# Children's unique vulnerabilities to environmental hazards

## Fragile Beginnings

**Children face unique vulnerabilities to environmental hazards at every stage of life.**

Children today face a new set of challenges that were unimaginable just a generation ago. Across the world, climate change and environmental degradation are threatening child survival, health and well-being. Children's specific metabolism, physiology and developmental needs, makes them more vulnerable to environmental harm.[1]

The Fragile Beginnings briefing note series provides a scientific stocktake of the growing body of research on the unique vulnerabilities in utero and at birth, infancy and childhood, and in adolescence. This note focuses on the specific effects of environmental hazards in infancy and throughout childhood. Health effects that emerge during childhood as a result of antenatal exposures are not reviewed.



## Children's rapidly developing bodies and longer lifespans make them more vulnerable to harmful exposures, increasing the risk of long-term health effects

- As soon as a newborn breathes for the first time, environmental hazards can begin to affect development due to the unique vulnerabilities of children.
- Children eat, drink and breathe relatively more than adults, meaning they also take in more harmful contaminants. In addition, they are less able to break down and expel toxicants.
- Children have more contact with environmental hazards. They are closer to the ground where toxicants like soil and dust settle. Their exploratory hand-to-mouth and object-to-mouth behaviours make them more likely to ingest harmful substances.
- Children – especially infants – grow rapidly, making them more at risk of malnutrition, which can be increased by environmental hazards that cause food and water scarcity.
- Moreover, children's limited diets can lead to greater exposure to food contaminants, like pesticides or microorganisms. Breast milk can pass harmful environmental exposures from mother to child.
- Infants and young children are more prone to dangerous heat loss as well as overheating. Even into later childhood, children are less able to adjust to rises in ambient temperature than adults.
- Anatomical differences can make children more vulnerable to environmental hazards, from developing airways to more absorbent skin and gastrointestinal tracts, more penetrable blood-brain barriers and, in the case of infants, even different haemoglobin.
- These vulnerabilities come at a time when a child's organs and body systems are rapidly developing from their antenatal form to the form the individual will carry into adulthood.
- Children's longer lifespans mean that exposures to harmful substances during childhood are more likely to result in disease or other adverse health effects later in life.
- Children are unable to protect themselves during this period of high vulnerability. They are entirely reliant on the adults in their lives to protect them from harm.

Healthy Environments for Healthy Children

# Examples of different environmental hazards and how they affect children



## Climate-related hazards

### Malaria

Children under 5 years of age account for around 80 per cent of malaria deaths in the WHO Africa Region (which has 95 per cent of global deaths) . A young child's immune system clears the infection differently than that of adults, which can lead to different syndromes, including severe anaemia. Malnutrition, which growing children are more vulnerable to due to their increased nutritional needs, also contributes to poor immune response and deaths from malaria.

### Extreme temperatures

Newborns, especially small and premature infants, regulate body temperature much less efficiently and thus are at risk of both hypothermia and hyperthermia. Hypothermia occurs when body heat loss goes unchecked, and can cause newborns to succumb to other illnesses. Hyperthermia can result from common situations such as overbundling or being left in direct sunlight, a hot car or around heaters or fires.

Infants and very young children are also vulnerable to extreme temperatures, with infants under 1 year of age being more prone to heat-related deaths. Older children can take longer to adjust to heat and thus may be more vulnerable when outdoor temperatures suddenly rise (particularly when playing sports).

### Food insecurity

Particularly in the first 5 years of life, children's growing bodies require more calories and nutrients relative to body weight than adults, making them more vulnerable to situations where nutritious food is not available. Malnutrition can negatively affect growth and development with lifelong lasting consequences. Malnutrition can also affect children's developing immune systems, and make them more likely to die of common infections such as diarrhoea, pneumonia and malaria.

### Contaminated food and water

Growing children eat and drink more relative to their body weight than adults. When food and water are contaminated with chemicals such as heavy metals or pesticides, children's developing organs can be harmed. Each chemical can do different kinds of damage due to different age-specific patterns of absorption or metabolism in the gut. For example, exposure to nitrates – common contaminants in drinking water – puts infants at risk of 'blue baby syndrome' (low oxygen levels) due to their particular metabolic activity. Hazardous chemicals, such as bisphenols (e.g., BPA), can also leach from plastic packaging and food contact materials and enter into children's food and drinks.

Contamination of food and water with pathogens can lead to bacterial, viral and parasitic infections which can be associated with both short- and long-term health problems including diarrhoea and malnutrition. Polio can also be transmitted through contaminated food and water.

# Pollution

## Air pollution

Young children have faster breathing rates and so breathe in more pollutants relative to their body weight than adults.  Exposure to air pollution, whether outdoors or in the household from use of polluting fuels for heating, cooking and lighting, can harm many systems of a child's body and have lifelong effects.

Air pollution can negatively affect the development of children's lungs, which sets the trajectory for their adult lung capacity. It is also associated with infectious diseases, such as upper respiratory tract infections and pneumonia, and chronic lung diseases, including asthma.

Air pollution can harm children's developing brains and immune systems. It can also affect sleep quality, which is important for brain development. Some adult medical problems such as high blood pressure, chronic obstructive pulmonary disease and lung cancer are associated with childhood exposure to air pollution.

## Lead

There is no safe level of lead. Young children, particularly toddlers, have increased exposure to lead because they put their hands and objects in their mouths, thereby ingesting lead-contaminated dust, soil and other substances. They also are far more likely than adults to absorb the ingested lead into their bloodstreams. Once in the body, lead can have significant and lasting impact on the developing brain, affecting a child's IQ, attention and school performance.

