World on Fire

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Keywords

Climate change ; heat ; child ; dehydration ; climate policy ; pollution

Abstract

Climate change is accelerating, with rising global temperatures leading to more frequent and severe heatwaves. This manuscript aims to outline current knowledge on the impact of heat, both direct and indirect, on child health, from the prenatal period to adolescence. Children represent a particularly vulnerable group due to their physiology, developmental stage, and dependence on adults.

Direct health effects include dehydration, heat exhaustion and life-threatening heatstroke, while indirect consequences range from increased asthma exacerbations and infectious diseases to reduced learning capacity and heightened exposure to air pollution. Pregnant women exposed to extreme heat are at higher risk of adverse outcomes such as preterm birth, low birth weight, and congenital anomalies. In addition to physical illnesses, climate change can have long-term implications for neurodevelopment and the development of chronic diseases.

Paediatricians play a key role in prevention, adaptation and advocacy, both at the clinical and policy levels. Establishing heat emergency protocols, integrating environmental health education in paediatric training, and supporting mitigation strategies are essential to safeguard future generations. Addressing the paediatric dimension of climate change is not only our medical duty but also a societal imperative. In this review we aim to oversee the consequences of heat on the paediatric population in Belgium.

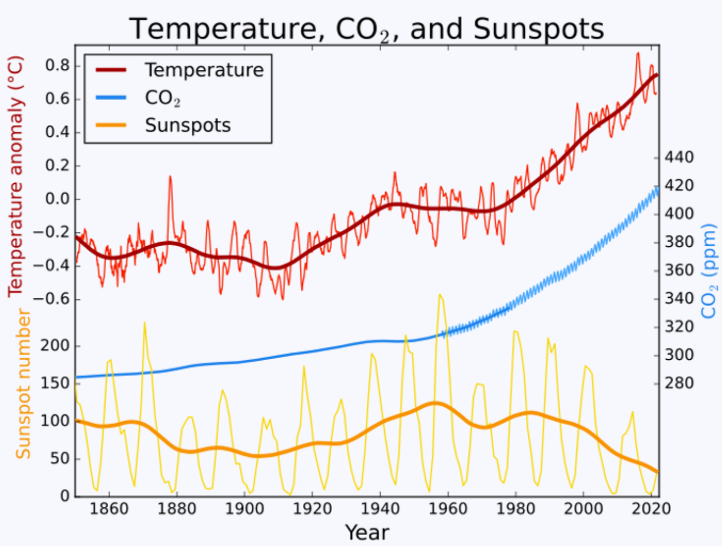
Introduction

Climate change represents a significant global health challenge in the 21st century. Rising temperatures, more frequent extreme weather events, and disruptions to ecological systems increasingly threaten human well-being. Within this context, children are an often overlooked but particularly vulnerable group (1). Due to their physiology, developmental stage and dependence on caregivers, children face disproportionate risks from heat-related illnesses.

The paediatric dimension of heat-related diseases extends beyond acute effects such as dehydration and heatstroke. Prenatal exposure to heatwaves has been linked to adverse pregnancy outcomes, while postnatal impacts range from exacerbation of respiratory diseases to long-term neurodevelopmental harm. In addition, climate change alters patterns of air pollution, allergen exposure, and vector-borne diseases, all of which have significant implications for child health.

This overview integrates epidemiology, physiology, and clinical management to support clinicians in understanding and addressing the impact of extreme heat on child health.

FIGURE 1: Global temperature, atmospheric CO_2, and sunspot activity since 1850. (*source: Leland McInnes at the English-language Wikipedia, CC BY-SA 3.0 <http://creativecommons.org/licenses/by-sa/3.0/>, via Wikimedia Commons*).



