rights

The *Lancet* Commission found that pollution is deeply intertwined with poverty and injustice and stated that pollution threatens fundamental human rights - the right to life, the right to health, the right to well-being, and the rights of the child (United Nations, 1948). Ninety-two per cent of pollution-related deaths occur in low- and middle-income countries - environmental injustice on a global scale, and in countries at every income level, pollution and pollution-related disease are disproportionately concentrated in poor, minority and marginalized communities (Bullard, 1990).

Pollution is not only a consequence of poverty. It can also can cause and deepen poverty by producing disease, dysfunction, premature death that results in diminished economic productivity, lost income and increased health-care costs for already impoverished families (Furie and Balbus, 2012). In children, early-life exposures to neurotoxic pollutants can permanently impair cognitive function thus contributing to school failure and reduced lifetime earnings.

Globalization is a powerful driver of the increasing concentration of polluting industries in low- and middle-income countries. Globalization has resulted in the relocation of industries such as chemical manufacture and steel-making from higher income countries to poorer countries where wages are often low, environmental and occupational regulations non-existent and not enforced, and the public health infrastructure weak. Seventy per cent of heavy chemical manufacture today occurs in low- and middle-income countries.

Globalization results also in the trans-shipment of hazardous materials from high-income countries where they are produced to low- and middle-income countries – another example of global environmental injustice. Such dumping includes the shipment of hazardous pesticides, industrial waste, electronic waste (e-waste), and toxic chemicals. Well publicized examples include the transport in 2006 of 500 tons of toxic chemical wastes from Amsterdam to Abidjan, Cote d'Ivoire aboard the vessel *Probo Koala*; the subsequent release of these chemicals resulted in 17 deaths and in >100,000 cases of illness (Margai and Barry, 2011). Another example is a large e-waste site at Agbogbloshie, Ghana where thousands of discarded computers, cell phones, kitchen appliances and other electronics have been shipped from European ports in containers misleadingly labelled “secondhand goods” (Caravanos et al., 2011).

2.5. Pollution is costly

The *Lancet* Commission undertook economic analyses and found that pollution is very costly. Pollution causes productivity losses by

removing economically active people from the workforce through disease and premature death. Pollution is also responsible for increases in health care spending. In rapidly developing, heavily polluted lower middle-income countries the health and productivity losses caused by pollution can amount to as much as 5% of gross domestic product. These great loses can undercut national trajectories of economic and social development (Landrigan et al., 2017). On the positive side of the equation, pollution control can yield substantial economic gains by reducing health care costs and boosting the economic productivity of healthier populations (Suk et al., 2018).

2.6. Pollution and climate change

Pollution is linked to global climate change (McMichael, 2017; Perera, 2017). Fuel combustion—fossil fuel combustion in high-income and middle-income countries, and biomass burning in low-income countries—accounts for 85% of airborne particulate pollution and for almost all pollution by sulfur and nitrogen oxides (Scovronick et al., 2015). Fuel combustion is also the major source of the greenhouse gases and short-lived climate pollutants that are the main drivers of global climate change.

2.7. The root cause of pollution

The global growth of pollution can be directly attributed to the linear, take-make-use-dispose economic paradigm—termed by Pope Francis "the throwaway culture" (Francis, 2015) — a materialistic way of life in which natural resources and human capital are viewed as abundant and inexhaustible, and the consequences of their reckless exploitation are given little heed. This paradigm focuses single-mindedly on short-term economic gain as measured by growth in Gross Domestic Product (GDP). It is unethical and ultimately unsustainable (Raworth, 2017).

2.8. Children's vulnerability to pollution

Fetuses, infants and young children are exquisitely sensitive to environmental pollution, especially during windows of vulnerability in early development (Suk et al., 2016; Vrijheid et al., 2016). Pollution exposures in infancy and early childhood and can result in lasting injury to cells and tissues that increases risk of disease in childhood and can also reverberate across the life span (Barker, 2004). A great danger of pollution exposure in early life can is that it can undermine efforts to enhance children's development though improved nutrition, early learning and better health care.

