



## Danger in the air:

How air pollution can affect brain development in young children

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*While all children are vulnerable to air pollution, the youngest children are most at risk. New UNICEF analysis focusing on very young children finds that almost 17 million babies (children under the age of one) live in some of the most severely affected regions of the world, where outdoor air pollution is at least six times higher than international limits. The majority of these babies – approximately 12 million – live in South Asia.*

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## Introduction

When we shift from direct to proximate causes of disease, the environment matters a lot.<sup>1</sup> Air pollution is associated with some of the biggest killers of children, such as pneumonia, which is responsible for the deaths of 920,000 children under 5 years of age every year.<sup>2</sup> Air pollution is also linked with asthma, bronchitis, and other respiratory infections and diseases, which can be debilitating, force children to miss school, and even cause long-lasting damage to their health and wellbeing.<sup>3</sup>

These effects are well established. But a growing body of scientific research points to a potential new risk that air pollution poses to children's lives and futures: its impact on their developing brains.<sup>4-6</sup> This should concern us all.

Few things are as important to a child's future as the first 1,000 days of life, when the brain undergoes the most critical and rapid growth. Every neural connection made during this critical window of brain development in early childhood forms the foundation for future neural connections, and ultimately influences the likelihood of healthy development of a child's brain. This, in turn, is crucial to children's ability to learn and later, to earn a living and fulfil their potential as adults.

So the stakes are very high – and unfortunately so is the magnitude of the risk. New UNICEF analysis focusing on very young children under the age of one has found that nearly 17 million babies live in areas where outdoor air pollution is at least six times higher than international limits – potentially putting their brain development at risk simply because of the air they breathe. The vast majority of these babies – over 12 million – are in South Asia.

Many of these children are already among the most disadvantaged. Children growing up in urban slums are already at great risk of multiple environmental threats – from lack of clean water and sanitation to risk of infectious disease. Adding high levels of air pollution compounds the risks these children face.

Moreover, air pollution is usually worst in urban centres. As more and more of the world urbanizes, and without adequate protection and pollution reduction measures, more children will be at risk in the years to come. Further, the harmful effects of air pollution on the developing brain are likely to manifest throughout children's lives, limiting their ability to fulfill their potential, in turn fueling intergenerational cycles of disadvantage.

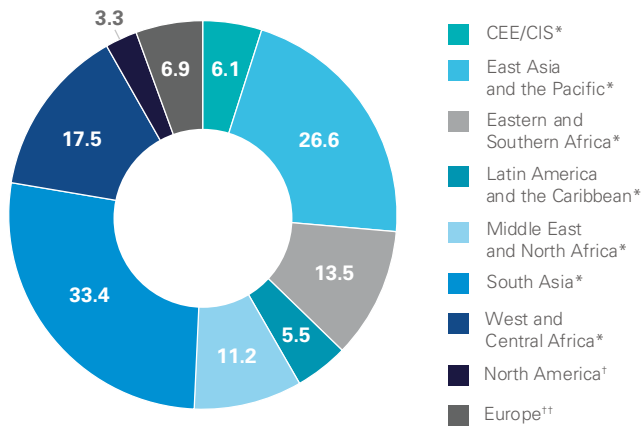
### ***Why are young children most vulnerable to the impact of air pollution?***

Young children's immune systems are still developing, and their lungs are still growing. With every breath, children take in more air per unit of body weight than adults. By extension, when air is toxic, they take in more toxic air per unit of body weight than adults. Moreover, the impacts have ripple effects into other critical aspects of children's lives. For example, when children get sick, they might miss school, further limiting their learning and development potential.