## Pesticides

Young children breathe, drink and eat more relative to body weight than adults, giving them higher exposure to pesticides in contaminated air, water and food (food being the most common source of chronic pesticide exposure). Children are closer to the ground and put their hands and objects in their mouths, which can expose them to pesticides in household dust and soil. Children are also at risk of unintentional poisonings which can be fatal, especially when pesticides are improperly stored, such as in soft drink bottles and food containers.

Pesticides can affect the enzyme systems in developing brains which are necessary for normal nervous system development and function. They can also damage cells which are rapidly dividing in growing tissue. Pesticides are associated with childhood cancers, including brain cancer and leukaemia, a type of blood cancer that is the most common cancer in children.

## Plastics

Children have widespread exposure to plastics in everyday items, including products designed for infants and children , such as bottles and toys. Young children put objects in their mouths as part of normal exploratory behaviour, which can increase exposure to harmful chemicals used in plastics, as well as microplastics and nanoplastics that are shed when plastics break down.

Numerous chemicals that migrate out of plastics can disrupt the body's hormone system, impacting processes such as metabolism, brain development, growth and reproductive development during critical periods. Some of these chemicals are linked to health problems in children, including obesity and early puberty.

## Second-hand smoke

Second-hand smoke can contain over 7,000 chemicals that harm children's developing respiratory systems and other organs. No amount of second-hand smoke is safe. Second-hand smoke is linked to ear infections, pneumonia and asthma, the most common chronic disease in childhood. It is also associated with sudden infant death syndrome.

## Carbon monoxide poisoning

Carbon monoxide is a colourless, odourless toxic gas released by use of polluting fuels in the home, inadequate ventilation and poorly functioning stoves and furnaces. Carbon monoxide poisoning can be fatal. Newborns and infants are more vulnerable to carbon monoxide poisoning than adults. Haemoglobin – the substance in the blood that carries oxygen – is different in infants than it is in adults. The haemoglobin in infants binds more readily with carbon monoxide, which results in lower capacity to carry oxygen to tissues that already have a high demand in growing infants.

# The factors which make children uniquely vulnerable to environmental hazards

Technical brief

Environmental hazards affect infants and children in different ways than adolescents and adults due to dynamic physiology and metabolism, unique and different exposures, cognitive immaturity and longer life expectancy.

## Dynamic physiology

### 1. Increased intake

Children eat, drink and breathe more per kilogram of body weight relative to adults because they are growing.[2] This difference is even greater in infants compared to older children. This can lead to higher rates of intake of harmful substances per kilogram of body weight when there are contaminants in food, water and air.[3] Hazardous chemicals, such as bisphenols (e.g., BPA), can also leach from plastic packaging and food contact materials and enter into children's food and drinks.[4] Microbial contamination of food and water can lead to bacterial, viral and parasitic infections which can be associated with an array of short- and long-term health effects including diarrhoea and malnutrition. Polio can also be transmitted through contaminated food and water.[5]

#### Growth rate and nutritional needs

Children's nutritional needs are different from those of adults, and vary with age. Infants, especially those aged 0–6 months, have the highest relative rate of weight gain.[6] Full-term infants double their birthweight in 4–5 months and triple it by 1 year of age.[7] Weight gain continues after infancy, although at a slower rate, and then accelerates again during adolescence.[8] Increased growth is accompanied by increased caloric intake, making infancy the period of relatively highest intake. When intake is inadequate, children can develop malnutrition, which can cause wasting (i.e., too thin for height) and subsequently lead to increased risk of death or stunting (i.e., too short for age), a condition which prevents children from reaching their physical and cognitive potential.[9] In 2022, an estimated 149 million children under 5 were stunted and 45 million were wasted.[10]

Children who are malnourished are also at a higher risk of death from infections such as diarrhoeal illnesses, pneumonia and malaria.[11] Malnutrition is seen as an important risk factor for cholera, a diarrhoeal disease for which children under 5 bear the greatest burden in endemic areas.[12]

Environmental exposures can affect children's growth, with the most sensitive period extending from conception until age 2 years.[13] For example, children exposed to household air pollution have been shown to have reduced linear growth and increased stunting compared to children who do not live in homes where polluting fuels are used.[14]

#### Increased fluid needs

The amount of fluids that children need per kilogram of body weight per day is highest from birth to 6 months,[15] with the ratio gradually decreasing until they are adults. This makes younger children more susceptible to dehydration when there is inadequate access to fluids, or when there are increased fluid losses from conditions such as diarrhoea or exposure to extreme heat.

#### Increased respiratory rates

Infants and young children also have a higher resting metabolic rate and rate of oxygen consumption per kilogram of body weight than adults.[16] Respiratory rates in early infancy are around 2.5–3.3 times higher than the respiratory rates of adults, making young infants particularly vulnerable to exposure to air pollution. Respiratory rates gradually decrease but remain higher than those of adults until early adolescence.