The diseases caused by traditional forms of environmental pollution (e.g., coliforms in water or air pollution from solid fuels) are predominantly diarrhea, pneumonia and other infectious diseases. Modern environmental threats, by contrast, are linked mainly to non-communicable diseases: asthma, neurodevelopmental disorders, birth defects, obesity, diabetes, cardiovascular disease, mental health problems, and pediatric cancer (WHO, 2018). Children in rapidly industrializing countries are simultaneously confronted by both ancient and modern environmental threats to health (Laborde et al., 2015).

A 1993 report by the US National Academy of Sciences (NAS, 1993) explored the origins of children's sensitivity to environmental pollutants and identified four key differences between children and adults:

1. Children breathe more air, drink more water, and eat more food than adults each day on a per-kilogram body-weight basis and therefore have proportionately greater exposures to environmental pollutants.
2. Children's metabolic pathways are immature and therefore children are unable to rapidly detoxify and excrete many toxic pollutants.
3. Children's exquisitely delicate developmental processes are easily disrupted. There exist windows of vulnerability in early human development that have no counterpart in adult life. Exposure to even very low doses of toxic chemicals or other environmental hazards during these sensitive periods can increase risk of disease in childhood and across the life span.
4. Children have more future years than adults to develop diseases of long latency that may be triggered by harmful exposures in early life.

2.9. Air pollution and children's health

Exposure to air pollution in early human development, especially exposure to fine particulate pollution can be extremely deleterious to children's health and development. Maternal exposure to particulate pollution during pregnancy can injure the developing fetal brain thus diminish children's intelligence (Perera, 2017). Air pollution exposure in pregnancy also increases risk for prematurity and low birth weight, two further risk factors for developmental disabilities (Woodruff et al., 2007; Jacobs et al., 2017). Exposure to air pollution during infancy and early childhood causes lung damage, impairs lung growth, and can increase subsequent risk for asthma, pneumonia and chronic obstructive pulmonary disease (Gauderman et al., 2015; Korten et al., 2017).

2.10. Chemical pollution and children's health

Young children and pregnant women are exposed daily to manufactured chemicals in air, water, soil, consumer products and food (Landrigan and Goldman, 2011). Routine monitoring surveys detect several hundred chemical pollutants in the bodies of all persons (CDC, n.d.). Some widely used chemicals are known to be toxic to children's development. Hundreds more have never been tested for safety or toxicity and their possible dangers to children's health and development are not known (Landrigan and Goldman, 2011).

Toxic manufactured chemicals have been responsible for multiple episodes of disease and death in both children and adults. Historical examples include asbestos (multiple cancers) (Selikoff et al., 1968); tetraethyl lead (adult and pediatric lead poisoning) (Needleman et al., 1979); benzene (leukemia and lymphoma) (Rinsky et al., 2002); benzidine-based dyes (bladder cancer) (Rehn, 1895); the rubber chemical, 1, 3-butadiene (leukemia and lymphoma) (Landrigan, 1990); and the organophosphate pesticides (developmental neurotoxicity) (Rauh et al., 2011).

Newer synthetic chemicals that have entered markets in the past 2–3 decades threaten to repeat this unfortunate history. They include developmental neurotoxicants such as phthalates and brominated flame retardants (Engel et al., 2010; Herbstman and Mall, 2014; Grandjean and Landrigan, 2014); endocrine disruptors (Gore et al., 2015); the herbicide glyphosate, recently found by the International Agency for Research on Cancer (IARC) to be a probable human carcinogen (Guyton et al., 2015); the neonicotinoid insecticides (Cimino et al., 2016); pharmaceutical wastes (Kümmerer, 2009); and manufactured nanomaterials. Early warnings that new chemicals and other environmental hazards might pose hazards to children's health have frequently been ignored (Jarosinska and Gee, 2007). As a result, efforts to control exposures and to prevent disease have often been delayed, sometimes for decades. (Landrigan and Goldman, 2011).

