The Toxic Truth: Children's Exposure to Lead Pollution Undermines a Generation of Future Potential

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	UNICEF	Pure Earth
Authors	Nicholas Rees	Richard Fuller
Overall Guidance and Direction	Gautam Narasimhan Abheet Solomon	Angela Bernhardt
Design and Visualization	Shangning Wang	
Editor		Debbie M. Price
Research and/or Review	Yoonie Choi Fiorella Polo Kam Sripada Lilydahn Stewart Amy Wickham Fangqian Xu Sarzah Yeasmin	Gordon Binkhorst Jack Caravanos Bret Ericson Greg Ferraro Andrew McCartor Elena Rahona

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Joanna Tempowski (World Health Organization)

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EXECUTIVE SUMMARY

Hundreds of millions of children are poisoned by lead. Some of these children live in poor communities in rich countries, but the vast majority live in poor countries where they are exposed to lead through multiple routes. Often unwittingly and with life-altering consequences, these children are growing up in harm's way, inhaling dust and fumes from informal used lead-acid battery recycling operations and open-air smelters, eating food contaminated by lead-glazed pottery and lead-infused spices, living in homes with peeling lead paint, playing, and even working, in lead-laced electronic waste dumps.

According to ground-breaking new analysis and research, around 1 in 3 children – up to approximately 800 million globally – have blood lead levels at or above 5 micrograms per decilitre (µg/dL), a level that the US Centers for Disease Control and Prevention (CDC)[1] have determined is cause for action and which the World Health Organization says may be associated with decreased intelligence in children, behavioural difficulties and learning problems.[2] Research on lead has been undertaken and compiled over many decades by UN Agencies such as the World Health Organization, the United Nations Environment Programme and the United Nations Children's Fund, as well as non-governmental organizations and research organizations such as Pure Earth, Human Rights Watch, the US National Institutes of Health, the Institute for Health Metrics and Evaluation, and numerous universities.

The unequivocal conclusion of this research is that children around the world are being poisoned by lead on a massive and previously unrecognized scale.

Most of these children impacted by lead live in Africa and Asia, but many are also affected in Central and South America and Eastern Europe. While blood lead levels have declined dramatically in high-income countries since the phase-out of leaded gasoline and in some places lead-based paint, blood lead levels for children and adults in low- and middle-income countries and in pockets in high-income countries continue to be dangerously high.

Childhood lead poisoning should command an urgent international response. But because lead wreaks its havoc silently and insidiously, it often goes unrecognized. It irreversibly damages children's developing brains and nervous systems, the heart, lungs and kidneys and often does so whilst causing no or only subtle symptoms in the early stages. Hence, the full magnitude of the scale of global lead poisoning is only recently coming to light.

Lasting Damage at Even Low Levels

According to the WHO, there is no known safe level of lead exposure. Relatively low levels of lead exposure that were previously considered 'safe' have been shown to damage children's health and impair their cognitive development. Lead is a potent neurotoxin that, with even low-level exposure, is associated with a reduction in IQ scores, shortened attention spans and potentially violent and even criminal behaviour later in life. Children under the age of 5 years are at the greatest risk of suffering lifelong neurological, cognitive and physical damage and even death from lead poisoning. Older children and adults, as well, suffer severe consequences from prolonged exposure to lead in food, water and the air they breathe, including increased risk of cardiovascular death and kidney damage in later life.[3]

The impact of lead on adults is so large that over 900,000 premature deaths per year are attributed to lead exposure.[4]

Children with blood lead levels above 5 µg/dL may score 3-5, or more, points lower on intelligence tests than do their unaffected peers.[5] These reductions in IQ undermine children's future potential and diminish their prospects. Widespread cognitive declines across large numbers in a city or country result in declines in creative and economic productivity across entire societies.[6]

Juvenile delinquency, violence and crime have been associated with preschool lead exposure.[7] Conversely, decreases in average blood lead levels in pre-schoolers from above 10 µg/dL to below 5 µg/dL have been linked to significant decreases in crime rates, with juvenile arrest rates for violent and property crimes dropping by as much as to 50 per cent.[8] All of these factors impact a country's economic growth, prosperity and security. Accounting for the wide range of effects, a cost/benefit study in the United States found that there was an estimated benefit of $3.10 for every dollar spent in US Environmental Protection Agency (EPA) rule enforcement to reduce lead hazards.[9]