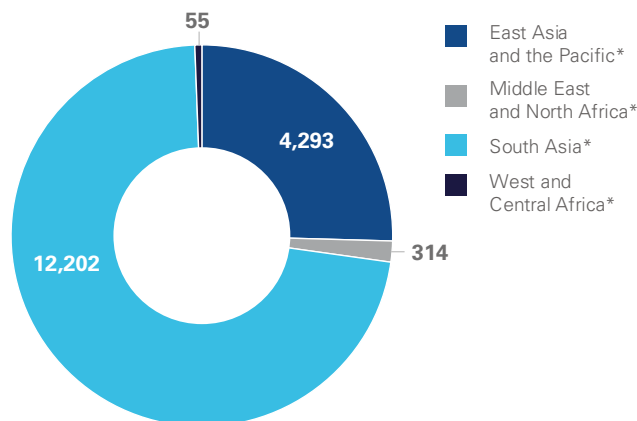


## Number of babies living in affected areas, by region

**FIG.1** Number of babies (in millions) living in areas where air pollution exceeds World Health Organisation recommended limits ( $10\mu\text{g}/\text{m}^3$ ).



**FIG.2** Number of babies (in thousands) living in the worst affected areas ( $\geq 6$  times World Health Organisation limits  $60\mu\text{g}/\text{m}^3$ ).



\*According to UNICEF Regional Classification

† Canada, Mexico, USA

†† According to UN Regional Classification

**Note:** The global total number of babies living in areas where outdoor pollution exceeds international limits is 121 million. There are differences and overlaps between UNICEF and UN regional classifications, with particular country overlap between CEE/CIS and Europe.

**Source:** Data derived from van Donkelaar, A., et al. "Global estimates of fine particulate matter using combined geophysical-statistical method with information from satellites, models and monitors." *Environ. Sci. Technol.* (2016), and intersected with a population map derived from Gridded Population of the World (GPWv4) with WorldPop data overlaid, distributed using the subnational population DHS data (for ages 0-12 months).

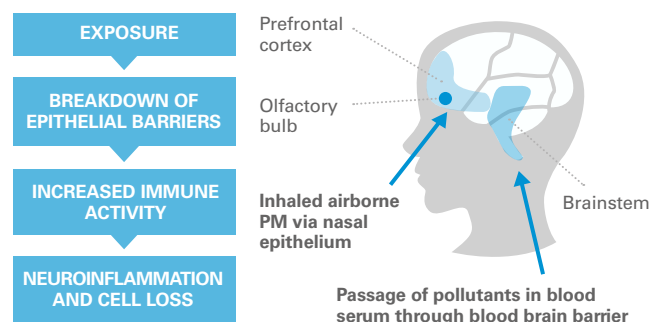
## The impact of air pollution on the developing brain

Air pollution potentially affects children's brains through several mechanisms. First, particulate matter can cause neuro-inflammation by damaging the blood-brain barrier – a thin, delicate membrane that protects the brain from toxic substances.<sup>7</sup> Ultrafine pollution particles (particulate matter that is equal or less than 2.5 microns in diameter) pose an especially high risk because they can more easily enter the blood stream and travel through the body to the brain. In older people, the breakdown of the blood-brain barrier has been strongly linked with Alzheimer's and Parkinson's disease. The dosage of toxic chemicals required to damage the growing brain in the first stages of life is much lower than that which would cause damage to an adult brain.<sup>8</sup>

Second, specific air pollution particles, such as magnetite, are so small that they can enter the body through the olfactory nerve and the gut. Magnetite is very common in urban outdoor air pollution, and a recent study found that it was considerably more present in brains of people living in areas where urban air pollution is high. Magnetite nanoparticles are highly toxic to the brain due to their magnetic charge and their ability to help create oxidative stress – which is often the cause of neurodegenerative diseases.<sup>9</sup>

Third, several studies also show that polycyclic aromatic hydrocarbons (PAHs), a specific class of pollutants formed from fossil fuel combustion and commonly found in areas of high automobile traffic, contribute to a loss of or damage to white matter in the brain.<sup>10,11</sup> White matter contains nerve fibers that are critical in helping neurons communicate across different parts of the brain. As children grow and experience the world around them, well-functioning neural connections provide the foundation for continued learning and development.