Two fundamental problems that underlie these recurrent episodes of disease and death caused by manufactured chemicals are failure of the chemical manufacturing industries to take responsibility for the materials they produce coupled with absence in most countries of chemical safety policies requiring that new chemicals be tested for safety or toxicity before they are allowed to enter commercial markets (Landrigan and Goldman, 2011). Fewer than half of the most widely used chemicals have ever been tested for safety or toxicity, and fewer than 20% have been assessed for potential to disrupt early human development. Premarket evaluation of new chemicals has become mandatory in only the past decade and in only a few high-income countries.

In children, multiple non-communicable diseases (NCDs) have been linked to toxic chemical pollutants. Prospective birth cohort epidemiologic studies that measure environmental exposures during pregnancy

and in early postnatal life and then follow children longitudinally have contributed greatly to discovery of these associations. Examples include:

- Asthma is increased in children exposed to particulate air pollution (Friedman et al., 2001; Suh et al., 2000);
- Neurodevelopmental impairment with reduction of IQ, shortening of attention span and disruption of behavior is caused by early-life exposure to lead (Budtz-Jørgensen et al., 2013);
- Neurodevelopmental impairment with reduction of IQ is observed in children exposed to PCBs (Jacobson and Jacobson, 1996);
- Neurodevelopmental impairment with reduction of IQ and shortening of attention span is seen in children exposed to methyl mercury (Grandjean et al., 1997);
- Neurodevelopmental impairment with loss of IQ is seen in infants exposed prenatally to arsenic (Wasserman et al., 2007) and to manganese in chemically contaminated drinking water (Khan et al., 2011);
- Neurodevelopmental impairment with loss of IQ and behavioral disruption is associated with prenatal exposure to organophosphate pesticides (Rauh et al., 2011). Prenatal exposures to organophosphates are also linked to changes in brain structure and function in children (Rauh et al., 2012).
- Neurodevelopmental impairment with loss of IQ, behavioral disruption and increased risk of attention deficit/hyperactivity disorder (ADHD) is associated with prenatal exposures to phthalates (Engel et al., 2010; Engel et al., 2018).
- Neurodevelopmental impairment with persisting loss of IQ and disruption of behavior is associated with prenatal exposure to brominated flame retardants (Herbstman and Mall, 2014).
- Slow brain maturation and delayed cognitive development with exposure of school-aged children to traffic-related air pollution. (Pujol et al., 2016, Sunyer et al., 2015)

A major unanswered question is whether there are additional chemical pollutants in wide use today that have not yet been recognized to endanger the health of children. Fig. 1 illustrates this concept in relation to developmental neurotoxicants. Commenting on the hazards inherent in children's widespread exposure to untested chemicals, the late David

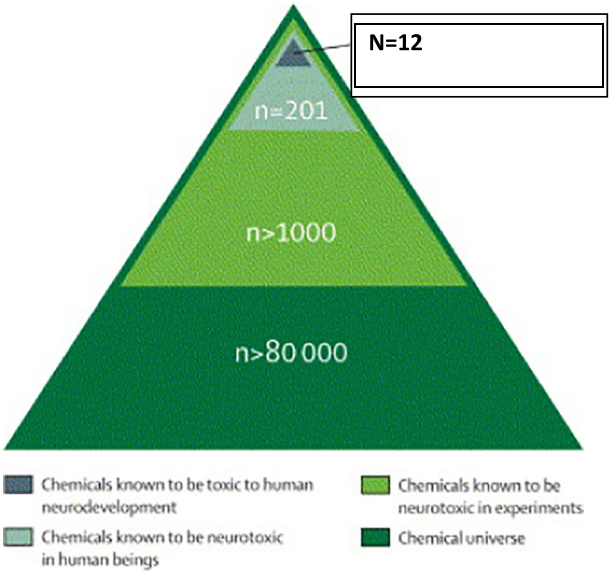

Fig. 1. The extent of knowledge of neurotoxic chemicals. Of the thousands of chemicals in commerce, only a small fraction have been proven to cause developmental neurotoxicity in children, but another 200 can cause neurotoxicity in adult workers and another 1000 are neurotoxic in experimental animals. Most of the chemicals in these two latter groups have never been tested for potential to cause developmental neurotoxicity (From Grandjean and Landrigan, 2006).