## 2. Increased absorption of toxicants

### Increased absorption from the gastointestinal tract

As children have different nutritional needs, the small intestine can respond by increasing the absorption of certain nutrients. For instance, calcium absorption in infants is around five times the rate of that in adults. Some environmental toxicants, such as lead, can compete with nutrients and also be absorbed at higher rates. For example, infants and children absorb 40–50 per cent of ingested lead, compared to 3–10 per cent in adults.[18]

### Increased absorption through the skin

The ratio of a newborn's skin surface area to body weight is three times greater than that of adults, meaning their skin can absorb more of a harmful substance per unit of body weight than that of an adult.[19] In addition, the outermost protective layer of the skin is 20–30 per cent thinner – and thus more absorptive – in children aged 3–24 months compared to adults.[20] Water loss through the skin is also higher in infants and children and decreases with age.[21] A small recent study showed that the skin's protective layer reaches adult thickness by age 6.[22]

| Age | Respiratory rate (breaths/min) |
|---|---|
| Premature infant | 40–70 |
| 0–3 months | 40–70 |
| 3–6 months | 30–60 |
| 6–12 months | 25–40 |
| 1–3 years | 20–30 |
| 3–6 years | 20–25 |
| 6–12 years | 14–22 |
| Over 12 years | 12–18 |

**Source:** Johns Hopkins Hospital.[17]

## 3. Dynamic and different metabolism

Children's ability to metabolize, or break down, harmful substances that enter the body changes with age. Take, for example, organophosphate pesticides, which can cause both acute poisonings and chronic low dose exposures and are known to affect cognitive development. The body has an enzyme called PON1 which detoxifies organophosphate pesticides. Measured activity of PON1 is lower in children up to at least 7 years of age, creating a period of increased vulnerability to these pesticides.[23]

## A closer look at the unique metabolism of infants: Nitrates and blue baby syndrome

Nitrates and nitrites, substances commonly found in foods and drinking water, can cause 'blue baby syndrome' that results from reduced oxygen levels in the blood. When infants ingest these substances, several metabolic factors lead to an increased formation of methaemoglobin, which, unlike normal haemoglobin, cannot bind and carry oxygen. Some of these factors include:

- The acid balance in an infant's gut makes it more favourable to bacteria that convert nitrates to nitrites. Nitrites can change the iron in haemoglobin, causing conversion to methaemoglobin.
- Infants have fetal haemoglobin, which is more readily converted to methaemoglobin.
- Infants have a reduced ability to convert methaemoglobin back to normal haemoglobin because, compared to adults, infants have only about half the level of methaemoglobin reductase, the enzyme which performs the conversion.

**Source:** Agency for Toxic Substances and Disease Registry, and American Academy of Pediatrics Council on Environmental Health.[24]

## 4. Differences in excretion

The body eliminates waste through the kidneys via urine, the gastrointestinal tract via faeces and the lungs via exhaled air. The kidneys are the main route of excretion. At birth, the filtration rate of the kidneys is about one third of adult values, increasing to adult levels by age 8–12 months.[25] This means that infants clear substances excreted by the kidneys at a slower rate than adults.

## 5. Differences in structure and function of respiratory system

In addition to having increased respiratory rates, there are structural and functional differences between the airways of infants and children compared to adults. Infants up to age 2–6 months breathe primarily through their nose which makes them more vulnerable to conditions which block their nasal passages, such as upper respiratory infections, which are associated with exposure to air pollution.[26]

The size and shape of the airway between the larynx and trachea is also different, which means that even small amounts of oedema can significantly reduce the diameter of the paediatric airway, decreasing airflow and making breathing more difficult.[27] This difference makes children far more vulnerable to infections, including the uncommon but potentially fatal respiratory infection called bacterial tracheitis.

### The middle ear

The anatomy of the middle ear is different in young children compared to adults. In children, the eustachian tubes are smaller and more level, making it more difficult for fluid to drain out of the ear and contributing to increased incidence of middle ear infections in children.[28] Tobacco smoke is a well-documented risk factor for middle ear infections, and recent evidence suggests ambient air pollution may also be a risk factor. Globally, middle ear infections affect over 80 per cent of children below the age of 3 years and can lead to hearing loss, language delay and impaired cognitive development.[29]

## 6. Differences in components that make up blood

Haemoglobin, the protein in red blood cells that carries oxygen, is different in infants compared to adults. At birth, newborns have 65–90 per cent fetal haemoglobin, which is present in utero. Levels of fetal haemoglobin decrease by 6–12 months of age, when only 2 per cent of total haemoglobin is in the fetal form.[30]

The presence of fetal haemoglobin makes infants more susceptible to carbon monoxide poisoning, because fetal haemoglobin is more likely to bind with carbon monoxide than adult haemoglobin.[31] Carbon monoxide is a colourless, odourless toxic gas.[32] Burning low-grade solid fuel and biofuels in a small stove or fireplace can generate high levels of carbon monoxide which can be deadly without appropriate ventilation. Burning high-grade fuels such as natural gas, butane or propane can also cause carbon monoxide poisoning if devices are not properly maintained or vented.[33]

## 7. Differences in thermoregulation

Infants and young children regulate temperature differently than adults which makes them more vulnerable to extreme temperatures, both low and high. Their ratio of body surface area to mass is greater than that of adults which permits greater heat transfer between their bodies and the environment. In addition, they have higher metabolic rates and heart rates, they spend more time outdoors and in vigorous activities, and they cannot remove themselves from environments with unsafe temperatures.[34] Children under 1 year of age are especially vulnerable to heat-related deaths. Extreme temperatures are increasingly more likely due to global climate change.

### Extreme temperatures: Risks to children with special health-care needs

While all children are vulnerable to extreme temperatures, children with special health-care needs may have increased loss of water through the skin and lungs that can't be measured, which can put them at increased risk of dehydration.

Source: Mangus and Canares.[35]

Children also take longer to acclimatize to a warmer environment than adults, which means they are slower to make necessary physiologic changes such as increasing sweat production and blood flow during exercise.[36] This is particularly important for young athletes when ambient temperatures change quickly.