Weather, climate, and global warming

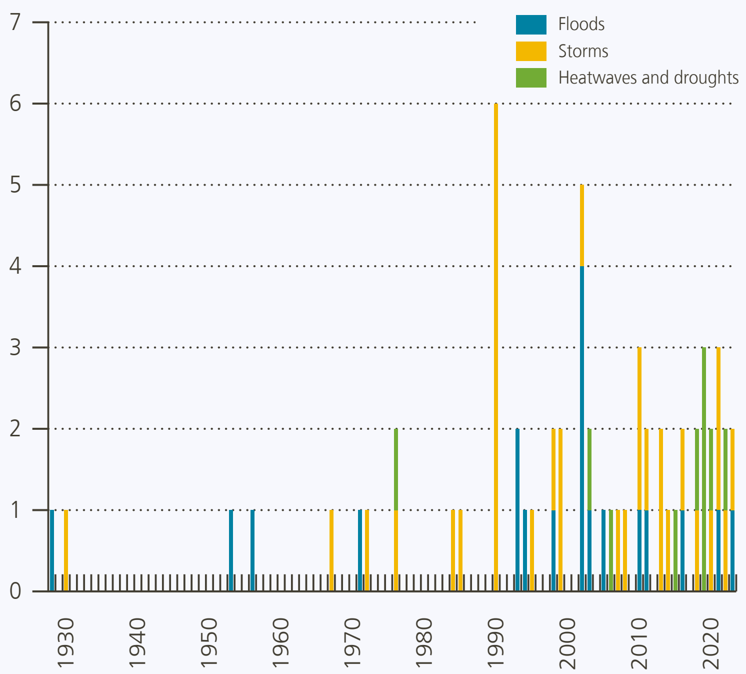
Weather describes the current conditions, such as temperature, precipitation or wind, in a specific location at a given moment. In contrast, climate refers to the average of weather conditions of a region, typically calculated over a period of 30 years or more. Belgium has a temperate maritime climate characterized by mild winters, cool humid summers, and relatively frequent rainfall. *Climate change* refers to long-term shifts in temperature and weather patterns. This distinguishes it from short-term weather fluctuations such as the El Niño-Southern Oscillation cycle which occurs every 2 to 7 years (2). Climate change, however, persists over decades.

Earth receives energy from the sun; this energy follows an 11-year solar cycle. During this cycle, solar flares and storms from the sun's surface can change, affecting the amount of energy reaching our planet. This solar variability has played a role in past climate changes. For example, a decrease in solar activity combined with increased volcanic eruptions contributed to the onset of the 16th century Little Ice Age (3). Figure 1 shows the increase in the average global temperature with a marked acceleration since the late 20th century, where the amount of sun-energy has either remained constant or decreased over the same period. The sun's impact is only one piece of the puzzle. The late 20th century was the start of the industrial revolution. Since that time, nitric oxide or NO (used in fertilizers) increased 18%, CO_2 from fossil fuel combustion 39% and methane 148%. These greenhouse gases (GHG) trap heat in the atmosphere leading to global warming. GHG emissions changed the planet by increasing global temperature, altering rainfall, causing sea levels to rise, acidifying oceans, increasing the frequency, strength, and duration of extreme weather events (1). Importantly, these effects are unevenly distributed: while some regions face catastrophic flooding or drought, others experience extended heatwaves or shifts in disease vectors. Also, some regions are more vulnerable to these events than others.

In Flanders an upward and accelerating trend is visible since the early 20th century (Figure 2). Where the mean average temperature worldwide has increased by 1.2-1.5°C compared to the pre-industrial period, the mean average temperature in Belgium has already increased by 2.9°C. This leads to more natural disasters, not only heatwaves and droughts but also storms and floods (Figure 3). Climate models predict that by the end of this century, children born today could experience summer temperatures several degrees higher (up to 8.5°C) than those faced by their (grand) parents: as a consequence, the 2020 birth cohort will experience 11 extreme heatwaves, increasing to 18 and 26 when global mean temperature increase reaches 2.5°C and 3.5°C, respectively (4).