**FIG.3** Possible channels through which air pollution may affect the brain



**Source:** Adapted from Brockmeyer, S., D'Anguilli, A. 'How air pollution alters brain development: the role of neuroinflammation' *Translational Neuroscience*. 2016; 7(1): 24–30. Figure 1.



## Air pollution and cognitive function

Reinforcing the neurological evidence, studies have found associations directly between air pollution exposure and cognitive outcomes, including verbal and nonverbal IQ and memory, reduced test scores, grade-point averages among school children, as well as other neurological behavioral problems.<sup>12-22</sup> Air pollutants inhaled during pregnancy can cross the placenta and affect the developing brain of a fetus, with potential lifelong effects. Research shows an association between prenatal exposure to high levels of air pollution and developmental delay at age three, as well as psychological and behavioral problems later in childhood, including symptoms of attention deficit hyperactivity disorder (ADHD), anxiety, and depression.<sup>23-27</sup> One study reports a four-point drop in IQ by the age of 5 among a sample of children exposed in utero to toxic air pollution.<sup>28</sup>

Air pollution has also been shown to affect the overall health of the fetus<sup>29-30</sup> causing serious effects such as low birth weight<sup>31</sup>, which in turn poses additional challenges for healthy early childhood development. Doctors have long advised that pregnant women should not smoke and that children should not be exposed to second-hand smoke. While some of the polluting agents in cigarette smoke are different than those in fossil fuel combustion, there are many overlaps.

Further research is needed to study the full impact of air pollution on children's developing brains. As yet, we know the minimum – but not the maximum – extent of the harm. The variety of types of pollutants that are in the air across different environments make it difficult to determine the full impact of air pollution. But this growing body of research does provide an indication of the scale of harm.

We know that reducing air pollution can help improve children's health, and even save their lives. We are learning it might also help protect their brains – and thus, their futures.

## Action is needed now to:

### Reduce Air Pollution

Reducing air pollution means replacing fossil fuel combustion with cleaner, renewable sources of energy, including appropriate use of solar, wind and thermal sources. Grid electrification systems can be made more flexible in order to accommodate multiple sources of electricity as well as variations in demand, which can fluctuate widely in a single day. Advanced filtration and scrubber systems can help reduce the amount of air pollution that comes from car and industrial exhaust.

Rapidly urbanizing areas have an opportunity to bypass some of the older planning models and take advantage of sustainable, cleaner innovations. They can also lay the right foundations from the onset. These include access to better and affordable public transportation. Parks, trees and green areas within urban centres can improve local air quality as well as offer a refuge for children to play.<sup>32,33</sup> Better waste management can reduce the amount of pollution caused by waste that is burned within communities. Proper disposal and recycling of paper, plastics, metals and organic materials can help prevent harmful chemicals from being burned and reaching children's lungs. Despite considerable reductions in lead in the air since it was removed from gasoline, it can still be found in the air when products containing lead, such as many car and mobile phone batteries, are burned.

Use of cleaner cook stoves can dramatically reduce indoor air pollution. Globally, solid fuels, such as wood, charcoal, dung and crop residues, are used in cooking and heating by around 3 billion people<sup>34</sup>, which can cause indoor air pollution to reach extremely high levels, especially if there is a lack of adequate ventilation.

### Reduce Children's Exposure

We also need to help families reduce their children's exposure to air pollution. This means reducing the time spent in areas where pollution is high, such as near or around areas of severe traffic congestion, or sources of industrial pollution. Where possible, travelling during times of day when air pollution is lower can help reduce exposure.

When air pollution is especially severe, it is best that children avoid strenuous activity, and playing or exercising in the harmful air should be minimized. This is especially the case if children have pre-existing medical conditions such as asthma or other respiratory infections. Use of effective air filtration masks can help in extreme conditions, provided they meet good filtration standards and fit a child's face properly.

Reducing exposure to air pollution must also include physical and structural changes to places where children live. This starts with smart urban planning. Major pollution sources such as coal-fired power plants should not be built near schools, clinics, hospitals or anywhere where they can cause harm to children. Renewable energy options would be cleaner alternatives to coal-fired power plants.