Common Sources of Exposure

The sources of childhood lead exposure include, but are certainly not limited to: lead in water from the use of leaded pipes; lead from active industry, such as mining and battery recycling; lead-based paint and pigments; leaded gasoline (which has declined considerably in recent decades, but was a major historical source); lead solder in food cans; and lead in spices, cosmetics, ayurvedic medicines, toys and other consumer products.[10] Parents whose occupations involve working with lead often bring contaminated dust home on their clothes, hair, hands and shoes, thus inadvertently exposing their children to the toxic element.[11] Children are also exposed to lead in-utero through exposure of their mothers, with adverse impacts on neurobehavioral development that are comparable to those from childhood lead exposures.[12]

One of the most concerning sources of lead exposure is the unsound recycling of used lead-acid batteries (ULABs), most of which are found in cars, trucks and other vehicles. Recycling activities are often conducted in informal, unlicensed, and frequently illegal open-air operations close to homes and schools.[13] Lead-based batteries are a vital component in the 1 billion petrol and diesel vehicles worldwide, as well as for critical stationary applications and telecommunication systems.[14] Since 2000, the number of new vehicles in low- and middle-income countries has more than tripled.[15] In fact, according to the World Lead Factbook by the Internatioinal Lead and Zinc Study Group, about 85 per cent of all lead used goes to produce lead-acid batteries.[16] The vast majority of this lead comes from recycled automobile batteries.[17]

Lead is recyclable. It can be reused safely and cleanly through practices consistent with the circular economy and closed-loop supply chain principles, as is the case in countries with appropriate environmental regulations and monitoring.[18] **However, many countries lack sufficient formal recycling infrastructure and capacity to handle the quantity of used lead-acid batteries flooding their markets.** As a result, as much as half of the used lead-acid batteries end up in the informal economy[19] where unregulated and often illegal recycling operations break open battery cases, spilling acid and lead dust onto the ground, and smelt lead in open-air furnaces that spew toxic fumes and dust that contaminate surrounding neighbourhoods.[20]

Lead from informal secondary recycling makes its way into products beyond vehicle batteries. In Mexico, lead-based pottery glaze on cookware and serving dishes remains a significant source of lead exposure for children and adults.[21] Spices, such as turmeric, are adulterated with lead chromate to enhance their colour and weight in many countries.[22] These lead-adulterated spices and lead-glazed pottery can contribute significantly to elevated blood lead levels among children and adults.

Lead exposure, whether associated with informal ULAB recycling or contaminated foods, not only impacts the affected children but also impacts entire communities. Yet this societal burden of disease, the lifelong injuries and cognitive damage, the increases in violence, and the tragic deaths are preventable.[23,24] The technology exists to improve ULAB and e-waste recycling and lead-smelting operations without remaking industrial cycles.[25] With financial and technical assistance, innovation, and collaboration between private industry, the public sector and non-governmental organizations, solutions can be implemented that establish good practices, eliminate unsafe lead recycling and smelting, clean-up contaminated communities, phase-out the use of lead in paint and consumer products, and manage the safety of drinking water. The return on investment is enormous: improved health, increased productivity, higher IQs, less violence and brighter futures for millions of children across the planet.[26]

A Six-Pronged Approach

Addressing lead pollution and exposure among children requires a coordinated and concerted six-pronged approach across the following areas:

Monitoring and Reporting Systems: This includes building capacity for blood lead level testing; strengthening the role of the health sector in prevention, diagnosis and management of childhood lead exposure; introducing blood lead level monitoring in household surveys; conducting source apportionment assessments at local levels to determine how children are being exposed; and identifying lead-contaminated sites.

Prevention and Control Measures: Prevention of exposure is paramount. This includes preventing children's exposure to high-risk sites; preventing pregnant women and children's exposure to products that contain lead (e.g., certain ceramics, paints, toys, and spices); and ensuring that children, pregnant women and lactating mothers are receiving adequate health services and nutrition, which can help mitigate the impacts of lead exposure. This also includes improving recycling practices and collection systems of ULABs; replacing lead in pottery glazes and cookware with safer alternatives; eliminating the adulteration of spices with lead chromate; eliminating the manufacture and sale of lead paint by adopting lead paint laws; and completely removing the potential for exposure to lead in areas where children live, play and learn.