FIGURE 2: Observed Annual Average Mean Surface Air Temperature of Vlaams Gewest, Belgium for 1901-2023. *(source: Climate Change Knowledge Portal, CCKP, World Bank. Permission obtained form AskClimate).*

FIGURE 3: Frequency of recorded natural disasters in Belgium (1928 to 2023, by type) *(source: The physical effects of climate change on food inflation, NBB Economic Review, 2024, Hoofdstuk 10 — PDF: https://www.nbb.be/doc/ts/publications/economicreview/2024/ecorevi2024_h10.pdf nbb.be, EM-DAT, RMI, NBB.)*



Heat and its effects on health

Heat and mortality

Temperature and mortality have a U-shaped relationship: deaths increase both at very low and very high temperatures, with a minimal mortality threshold (MMT) (Figure 4). This MMT is location-specific: populations in northern climates have a lower MMT (e.g., Vancouver, Canada, 17°C), compared to those in warmer regions (e.g., Austin, Texas, 27°C) (5). Heatwaves represent one of the deadliest manifestations of climate change; they especially increase mortality among the elderly, people with cardio-respiratory conditions, and children < 5 years. In the seventies, Belgium faced a heatwave every 5 years; now heatwaves happen at least yearly (4) (Figure 3). Unlike natural disasters such as floods or hurricanes, their impacts are less visible: the 2003 European heatwave, for example, caused more than 70,000 excess deaths directly related to heat, including nearly 400 children.

Heat and pregnancy

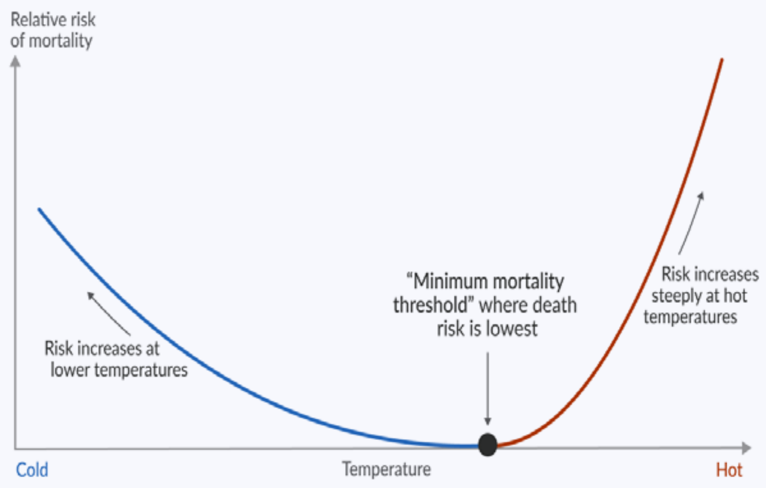
A range of physiological and behavioural adaptations must occur during pregnancy, including an alteration of thermoregulation. During gestation, heat production is increased due to metabolic heat from the developing placenta and foetus. The foetus is entirely dependent on maternal heat dissipation and temperature stability, which needs to be maintained within a narrow margin. Maternal heat dissipation mechanisms in pregnancy include reducing body temperature, cutaneous vasodilation, increased sweat production, increased plasma volume, and heightened thermal heat capacity due to increased body mass (6,7). These changes increase sensitivity to heat stress, especially during prolonged (nightly) exposure. Additionally, maternal overheating may compromise uteroplacental blood flow, reducing oxygen and nutrient delivery to the foetus. All these increase the risk of complications such as pre-eclampsia, gestational diabetes, and placental insufficiency (7).

An increasing number of studies show that heat can lead to adverse pregnancy outcomes, including stillbirth, low birth weight, and preterm birth (6,7). The risk is especially pronounced during the 3rd trimester, when maternal dehydration and heat stress may trigger uterine contractions or placental dysfunction. Research also suggests that exposure to high temperatures during the 1st trimester increases the risk of congenital heart defects and neural tube defects, such as spina bifida or anencephaly (8,9). While the precise mechanisms remain unclear, possible pathways include maternal hyperthermia disrupting protein synthesis, oxidative stress, or impaired folate metabolism.

Heat can also interfere with the pre-conception phase, causing menstrual irregularities and lower fertility rates. Or affect the success of IVF treatments, as heat can impact embryo viability (9).

Health impacts from heat in pregnancy are largely preventable through interventions to facilitate cooling (improved housing or workplaces, fluid availability, and limiting outdoor activity during heat waves) (6,8). In Belgium, implementing sustainable cooling centres in community buildings or schools during heat waves can provide respite for pregnant women, ensuring they are accessible to vulnerable populations. Additionally, increasing urban green spaces and introducing programs to subsidize sustainable air conditioners (featuring high energy efficiency, eco-friendly refrigerants, and smart or renewable-energy-based technologies) for lower-income households would further mitigate heat exposure risks. Public health campaigns tailored to reach expectant mothers could also emphasize the importance of staying hydrated and recognizing early signs of heat stress.