Within buildings, improvements to ventilation and air filtration systems, particularly in classrooms, clinics, houses and in hospitals, can make indoor air pollution less harmful. Good quality childcare centres should have access to green spaces for children to play and learn.

Other indoor air pollutants should be avoided too. For example, reducing children's exposure to second-hand cigarette smoke has long been known to reduce health risks. Other common sources of indoor contaminants include building and paint products, cleaning supplies and household chemicals. From these, contaminants such as asbestos, formaldehyde, lead and radon can possibly enter the air either directly or indirectly through, for example, sanding, moving, disposal, burning and other forms of disturbance. The more we understand what chemicals are in the products in and around our home, and how they can be dangerous, the better we can protect ourselves and our children.

### Improve Children's Overall Health

Healthy diets and lifestyles can help reduce the overall impact of air pollution on children. The healthier a child is, the less likely that health complications arise as a result of exposure to air pollution. Moreover, a healthy child is more able to participate in activities that matter for his or her overall development, including going to school, playing and learning.

As air pollution can increase the risk and severity of pneumonia, comprehensive approaches to address these risks, such as appropriate provision of pneumococcal vaccines, is important. Measures such as exclusive breastfeeding can also better protect children from the risks of pneumonia associated with air pollution.

## Be Air Aware

Finally, parents and families should have access to information about the air quality in their homes and communities, because ‘knowing your air’ is often a first step for action. Better monitoring of air pollution helps people adjust their behaviors and exposure levels on a daily basis, provides a basis for advocacy, can inform policy, and helps to measure success of actions to reduce air pollution. A growing number of cities around the world are installing monitoring stations to better assess and publicize air pollution in real time on the internet.

Technological innovation has resulted the proliferation of smaller, wearable devices. While accuracy of these devices might vary, they can help to better inform people about the overall quality of the air around them, and also spark behavior change and advocacy for clean air policies. Air pollution can change dramatically, depending on location, weather conditions, time of day and the variety of different sources from where it can come. It can spike at a moment’s notice – and air pollution wearables can help inform that sudden change.

## Conclusion

During the 1970s and 1980s, air pollution from the combustion of gasoline which contained lead was found to cause serious damage to children’s nervous system and cognitive development. Countries around the world responded to this threat decisively, banning leaded gasoline almost everywhere.<sup>35</sup>

What research is showing us now is that a variety of other air pollutants may also be harming children’s brains. The potential scale and impact are too high for us to ignore. Given all the risks that air pollution poses, the need to act is urgent.

Children are often passionate about the environment, and combatting climate change is something that matters greatly to many. Children should know about the risks that air pollution can have to both their health and the environment. They should know how bad their air can be, and what can be done to reduce it and protect themselves from it. Children are the future change agents; we have an obligation to provide them with the knowledge and tools to make the world a better place.

The good news is that reducing air pollution has many benefits. Actions to reduce air pollution help also reduce greenhouse gas emissions and, in turn, combat the climate change they cause.<sup>36</sup> And that is a win-win situation for children, for their societies, and for the future we share.