## 8. Immature immune systems

### Innate immune system

The innate immune system is the first line of defence and is present at birth. While it was previously thought that the innate immune system of neonates was simply immature, scientists are beginning to understand its complexity.[37] There are many cells in the innate immune system that are not fully functional at birth – such as neutrophils, which kill bacteria – which puts newborns, and in particular preterm infants, at higher risk of bacterial and viral infections.[38]

### Adaptive immune system

Adaptive immunity is not present at birth but is developed over time. It involves specialized immune cells and antibodies that attack and destroy foreign invaders and are able to prevent future diseases by remembering what those substances look like and mounting a new immune response.[39] A newborn's adaptive immune system functions differently, making them more susceptible to respiratory infectious diseases and reducing their response to vaccination.[40]

Antibodies passed from mother to fetus during pregnancy can provide protection against many infections, but these antibody levels generally wane by 6 months of age. Breastfeeding infants also can benefit from passive immunity from antibodies transferred through breast milk.

### Microbiome

At birth, as newborns go from a sterile in-utero environment to an external world laden with microbes, they need to be able to quickly respond to some foreign pathogens while tolerating other microbes. Some of these microbes will become part of the microbiome, the community of microorganisms that live on the skin, in the gut and in other parts of the body.[41]

### Deadly combination: Children's immature immune systems face increased challenges from vector-borne diseases in a changing climate

The incidence of vector-borne diseases is expected to rise in the context of a changing climate. While people are at risk of these diseases, children are at higher risk of mortality due to immature immune and other body systems.

#### Malaria

In 2022, children under 5 years of age accounted for about 78 per cent of all malaria deaths in the WHO Africa Region, where 94 per cent of all malaria cases and 95 per cent of deaths occurred. The effect of malaria on organs in the body changes with age and may influence how often different malaria syndromes in children and adults occur. In areas with high malaria transmission, severe anaemia is especially noted during the first and second years of life, partly due to the way the spleen clears malaria-infected red blood cells in young children. Children's brains may also be particularly vulnerable to malaria.

#### Dengue virus

Dengue virus infection can manifest as a benign syndrome, dengue fever, or a severe syndrome with haemorrhagic fever and shock. In severe dengue, clinical symptoms are more significantly associated with death in infants compared with older children. Infants born to mothers with immunity to dengue can develop severe dengue the first time they are infected with the dengue virus. This occurs because maternal antibodies initially protect infants from dengue infection, then break down during the course of infancy, creating a period of enhanced infection where severe dengue can develop.

**Source:** Moxon et al., World Health Organization, and Jain and Chaturvedi.[42]

The microbiome is increasingly being recognized for its role in health and disease across the lifespan.[43] It contributes to metabolic functions, protects against pathogens and educates the immune system.[44] Breakdown products of the microbiome in the gut can also affect maturation of the nervous system.[45] While early research suggested that the gut microbiome reaches adult composition by age 3, recent studies suggest it may continue to evolve during childhood. Environmental hazards including air pollution, tobacco smoke, pesticides and extreme heat can affect the microbiome.[46]

## 9. Altered permeability of the blood-brain barrier

The blood-brain barrier is a network of blood vessels and tissue comprised of closely spaced cells that allows transport of vital molecules like oxygen into the brain while limiting harmful substances and microbes from reaching the brain.[47] Although the barrier is fully functional at birth, activity of transporters and enzymes at the barrier differs from adults to meet the needs of the developing brain.[48] This means that movement of harmful substances can differ, making infants more vulnerable to chemicals.[49] Some harmful substances, such as lead and cadmium, may cause oxidative stress leading to a weakening of the blood-brain barrier and allowing transmission of these substances into the brain.[50]

# Unique and different exposures

## 1. Behavioural changes

Children in LMICs may be at particular risk of increased exposures related to hand-to-mouth behaviours. For example, in these countries, homes are more likely to have earthen floors, increasing risk of soil ingestion. A recent study done in Bangladesh showed that children's ingestion of soil was higher than that of children in high-income countries. Infants aged 6–23 months had the highest rates of soil ingestion, with crawling children touching soil more than walking children.

Source: Kwong et al.[51]

### Hand-to-mouth and object-to-mouth behaviours

As children grow and their brains and bodies develop, they engage with the world in unique ways. The milestones that children meet as part of the healthy acquisition of physical, cognitive and social skills can, however, put them at increased risk of environmental exposures.[52] For example, the 6-month cognitive milestone of putting things in their mouths to explore them and the 9-month motor milestone of crawling can increase exposures to soil, dust and toxicants on floors and objects.[53]


The composition of house dust can be significantly affected by activities near the home. For instance, the application of pesticides within 4 kilometres of a home has been shown to be a significant determinant of indoor contamination, putting young children at risk of pesticide exposure.[55] Toddlers in agricultural communities have also been shown to have higher levels of pesticides in their urine compared to adults.[56]

### Mouthing objects: How children's products may put them at risk

During different developmental stages, children use bottles and various toys. Some are designed to be put in the mouth, while others may be put in the mouth as part of normal exploratory behaviour. Mouthing plastic objects can expose children to chemicals such as plasticizers (like BPA, phthalates and others) and flame retardants, as well as microplastics and nanoplastics. A 2024 umbrella review found that major classes of plastic-associated chemicals are associated with health effects in children including obesity, adverse neurodevelopment and early puberty.

Source: Aurisano et al., and Symeonides et al.[54]

### A perfect storm: How children's unique vulnerabilities put them at risk of lead poisoning

Globally, 800 million children have been shown to have lead poisoning. The majority of these children live in LMICs. There is no safe level of exposure to lead, which is found in many items including lead-based paint, lead pipes, contaminated waste sites, some toys and jewellery, traditional cosmetics, lead-based ceramic glazes, certain spices and others. Young children's hand-to-mouth and object-to-mouth behaviours, crawling, higher gut absorption and developing brain put children at high risk of negative effects of lead poisoning. Lead levels typically peak between 18 and 30 months of age. Children living in a town in Zambia with historical mining of lead, which resulted in polluted soils and homes, had higher blood lead levels than adults living under similar conditions, with peak levels around 2 years of age.