FIGURE 4: The relative risk of mortality (Y-axis) plotted against the mean temperature (X-axis) showing the minimum mortality threshold. *(source: Our World in Data. How many people die from extreme temperatures, and how this could change in the future: Part one. Oxford: Our World in Data. Available from: https://ourworldindata.org/part-one-how-many-people-die-from-extreme-temperatures-and-how-could-this-change-in-the-future. Permission obtained from Hannah Ritchie.)*



Heat and children

Children's bodies are less efficient at coping with thermal stress compared to adults:

- Their higher metabolic rate generates more heat, particularly during physical activity
- Their greater body surface area relative to their weight increases heat absorption from the environment
- Their sweat glands are less developed, reducing the effectiveness of evaporative cooling, the body's primary cooling mechanism
- Children typically have less prior exposure to hot weather and are less physiologically acclimatized to high temperatures than adults. Consequently, their adaptation to extreme heat is slower and less effective.
- Infants and young children are even more prone to dehydration because of their higher total body water content.

What makes them also vulnerable is their dependence on others to protect them from extreme heat, providing shade and water during prolonged exposure: infants, very young children and children who have disabilities are at greater risk because of their limited ability to communicate thirst or symptoms of heat stress (10).

Direct impacts of heat on children

Direct health effects of heatwaves include dehydration, heatstroke, heat exhaustion, electrolyte imbalances, kidney-related diseases, and respiratory and infectious diseases.

1. *Acute dehydration.* Water is a fundamental ingredient for life on earth as we know it. Nevertheless, it is estimated that 1 in 4 people do not have access to clean drinking water. Climate change, severe droughts, population growth, increasing demands, and poor management resulted in severe freshwater shortages in many regions (12, 13).

Dehydration reduces total body water (TBW), affecting both intra- and extracellular fluids. Infants, having higher TBW percentages, lose more body weight compared to older children at the same dehydration level (14). Furthermore, children need 2.5 times more water intake per body weight compared to adults. It is therefore no surprise that dehydration is a major cause of paediatric illness, leading to approximately 750,000 deaths annually, accounting for nearly 16% of global child fatalities. During healthy periods and sickness maintaining fluid balance in these children is influenced by many factors, but also significantly by exposure to a hot environment.

2. *Other effects of (chronic) dehydration*. There are several other effects linked to dehydration. Heat waves as we know, bring an elevated risk of acute dehydration, which, if occurring more frequently, can cause cognitive dysfunction and acute or chronic kidney injuries (13). Moreover, increased evaporation during breathing in a warming climate was recently linked to increased airway inflammation and exacerbations of lung disease (14).

Chronically dehydrated humans on the other hand, are less able to excrete toxins, leading to a higher serum concentration of salts and glucose. Those substances are linked with an increased risk for diabetes and metabolic syndrome, a combination of high blood sugar and cholesterol, hypertension and abdominal obesity. The physiology behind this phenomenon is well known in animals: when they develop dehydration, fructose production from carbohydrates is increased. Fructose stimulates the production of vasopressin, which helps store water in the body, but also stimulates the production of fat. Camels don't store water in their humps; they store fat. When the fat is burned, it produces water. Fat production is the body's reaction to dehydration. While these mechanisms are established in animals, in humans, the fructose–vasopressin pathway is proposed as a likely contributor to obesity risk, though longitudinal data is still required for confirmation. Chronically hypo-hydrated children, who clinically seem well-hydrated but maintain normal water levels primarily through vasopressin stimulation and

FIGURE 5: Heat exhaustion and heat stroke: know the signs. *(Source: Centers for Disease Control and Prevention, National Weather Service. Heat exhaustion vs. heat stroke. The Scientific Parent)*

other water conservation mechanisms, are at increased risk for obesity (13).