## Endnotes

1. Landrigan, Philip J., et al., *The Lancet Commission on pollution and health*. The Lancet, New York, 10 October 2017.
2. United Nations Children's Fund, *One is too many: Ending child deaths from pneumonia and diarrhoea*. UNICEF, New York, 11 November 2016, p.7.
3. United Nations Children's Fund, *Clear the Air for Children: The impact of air pollution on children*. UNICEF, New York, 30 October 2016, pp.8-63.
4. Brockmeyer, Sam and Amedeo D'Angiulli, 'How air pollution alters brain development: the role of neuroinflammation', *Translational Neuroscience*, vol. 7, issue. 1, 21 March 2016, pp.24-30. Available at: <https://www.ncbi.nlm.nih.gov/pubmed/28123818>
5. Peterson, Bradley S., et al., 'Effects of Prenatal Exposure to Air Pollutants (Polycyclic Aromatic Hydrocarbons) on the Development of Brain White Matter, Cognition, and Behavior in Later Childhood', *The Journal of the American Medical Association Psychiatry*, vol. 72, no. 6, 25 May 2015, pp.531-540.
6. Weir, Kirsten, 'Smog in our brains', *American Psychological Association*, vol. 43, no. 7, July 2012, p. 32. Available at: <http://www.apa.org/monitor/2012/07-08/smog.aspx>
7. Garciduenas, Calderon L., et al., 'Air pollution and children: barrier breakdown, inflammation, brain immunity and neurodegeneration'. *Journal of the Neurological Sciences*, vol. 357, 15 October 2015, pp.1039-1058.
8. Grandjean, Philippe. and Landrigan, Philip J., 'Developmental neurotoxicity of industrial chemicals'. *The Lancet*, vol. 368, no. 9553, 16 December 2006, pp.2167-2178.
9. Barbara A. Maher, et al., 'Magnetite pollution nanoparticles in the human brain', *Proceedings of the National Academy of Sciences of the United States of America*, vol. 113, no. 39, 27 Sep 2016, pp.10797- 10801.
10. Peterson, Bradley S., et al., 'Effects of Prenatal Exposure to Air Pollutants (Polycyclic Aromatic Hydrocarbons) on the Development of Brain White Matter, Cognition, and Behavior in Later Childhood', *The Journal of the American Medical Association Psychiatry*, vol. 72, no. 6, 25 May 2015, pp.531-540.
11. Calderón-Garcidueñas, Lilian, et al., 'Air pollution, cognitive deficits and brain abnormalities: A pilot study with children and dogs', *Brain and Cognition*, vol. 68, issue. 2, November 2008, pp.117-127.
12. Siddique, Shabana et al., 'Attention-deficit hyperactivity disorder in children chronically exposed to high level of vehicular pollution', *European Journal of Pediatrics*, July 2011, vol.170, issue. 7, pp. 923-929.
13. Chiu, Yueh-Hsiu Mathilda, et al., 'Associations between Traffic-Related Black Carbon Exposure and Attention in a Prospective Birth Cohort of Urban Children', *Environmental Health Perspectives*, vol. 121, no. 7, July 2013, pp. 859-864.
14. Newman, Nicholas C. et al., 'Traffic-Related Air Pollution Exposure in the First Year of Life and Behavioral Scores at 7 Years of Age', *Environmental Health Perspectives*, vol. 121, Issue. 6, July 2013, pp. 731-736.
15. Miller, Sebastián J. and Mauricio A. Vela, 'The Effects of Air Pollution on Educational Outcomes: Evidence from Chile', Working Paper, Inter-American Development Bank Department of Research and Chief Economist, December 2013.
16. Wang, Shunqin, 'Association of Traffic-Related Air Pollution with Children's Neurobehavioral Functions in Quanzhou, China', *Environmental Health Perspectives*, vol. 117, no. 10, October 2009, pp.1612-1618.
17. Volk, Heather E., et al., Traffic-Related Air Pollution, Particulate Matter, and Autism, *The Journal of the American Medical Association Psychiatry*, vol. 70, January 2013, pp. 71-77.
18. Suglia, Shakira F., et al., 'Association of Black Carbon with Cognition among Children in a Prospective Birth Cohort Study', *American journal of Epidemiology*, vol. 167, Issue. 3, 1 February 2008, pp. 280-286.
19. Grineski, Sara E., 'School-based exposure to hazardous air pollutants and grade point average: A multi-level study', *Environmental Research*, vol. 147, May 2016, pp. 164-171.
20. Marques, Sibila and Maria Luísa Lima, 'Living in grey areas: Industrial activity and psychological health', *Journal of Environmental Psychology*, vol. 31, issue. 4, December 2011, pp. 314-322.
21. Sunyer, Jordi et al., 'Association between Traffic-Related Air Pollution in Schools and Cognitive Development in Primary School Children: A Prospective Cohort Study', *PLOS Medicine*, 3 March, 2015, pp. 1-24.
22. Perera, Frederica P, et al., 'Benefits of Reducing Prenatal Exposure to Coal-Burning Pollutants to Children's Neurodevelopment in China', *Environmental Health Perspectives*, vol. 116, 14 July 2008, pp.1396-1400.
23. Perera, Frederica P, et al., 'Effect of Prenatal Exposure to Airborne Polycyclic Aromatic Hydrocarbons on Neurodevelopment in the First 3 Years of Life among Inner-City Children', *Environmental Health Perspectives*, vol. 114, August 2006, pp. 1287-1292.
24. Perera, Frederica P, et al., 'Prenatal Polycyclic Aromatic Hydrocarbon (PAH) Exposure and Child Behavior at Age 6–7 Years', *Environmental Health Perspectives*, vol. 120, pp.921-926.
25. Jedrychowski, Wieslaw A., et al., 'Prenatal exposure to polycyclic aromatic hydrocarbons and cognitive dysfunction in children', *Environmental Science and Pollution Research*, Vol. 22, Issue 5, March 2015, pp. 3631–3639.
26. Yurifuji, Takashi, 'Prenatal Exposure to Traffic-related Air Pollution and Child Behavioral Development Milestone Delays in Japan', *Epidemiology*, vol 27, January 2016, PP. 57-65.
27. Perera, Frederica P, et al., 'Early-Life Exposure to Polycyclic Aromatic Hydrocarbons and ADHD Behavior Problems', *PLOS Medical*, vol. 9, 5 November 2014.