Source: United Nations Children's Fund and Pure Earth, Lanphear et al., and Yabe et al.[57]

## A closer look: The microenvironment of the school bus

Children who travel to school on a bus with a diesel engine can be exposed to high concentrations of pollutants during their commutes or at loading and unloading zones. Diesel exhaust is a toxic mixture containing fine particulate matter, sulfur dioxides, heavy metals, polyaromatic hydrocarbons, volatile organic compounds and other toxicants. While all children are vulnerable to diesel exhaust, children with asthma may be at particular risk. Buses fueled with cleaner fuels (such as ultralow sulfur diesel) have been shown to improve lung function and reduce school absenteeism, especially in children with asthma.

Source: Adar et al., Pandya et al., and Behrentz et al.[58]

### Different microenvironments of exposure

Children have different microenvironments of exposure. Depending on age and mobility, children spend their time closer to the floor than adults, putting them at increased risk of exposure to chemicals which settle closer to or on the ground. For example, mercury vapour, aerosolized pesticides and radon are heavier than air, so concentrations are highest near the floor.[59] Radon is a naturally occurring radioactive gas and carcinogen that can leak through cracks and gaps into homes.[60]

### Time spent indoors and outdoors

Young children also require more sleep and naps which may lead to more time spent in the house, which can be problematic in the presence of household air pollution (such as emissions from unclean fuels burned for cooking, heating and lighting), volatile organic compounds and particles from plastics, mould and dust.[61] Home based informal e-waste recycling activities can also present toxic hazards for children.

As children enter preschool and school, they also begin to spend more time outside, which is essential for their physical, cognitive and mental health. Outdoor play has been shown to be associated with lower obesity rates, improved mood, increased attention and better learning outcomes.[62] When outdoor environments are unhealthy and lack safe open play spaces, however, children can be put at risk of exposure to air pollution, pesticides and other toxic chemicals, climate hazards such as heat waves and floods, and contaminants of war (such as heavy metals).

## 2. Unique diets

### Breastfeeding

Breast milk is the ideal food for newborns and infants. It has been shown to have nutritional, metabolic, immune and neurological benefits.[63] Both the World Health Organization (WHO) and UNICEF recommend exclusive breastfeeding for the first 6 months of life, and the introduction of nutritionally adequate and safe complementary foods at 6 months together with continued breastfeeding up to 2 years of age or beyond.[64]

Breast milk can also unfortunately be a significant source of environmental chemical exposures.[65] Breast milk has a higher fat content than blood, so chemicals which concentrate in fat may be present in higher levels in breast milk. Many chemicals have been found in breast milk, including heavy metals, flame retardants, plasticizers, sunscreens and various persistent organic pollutants.[66] In 2017, WHO conducted a global monitoring study of human milk in 52 countries, analysing levels of many persistent pollutants including dioxins, furans, polychlorinated biphenyls (PCBs) and DDT. The highest pollutant levels in milk were seen mostly in areas with industrial activity. The highest levels of DDT and its metabolites were almost exclusively associated with countries where malaria is still endemic.[67]

Contaminants in milk can also come from substances stored within a mother’s body. For example, releasing calcium from bones during lactation can also release stored lead that can then be excreted into breast milk.[68] Chemicals stored in fat can also be excreted into breast milk, meaning maternal weight loss may lead to increased organic pollutants in breast milk.[69]

Despite potential risks from environmental exposures in breast milk, it remains widely agreed that breast milk is still best given its well-documented benefits.[70] Efforts should be focused on reducing environmental contamination in the first place in order to reduce maternal exposures and protect breast milk.

### Limited diets

Children’s diets differ from those of adults. They consume more milk, fruits and vegetables than adults. They may eat a diet that is less varied than that of adults, putting them at higher risk of ingesting environmental contaminants in favoured or commonly eaten foods.[71] For example, because inorganic arsenic can be found in rice, infants who eat rice cereal are at increased risk of arsenic exposure. In some countries rice cereal is one of the first solid foods given to infants and is a significant part of their diet.[72]

## Cognitive immaturity and dependence on adults

Children do not yet have the cognitive maturity necessary to protect themselves from harm in both natural and built environments. Children are curious but lack judgement and the ability to read warning labels or instructions. Children also may be reluctant to admit they have ingested a substance or be unable to communicate details of what happened.[73]

Common household items including medications, cosmetics, personal care products, household chemicals including pesticides, and (in LMICs) kerosene are among the most common causes of unintentional childhood poisonings.[74] Age and developmental stage can affect access to substances – infants, for example, have increased risk of exposure to harmful substances at ground level. Poisoning rates increase around the age of 2 years as children become more mobile and have more access to harmful substances.[75]

Children under the age of 1 year have the highest rate of fatal poisonings, especially in LMICs.[76] Poisoning mortality rates are generally highest in infants and decrease until age 14, then increase again after age 15, potentially due to substance use, unintentional or undetermined drug overdoses or entry into the workplace.

Household products that look and feel like toys or candy can be particularly dangerous to children. For example, laundry detergent pods have been shown to be especially attractive to children because of their candy-like appearance. These pods have been shown to cause more severe symptoms and adverse health outcomes than exposures from non-pod laundry detergent. In one US-based study, 94 per cent of laundry pod exposures involved children under 5 years of age.