3. *Heat exhaustion and heat stroke*. Heat exhaustion and heat stroke are critical heat-related conditions requiring prompt action. Heat exhaustion, a milder yet significant form, manifests with symptoms like fatigue, dizziness, nausea, and muscle cramps. If untreated, it can escalate to heatstroke, a medical emergency marked by core body temperature exceeding 40°C, hot, dry skin, and neurological dysfunctions such as confusion, lethargy, or coma (Figure 5). In this stage, the body can no longer sweat to regulate temperature. This is a life-threatening emergency, quickly leading to rhabdomyolysis, acute kidney failure, electrolyte disturbances, and coagulopathies or severe neurological damage. Prompt recognition and rapid cooling are crucial as clinical outcomes depend on the duration of hyperthermia. Effective heatstroke management starts with removing the patient from the heat source and performing ABCDE stabilization. Aggressive cooling should be initiated immediately, preferably through evaporative methods (spraying and fanning) or cold-water immersion. In children under five, lukewarm immersion is advised to avoid hypothermia, while in older children ice packs can be added to the axillae, groin, and neck. Antipyretics are ineffective, as hyperthermia results from failed thermoregulation rather than infection. Cooling must be stopped once the temperature falls to 38.5 °C. Fluid resuscitation with isotonic, balanced crystalloids supports circulation and thermoregulation, and benzodiazepines may be given to suppress shivering, which otherwise increases metabolic heat. In severe cases, intubation and ventilation with neuromuscular blockade might be necessary. Definitive treatment occurs in the PICU, requiring close monitoring for multiorgan complications (15). Adolescents who experience exertional heatstroke, often from sports activities, may have better outcomes if immediately treated, though mortality remains significant. Survivors may suffer lasting neurological damage, particularly if core temperature rises above 42°C.

Some medications or medical conditions predispose for heatstroke due to poor temperature management. Among them are cardiovascular medication influencing volume status and vasodilation, SSRI's, TCA and anti-epileptic medications decreasing sweating or urine production. Paediatricians should be more aware and warn their patients considering the current predictions of yearly recurring heat waves (16).

Indirect impacts of heat on children

Indirect health effects **include an increased transmission of vector-borne diseases**, such as those spread by mosquitoes, ticks, or fleas. Climate change alters temperature and rainfall patterns, expanding the habitats of these vectors and increasing their activity. This topic is discussed elswhere in this issue.

Extreme heat **reduces productivity and raises accident risk**. In very hot weather, work and learning tasks become difficult, sometimes forcing schools or institutions to close.

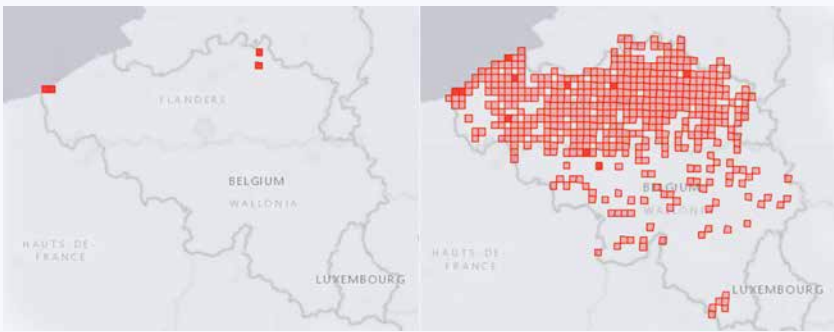
Heat can also **indirectly affect health services**. During heatwaves, emergency department (ED) visits among children rise, particularly in infants. Asthma is often the leading cause, though heatwaves are also linked to a rise in unintentional injuries. Deaths and hospitalizations related to extreme heat typically occur rapidly—on the same day or within a few days—so timely interventions after a heat alert are essential. However, heat can also disrupt health services by affecting electricity supply and transport, further endangering public health.

Heatwaves are frequently associated with **dangerous air pollution episodes**.

The following section examines the effects of climate change on pollen, the phenomenon of thunderstorm asthma, and the interaction between heat and air pollution.