- 28.** Perera, Frederica P., et al., 'Prenatal Airborne Polycyclic Aromatic Hydrocarbon Exposure and Child IQ at Age 5 Years', *PEDIATRICS*, vol. 124, pp.195-202.
- 29.** Sly, Peter D., 'Environmental Pollutants and Postnatal Growth', *Handbook of Growth and Growth Monitoring in Health and Disease*, vol. 1, 2012, pp. 757-768.
- 30.** Goldizen, Fiona C., et al., 'Respiratory effects of air pollution on children', *Pediatric Pulmonology*, vol 51, Issue. 1, January 2016, pp.94-108.
- 31.** Fleischer, Nancy L., et al., 'Outdoor Air Pollution, Preterm Birth, and Low Birth Weight: Analysis of the World Health Organization Global Survey on Maternal and Perinatal Health', *Environment Health Perspective*, vol. 122, no, 151, 01 June 2014. pp. 425-430.
- 32.** European Commission, 'Science for Environment Policy', <[http://ec.europa.eu/environment/integration/research/newsalert/pdf/green\\_spaces\\_linked\\_to\\_improved\\_cognitive\\_development\\_in\\_children\\_432na1\\_en.pdf](http://ec.europa.eu/environment/integration/research/newsalert/pdf/green_spaces_linked_to_improved_cognitive_development_in_children_432na1_en.pdf)>, *European Commission DG Environment News Alert Service*, issue. 432, published 22 October 2015, accessed 20 November 2017.
- 33.** Davvand, Payam, et al., 'Green spaces and cognitive development in primary schoolchildren', *Proceedings of the National Academy of Sciences of the United States of America*, vol. 122, no. 26, 30 June 2015, pp. 7937-7942.
- 34.** World Health Organization, 'Household air pollution and health', <<http://www.who.int/mediacentre/factsheets/fs292/en/>>, WHO Fact Sheet, accessed 20 November 2017.
- 35.** Six countries continue to use leaded gasoline: Afghanistan, Algeria, Democratic People's Republic of Korea, Iraq, and Myanmar. United Nations Environment Programme, Chemicals and waste management: implementation of decision 27/12, Report of the Executive Director to the United Nations Environment Assembly, EP/EA.1/5, 11 April 2014.
- 36.** Perera, Frederica P., 'Multiple Threats to Child Health from Fossil Fuel Combustion: Impacts of Air Pollution and Climate Change', *Environmental Health Perspective*, vol. 125, 21 June 2016, pp. 141-148.

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