Source: United States Centers for Disease Control and Prevention.[77]

## Longer life expectancy

When children are exposed to environmental hazards early in life, some health outcomes may not appear for decades. It is now widely accepted that early life exposures are associated with many non-communicable diseases later in life including cancer, obesity, diabetes, high blood pressure, heart disease and lung disease.[78]

During childhood, cells and tissues are rapidly dividing, which make them prime targets for carcinogens that can cause mutations in dividing DNA.[79] Early exposure to carcinogens is a risk factor for cancer later in life.[80] Because young people have many expected years of life, cancers which have long latency periods can affect them more than if the same exposure happened to an older person who will not live enough years for the cancer develop. For example, it is well established that early childhood sunburns are a risk factor for malignant melanoma, the deadliest form of skin cancer, later in life.  Other childhood exposures that are associated with cancers in adulthood include household air pollution, ambient air pollution and diesel exhaust (lung cancer); asbestos (mesothelioma); arsenic (lung, urinary and non-melanoma skin cancer); and aflatoxins (liver cancer).[81]

# Period of extreme vulnerability: The neonatal period

A healthy start in life begins in the antenatal period, which is the most vulnerable time for environmental exposures. The next most vulnerable period is after birth, from the first day of life through day 28.

### Transition to life outside the womb

The transition to life outside the womb is a time of dramatic and unparalleled changes in an infant's organs.[82] The lungs take their first breath and begin gas exchange, triggering radical shifts in cardiovascular blood flow and function so that the heart can take over the work of the placenta and umbilical vessels. Feeding via the gastrointestinal tract begins. Red blood cell counts, which are relatively higher in utero, begin to fall to postnatal levels and in the process can cause transient jaundice.[83]

During and after the immediate transition, vulnerability is heightened. While organs are functional, function can be substantially different from that of older children and adults. For instance, a neonate's immune responses are inefficient, relying on innate rather than adaptive or specific immunity, which contributes to their susceptibility to infections.[84] The immune cell response in neonatal lungs is also deficient, putting them at risk of pneumonia.[85] Additionally, neonates have a limited capacity to regulate their body temperature, making them vulnerable to heat loss as well as overheating.[86]

### A period of increased mortality

Newborns are, in fact, the most vulnerable population in the world; the risk of dying in the first week of life is higher than in any other period in the human lifespan.[87] Every year, 30 million newborns require special or intensive newborn care in a hospital.[88] In 2022, almost one half of all deaths in children under 5 years of age occurred in the newborn period.[89] Maternal exposures to environmental hazards during pregnancy can also play a role, as they may be associated with conditions such as low birthweight, prematurity and birth defects that increase vulnerability to diseases and death, especially in the neonatal period.[90]

### Special considerations for premature infants

The neonatal period presents more difficult challenges for babies born prematurely, i.e., before 37 weeks of gestation. Unlike full-term infants, the organ systems of premature babies are not prepared to support life outside the womb, especially in infants born severely premature who require more interventions to survive.[91] Short-term complications of prematurity include respiratory distress, unstable circulation, feeding difficulties, infections, brain injury, eye damage and anaemia.[92]

### What happens when newborns are faced with environmental challenges

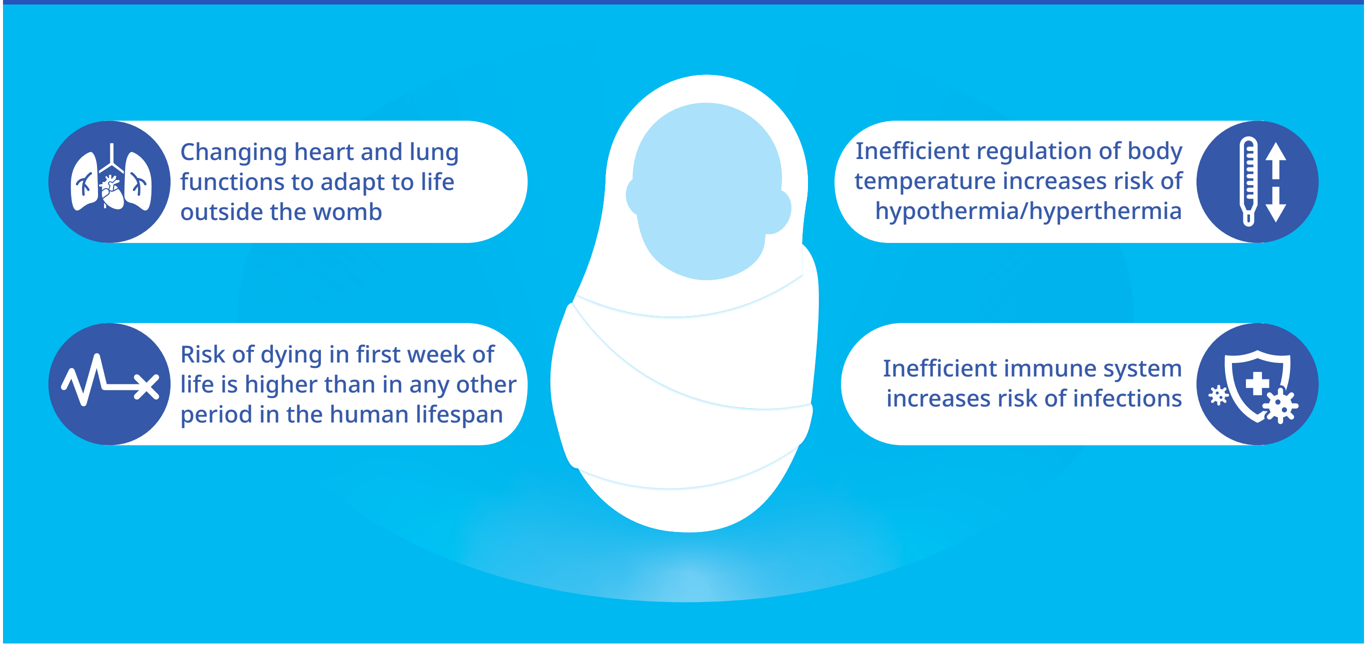
While the newborn baby is adjusting to their first critical month outside the womb, environmental challenges may be especially problematic. Newborns – especially premature infants – can become hypothermic if they are not in a sufficiently warm environment, which can contribute to mortality from other neonatal illnesses.[93] A naked newborn exposed to an environmental temperature of 23°C suffers the same heat loss as a naked adult in 0°C.[94]

Newborns also are particularly susceptible to hyperthermia, which can result from overbundling, especially in hot, humid climates; being left in direct sunlight or in a parked car in hot weather; or being placed too close to a fire, heater or hot water bottle.[95] Hyperthermia can lead to severe dehydration and potentially death.