1. *Pollen allergy in a changing climate*:
Both the production of larger amounts of pollen as well as the increased duration of the pollen season due to new species blooming later in the year are leading to more severe symptoms. Take Ambrosia (ragweed) as an example. Originally from North America, it has spread from South to North Europe over the past 25 years (Figure 6). Ragweed's pollen potency is far stronger than grass pollen: as few as 10 grains/m^3 air can trigger symptoms like those caused by 50 grass pollen grains/m^3 air. Ambrosia is also a superspreader: a single plant can emit one billion grains.

FIGURE 6: Ambrosia sightings in 2002 (left) and 2025 (right). *(Source: waarnemingen.be)*



Ragweed pollen can cause severe hay fever, and even skin contact with the flowers may cause symptoms. Allergies to ragweed pollen already affect 50 million people in the US alone. The late flowering of the plant, in September and October, extends the pollen season by at least 2 months (17).

2. *Supercharged pollen*:
Although still rare, events of supercharged pollen or "thunderstorm asthma" are increasing and triggered by several climate factors. The most significant recent event of supercharged pollen occurred in Melbourne (18). On Nov 21, 2016, it was the first hot day of the year when a severe thunderstorm moved to Melbourne in the late afternoon. Within 1 hour, the health care sector noticed a peak in patients with asthma-related symptoms. The demand for ambulances was so high that they could not timely respond to patients stuck at home. ED presentations increased by 58%, and the number of people presenting with respiratory symptoms increased by 672%! Asthma-related admissions increased by 992%, with 30 ICU admissions. Five ICU patients died due to neurological complications associated with cardiac arrest. The other 5 deaths were out-of-hospital deaths either while awaiting emergency transport, or who could not be resuscitated by ambulance services (18). A newspaper rightfully talked about "an event equivalent to a terroristic attack" (19).

In June 2023, a thunderstorm in London caused a similar sharp increase in children presenting with wheeze at a paediatric ED. Strikingly, 57% occurred in children without prior asthma, though many had a history of eczema or hay fever (44%). Of all presentations, 59% were severe and 6% life-threatening. No intubations or deaths were reported (20).

"Thunderstorm asthma" describes acute asthma attacks triggered by thunderstorms, particularly when pollen counts are high. How thunderstorms trigger asthma is not fully understood. The theory is that cold air downdrafts generate strong winds, stirring up (grass) pollen grains and fungal spores. They get carried high into the clouds, where moisture causes them to swell and break apart into smaller fragments, massively increasing the number of allergen particles in the air. Lightning may also enhance their rupture. The smaller particle size makes it easier for the fragments to go deep into the airways, leading to severe bronchospasm in susceptible individuals (18,20). Pollen levels seem to spike during the first 20-30 minutes of a thunderstorm. Younger people seem to be particularly affected.

Notably, having asthma is not the strongest predictor of risk. Instead, allergic rhinitis (hay fever) appears to be a more reliable indicator (18). Preventive measures include forecasting risks, early warning systems, and limiting outdoor exposure during high pollen conditions. In addition, adherence to inhaled corticosteroids and the use of allergen immunotherapy before or during storm seasons may reduce the risk (18,20).

As climate change worsens weather patterns and increases pollen production, the risk of thunderstorm asthma is likely to rise.

3. *When pollution and heat meet*:
Alerts on heat waves and air pollution often come together, because heat exacerbates air pollution through several mechanisms:

- *Increased primary emissions*. High temperatures raise energy demand, particularly for air conditioning, resulting in greater emissions. Heat also facilitates the occurrence of wildfires, which release pollutants that spread over wide areas (21).
- *Formation of secondary pollutants*: Sunlight and heat accelerate chemical reactions that convert NO (emitted from vehicles and industry) and volatile organic compounds (VOC's, originating from gasoline, paints, and cleaning agents) into ground-level ozone. While stratospheric ozone protects against harmful ultraviolet radiation, ground-level ozone is a toxic respiratory irritant that aggravates asthma and other pulmonary conditions. Most urban smog observed today is ground-level ozone (21,22).