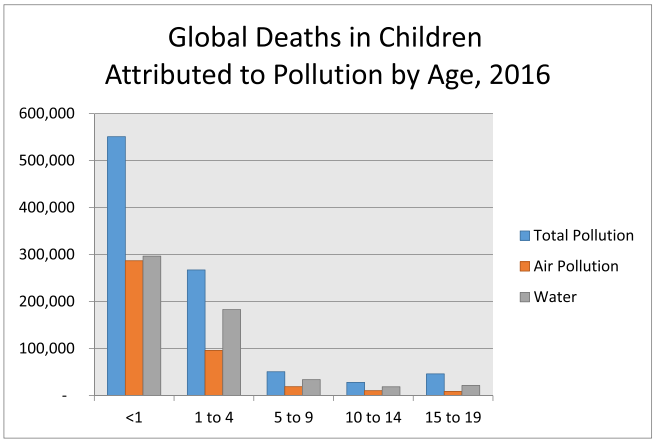

Fig. 2. Global deaths in children attributed to pollution by age, 2016.

Rall, PhD, MD, former director of the US National Institute of Environmental Health Sciences, observed that:

> *"If thalidomide had caused a ten-point loss of IQ instead of obvious birth defects of the limbs, it would probably still be on the market."*
> [(Weiss, 1982)]

2.11. Pollution's contribution to the global burden of disease in children

The World Health Organization estimates that physical, chemical, and biological hazards in the environment are responsible for 26% of all deaths in children under the age of five years – nearly 1.5 million deaths worldwide (WHO, 2018). The WHO definition of environmental risks is broad and includes road accidents, ultraviolet and ionizing radiation, noise, electromagnetic fields, occupational psychosocial risks, built environments, agricultural methods, and man-made climate and ecosystem change as well as pollution.

The *Lancet* Commission on Pollution and Health found that pollution – defined specifically as air, water, soil, and toxic chemical pollution - was responsible in 2016 for 940,000 deaths in children, two-thirds of them in children under the age of 5 years (Landrigan et al., 2017) (Fig. 2). The overwhelming majority of these pollution-related deaths occurred in low- and middle-income countries. (Fig. 3 and Fig. 4) Most were due to respiratory and gastrointestinal diseases caused by polluted air and water. (Fig. 2 and Table 1).

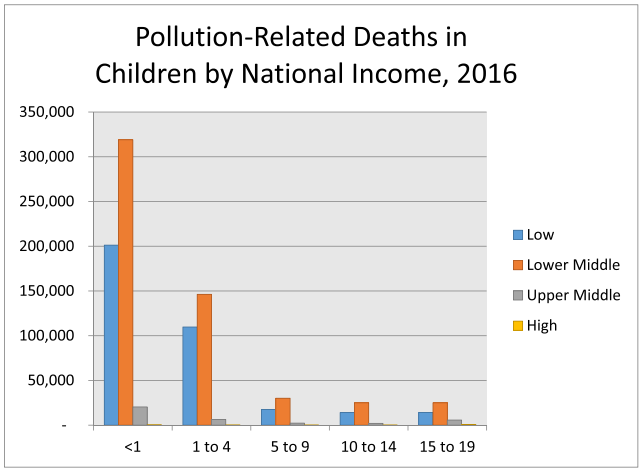

Fig. 3. Pollution-related deaths in children by national income, 2016.