Other environmental challenges include air pollution and lack of adequate water, sanitation and hygiene (WASH), which can increase the risk of infections, including pneumonia.[96]

With environmental challenges that can put already vulnerable newborns at increased risk, appropriate care can be critical. Access to special care (which includes access to WASH, electricity, oxygen supply, specialized nursing staff and other requirements) can help prevent neonatal deaths.[97] Nearly all neonatal deaths (98 per cent) occur in low- and middle-income countries (LMICs), with the highest neonatal mortality rates being found in countries with humanitarian crises.[98]

## The first week of life: The highest risk of death, intensified by environmental hazards




# Developing organ systems in childhood and environmental hazards

## 1. Brain and central nervous system

Early childhood is a period of significant and dynamic brain development. Brain plasticity (which is at its maximum during the first years of life) allows a child to learn and develop through their experiences. It also, however, makes the brain susceptible to environmental hazards which can alter the trajectory of brain development.

Children are born with most of their neurons, the nerve cells that send and receive signals that allow us to do everything from breathing to talking, eating, walking and thinking.[99] There is some evidence to suggest that neurons also continue to form throughout life.

Neurons undergo many phases of development that are critical for building the networks that make up the complex architecture of the brain. After neurons proliferate, they migrate to their final location in the brain. Most migration takes place in utero but recent evidence suggests that in some areas of the brain, migration can continue for several months after birth.[100] Connections between neurons, called synapses, start to develop in utero. In the first few years of life, more than 1 million new synapses form every second.[101]

Different parts of the brain reach peak synapse production at different times, affecting the plasticity of each region. Synapses are also pruned, a process driven by experiences. The overproduction of synapses followed by pruning and the interconnection of neurons to form neural networks are essential to a child's learning. Finally, neurons complete development through myelination, the wrapping of fatty cells around the axon of the neuron which helps the neuron send signals faster.[102]

Environmental hazards can affect all these crucial steps in the building of the brain's architecture, with implications on future cognitive function. For instance, lead can interfere with the normal function of important chemical messengers in the brain, which in turn affects the formation and sculpting of neural networks as well as myelination.[103] Even at low levels of exposure, lead is associated with decreased academic achievement, lower IQ and attention problems.[104] Exposure to air pollution and hazardous chemicals in plastics in early childhood also can affect neurodevelopment.[105] Air pollution can also affect sleep quality in young children which is important because insufficient sleep in early years is associated with cognitive impairments.[106]

Exposure to various environmental hazards, including heavy metals and other pollutants, can also cause epigenetic changes (or changes to the way a gene is expressed) in the developing brain, particularly in early childhood.[107]

## 2. Respiratory system

### Lungs and respiratory tract

After birth, the lungs continue to develop. The alveoli, the tiny air sacs where oxygen and carbon dioxide are exchanged, grow in number. The greatest increase happens during the first 18–24 months of life and continues to age 8.[108] The blood vessels in the lungs also develop during the first 2–3 years of life.[109] Lung function develops throughout childhood and continues until late adolescence.[110] Lung function tracks along percentiles, which means that the lung function an infant has at birth largely determines lung function throughout life.[111]

Environmental hazards can negatively affect lung development, especially during the period when alveoli are rapidly increasing. Adverse exposures can also affect the epithelium, which is a protective lining in the airways that also has multiple immune functions. Early life exposures to environmental hazards such as fine particulate matter in air pollution can affect the structural and functional integrity of the epithelium and contribute to the development of respiratory diseases, including asthma.[112] Exposure to air pollution in childhood is also associated with pneumonia with complicated course and poor health outcomes.[113] Second-hand smoke, which can contaminate children's environments when tobacco products are burned or when a smoker exhales smoke, contains over 7,000 chemicals, including approximately 70 that can cause cancer.[114] Second-hand smoke is linked to respiratory infections and asthma attacks.[115] It is also linked to sudden infant death syndrome.

Effects from air pollution on the developing respiratory system can last throughout life. For example, chronic obstructive pulmonary disease (COPD) is an adult condition that has links to early exposures to air pollution.[116]

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## 3. Kidneys and urinary system

Children's kidneys are more vulnerable to environmental hazards than those of adults. Although the generation of nephrons – the functional units of the kidneys – is complete by birth, the filtration function of the kidneys matures during infancy, making it a period of vulnerability of the kidneys to environmental hazards such as heavy metals.[117] Altered kidney filtration is an established risk factor for chronic kidney disease[118] as kidneys cannot generate new nephrons to compensate for altered function of existing nephrons.[119]

## 4. Immune system

The immune system and the microbiome develop in early postnatal life through complex processes that aim to meet the challenge of protecting against foreign pathogens while not attacking the body's own tissue, which would lead to autoimmune diseases. These developing processes are more or at least differently susceptible to environmental hazards than their adult counterparts. For example, dioxins – persistent organic pollutants – are harmful to children at significantly lower doses than those needed to produce effects in adults.[120] Effects of early exposure to environmental hazards can be long lasting or appear long after exposure.