  Furthermore, heat drives the formation of ultrafine particles (a mixture of solid and liquid droplets suspended in the air, discussed elsehwere in this issue) that penetrate deep into the lungs and even the bloodstream. Despite representing only a small proportion of particular matter $(PM)_{2.5}$ mass, these ultrafine particles are highly toxic and increasingly recognized as a major determinant of air-pollution-related morbidity (23).
- *Atmospheric stagnation*. Heatwaves are often associated with high-pressure weather systems that trap pollutants near ground level, leading to higher pollutant concentrations. Almost no Belgian city currently meets the WHO target for particulate matter. Air quality in Ghent, Antwerp, and Brussels is worse than in most other European cities (24).

  Children are more susceptible to air pollution and may be more exposed than adults too:
- Their lungs are growing, and the epithelial barrier is more permeable.
- Their developing immune system is less efficient, strengthening the effects of pollution.
- They breathe faster and inhale more air/kg of body weight, resulting in higher doses of pollution
- They breathe air closer to the ground where traffic-related pollutants are concentrated.
- They inhale mostly through their mouths, allowing pollutants to penetrate deeper into the lower respiratory tract

Air pollution is linked to many adverse health effects in children, including an increased risk of upper airway infections and otitis media (25); exacerbation of asthma (26); impaired lung function and postnatal lung development, particularly due to short-term exposure to ozone and nitrogen dioxide, and long-term exposure to $PM_{2.5}$ (27). Emerging evidence also links air pollution to harmful effects on the developing brain. Its ultrafine particles can enter the bloodstream and trigger neuroinflammation or even reach the brain via the olfactory nerve, as magnetite does, causing oxidative stress tied to neurodegenerative disorders. Other pollutants, such as polycyclic aromatic hydrocarbons, harm brain regions essential for neuronal communication and children's cognitive development (28).

Air pollution can also affect the foetus: exposure during the 2nd trimester, when airways develop, is associated with a significantly increased risk of childhood asthma. Continued exposure during the first 2 years of life increases the risk even further. Pregnant women should be advised to minimize exposure to air pollution, just as they are advised to avoid (second-hand) smoking (29).

Heat waves and air pollution are a deadly combination. In Europe, air pollution is estimated to cause more than 1,200 deaths annually in children under 18, and this number is likely to increase with global warming. Beyond mortality, it contributes substantially to morbidity, leading to school absenteeism, chronic respiratory disease, and long-term impairments (30).

Conclusion

Global warming is an immediate threat to global health, particularly for our children. Rising temperatures intensify air pollution, increase water and food insecurity, and amplify the risks of infectious diseases and natural disasters. Even under optimistic scenarios (global warming to be held at 2°C by 2100), billions of people will face chronic flooding, water scarcity, and deteriorating living conditions. If global warming reaches 3°C or higher, sweating might no longer be enough to keep the human body from overheating in certain regions.

Addressing this crisis relies on 3 strategies: *mitigation* or reducing GHG emissions; *adaptation* or learning to live with the consequences; and *innovation* to engineer our way around the problem. Of these, mitigation attacks the source of the problem. At the present rate of consumption, oil, gas, and coal reserves are projected to decline dramatically by 2080 according to the International Energy Agency; fossil fuels must be replaced anyway. Advances in renewable energy, shifts in public policy, and individual behavioural changes all demonstrate that solutions are within reach.

Nevertheless, the temperature will hardly drop at all over the first thousand or so years after emissions cease, reflecting mostly the effects of heat storage in the oceans. In the absence of technology for removing CO_2 from the atmosphere, we will have to live with (adapt to) altered climate for many thousands of years. We could build dikes, restore wetlands and the diversity of forests, paint roofs with white reflective paint or support green rooftops, increase tree cover and green spaces to battle the heat island effect in our cities, stop deforestation, eat a plant-based diet, have one fewer child, and implement heat action plans to make societies more resilient.

Paediatricians have a role in this process: advocating for children's health, preparing for climate-related emergencies by developing protocols and heat action plans, raising awareness by providing anticipatory guidance to caregivers on managing heat exposure, and integrating the health consequences of climate change into clinical practice and medical education. Every action, no matter how small, will contribute to safeguarding the health and future of our children. We cannot and should not wait any longer: the momentum for change is here—and the responsibility to act is ours. Start today.

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