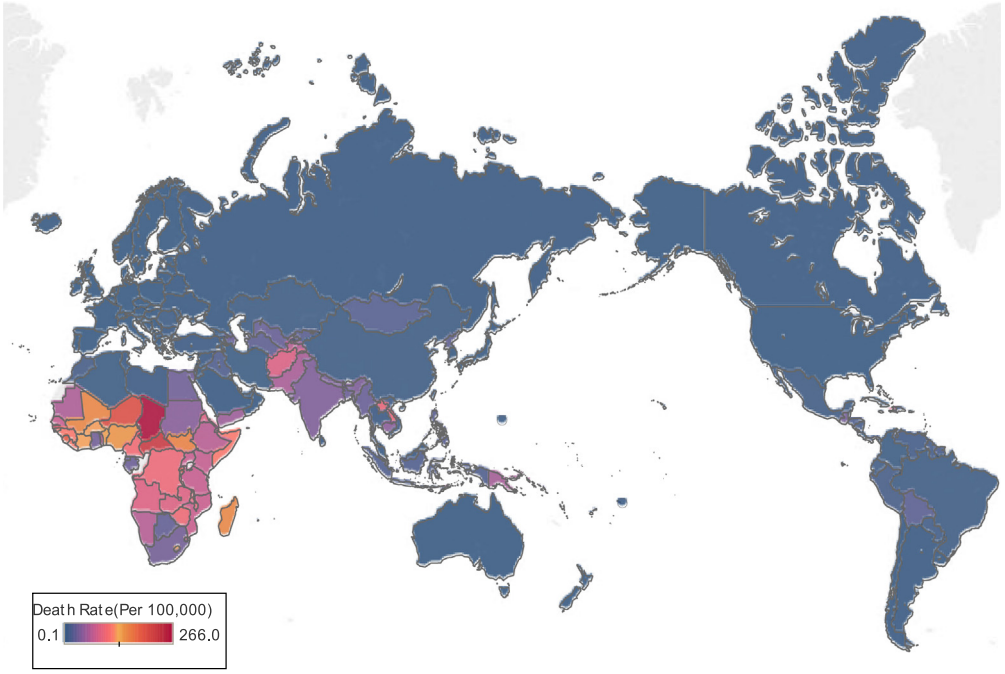

Fig. 4. Number of deaths per 100,000 children, 0–19 years of age, attributable to all forms of pollution, by country, 2016.

Pollution is linked additionally to multiple non-communicable diseases (NCDs) in children including low birth weight, asthma, cancer and neurodevelopmental disorders. Pollution exposures in early life also increase risk across the lifespan for a range of NCDs including chronic obstructive pulmonary disease, cardiovascular disease, stroke and cancer (Barker, 2004). The full impact of pollution and especially of toxic chemical pollution on the global burden of NCDs in children is not yet known and almost certainly is undercounted. A root cause of this lack of information is failure to assess the safety and characterize the potential toxicity of many chemicals to which children are extensively exposed. It is likely that the list of NCDs in children attributed to pollution will expand as the health effects of newer chemical pollutants are better defined and additional associations between pollution and disease are discovered.

3. Conclusion

A key message of the *Lancet* Commission on Pollution and Health is that with leadership, resources and clearly articulated, data-driven strategies, pollution can be controlled and pollution-related disease prevented (Landrigan et al., 2017). The experience of the many cities and countries that have developed, field-tested and successfully implemented pollution control policies provides strong support for this proposition. Implementation of pollution control strategies can provide multiple benefits, both short-term and long-term, for human health, the economy and the environment for societies at every level of income (Grosse et al., 2002; Samet et al., 2017).

Table 1
Global deaths in children attributable to pollution, 2016.

Age range	Total pollution	Air pollution	Water
<1	550,854	286,863	296,655
1 to 4	267,241	95,999	182,924
5 to 9	50,617	18,871	33,882
10 to 14	27,912	10,409	18,660
15 to 19	46,085	8788	21,389

Long-term control of pollution and prevention of pollution-related diseases in children will require that societies at every level of income prevent pollution at source by fundamentally changing societal patterns of production, consumption and transportation (Collins et al., 2013; Collins et al., 2013; Whitmee et al., 2015; McMichael, 2017). This transition will require movement away from the current, fundamentally unsustainable linear economic paradigm towards a new paradigm rooted in the concept of the circular economy and based on recognition of human rights, especially the right of children to health and well-being (Francis, 2015; World Economic Forum, 2014; HEAL, n.d.).

Pollution prevention presents a major, underexploited opportunity to improve child health, prevent NCDs in children, and advance social justice in all countries and especially in low- and middle-income countries. Failure to incorporate pollution prevention into NCD control programs is a major missed opportunity for disease prevention.

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