The developing innate and adaptive immunities are vulnerable to negative effects from environmental hazards such as air pollution, which can disrupt immune function in the respiratory tract and contribute to the development of allergic rhinitis and asthma.[121]

## 5. Endocrine and reproductive systems

### Reproductive cells

Children are born with the cells that will become eggs and sperm. Damage to these cells can occur anytime, including during childhood and adolescence, all the way up to conception.[122] Egg and sperm cells also develop differently, which can affect the windows of sensitivity to environmental hazards and, ultimately, fertility and health impacts.[123]

### 'Mini-puberty'

After birth, there are two periods of activation of the system that controls reproductive and sexual development, i.e., the hypothalamic-pituitary-gonad axis which connects the brain with the testicles and ovaries. The first period is called 'mini-puberty' and takes place from birth to around age 6 months in boys and from birth to potentially age 2–4 years in girls. The second period is puberty, which takes place during adolescence.

'Mini-puberty' is less well known than its adolescent counterpart but can have lasting impacts on a child's reproductive and sexual health. After birth, the drop in placental hormones in the newborn's circulation leads to a surge in activity in the hypothalamic-pituitary-gonad axis that causes the release of hormones. In boys, this affects the development of the testes, penis and prostate gland while in girls the effects are less well understood. 'Mini-puberty' is a critical window for exposure to endocrine-disrupting chemicals, including those found in plastics (BPA, phthalates, flame retardants), polychlorinated biphenyls (banned worldwide but still widely found in the environment)[124] and DDT. These chemicals have a wide array of effects, including premature breast development and both early and late puberty.[125]

## 6. Haematologic system

The production of blood cells in children takes place in the bone marrow and involves high rates of cell division and growth. The rapid division of blood cells makes them vulnerable to environmental hazards. Leukaemia is a cancer of the white blood cells, which help fight infections, and is the most common type of cancer in children. Several environmental hazards are associated with leukaemia, including ionizing radiation, benzene and pesticides.[126]

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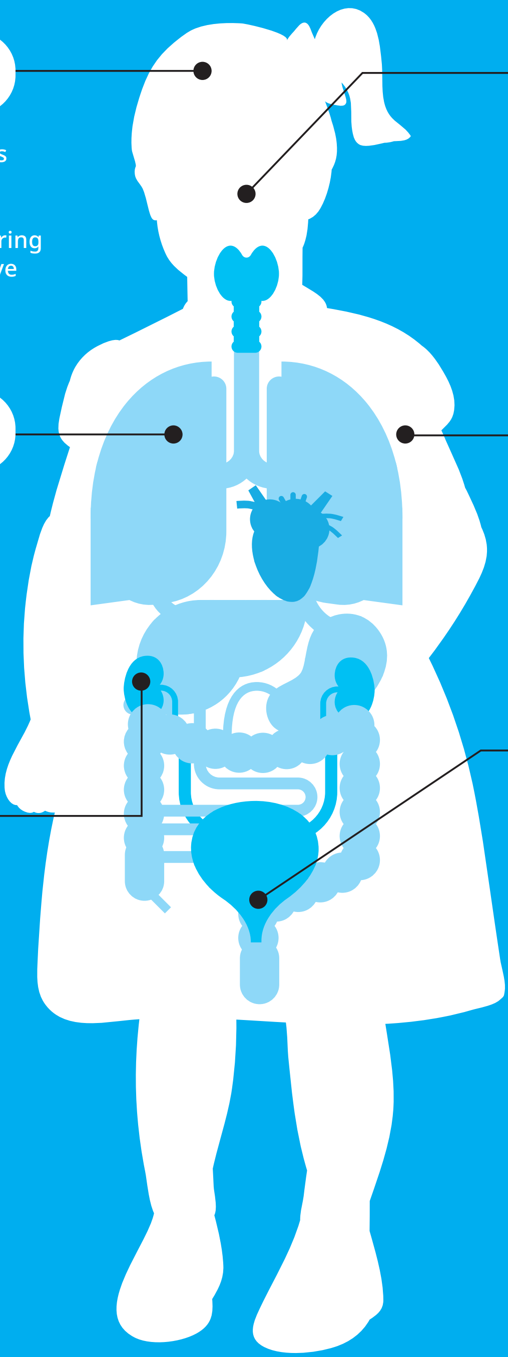
## Environmental exposures during critical windows of vulnerability in childhood can have lasting negative effects on a child's health



### Brain and central nervous system

Rapid growth of the brain's architecture and function means damage from environmental hazards during early development can have lifelong impacts.

### Immune system

Early development of the immune system and microbiome is sensitive to exposures, raising risks of infections, asthma and allergies.

### Lungs

Rapid growth of alveoli from birth to age 2 and up to age 8 means early exposures can lead to issues like pneumonia, childhood asthma and chronic lung disease in adulthood.

### Haematologic system

Rapid blood cell division during childhood makes this period sensitive to exposures linked to blood cancers like leukaemia.

### Kidneys

Maturation of kidney filtration occurs in infancy. Harmful exposures during this period increase the risk of chronic kidney disease.

### Reproductive system

Reproductive cells, present from birth, can be damaged by harmful exposures. The ‘mini-puberty’ phase is critical for organ development and is vulnerable to endocrine-disrupting chemicals.

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## Acknowledgements

**Author:** Maria Brown, with guidance from Abheet Solomon
**UNICEF reviewers:** Katelyn Greer, Desiree Narvaez, Chemba Raghavan, Eduardo Garcia Rolland, Kam Sripada
**External reviewers:** Julia Gorman, Phil Landrigan





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