Management, Treatment and Remediation: This includes strengthening primary health care, including providing training for healthcare workers about how to identify, manage and treat lead exposure in children and pregnant women; providing children with improved nutrition and health services to help treat lead exposure; providing enhanced educational interventions and cognitive behavioural therapy to children who have ADHD-type behaviours and high blood lead levels; supporting the development and use of non-toxic pottery glazes; and containing and cleaning up lead-contaminated sites.

Public Awareness and Behaviour Change: This includes creating continual public education campaigns about the dangers and sources of lead exposure with direct appeals to parents and caregivers, schools, youth associations, community leaders and healthcare workers; utilizing existing media and communications resources and mediums to reach audiences that may not be aware of the risks of lead exposure to children and pregnant women; educating workers and owners of lead-related industries (e.g., ULAB recyclers and smelters, ceramic potters, spice adulterators) about the risks from lead exposures and the ways to protect themselves, their families and their communities; and educating classroom teachers and children themselves about the risks as part of school health interventions.

Legislation and Policy: This includes developing, implementing and enforcing environmental, health and safety standards for manufacturing and recycling of lead-acid batteries, e-waste and other substances that contain lead; enforcing environmental and air-quality regulations for smelting operations; eliminating the use of lead compounds in paint and gasoline (in places where it is still being used), eliminating the use of lead in ceramics and pottery, children's toys, cosmetics, spices and medicines; adopting legally binding limits on lead paint; legitimizing informal ULAB recyclers so that they are in compliance with standards; eliminating child labour in e-waste picking or metals mining; reducing access to toxic sites, especially for children and pregnant women; and managing drinking water safety so that quality standards have strict parameters on lead.

Global and Regional Action: This includes creating global standard units of measure to verify and track the results of pollution intervention on public health, the environment and local economies; building an international registry of anonymized results of blood lead level studies; creating international standards and norms around recycling and transportation of used lead-acid batteries, including transboundary movement; establishing partnerships that mobilize resources and technical assistance, including from the private sector and industry, to address unsound ULAB recycling and other lead sources; and fostering research in areas where there are evidence/research gaps.

1 HOW LEAD HARMS CHILDREN

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Lead is a potent neurological and cardiovascular toxicant that is responsible for nearly 1.5 per cent of annual global deaths (900,000 deaths).[1] That is almost as many deaths as result from HIV/AIDS (954,000) and more than from malaria (620,000), war and terrorism (150,000) or natural disasters (90,000).[2] However, annual deaths capture only a small slice of lead's true impacts. The most insidious effects of lead exposures occur within the brains of children. Once in the body, lead affects a child's developing brain and central nervous system, causing reduced intelligence, lower educational attainment, behavioural disorders, increased tendencies for violent crime and reduced lifetime earnings.[3] It is these impacts to children's potential and to their future role in society that make lead not just an environmental and health issue, but also a critical and under-recognized determinant of international economic development and societal stability.

The toxicity of lead, perhaps originally identified in antiquity, has been recognized as a possible public health hazard since the 1920s.[4] Lead is a relatively recalcitrant compound that long after its use remains in the environment where it can continue to be a source of exposure. For example, it remains in soil associated with atmospheric deposition from lead smelters long after such operations have ceased or from historic use of leaded gasoline long after leaded gasoline was banned. Leaded paint remains on walls until it is properly removed or, until it peels off, contaminating the surrounding area, including soil. Lead can also move from soil to groundwater, depending on the type of lead compound and the characteristics of the soil and hydrological processes surrounding it.[5]

Once ingested, lead is absorbed through the digestive tract and distributed via the bloodstream throughout the body, most significantly affecting the kidneys, liver, heart and central nervous system, as well as the hematopoietic, endocrine and reproductive systems.[6] Like calcium, which it mimics,[7] lead is stored in teeth and bones where it builds up over time to be released into the bloodstream in demanding situations, such as during pregnancy or when a bone is broken or when calcium blood levels are low.[8] Recent exposure to lead can be measured in blood samples, while cumulative exposure can be measured in teeth or bones.[9]

Greater Harm for Children

The potential negative effects of lead are far greater for children than for adults for several reasons:

First, infants and young children absorb about 4-5 times more of the lead that enters their bodies than do adults.[10]

Second, children breathe, drink and eat more per unit of body weight than adults. Consequently, their relative intake of lead from contaminated air, food or water is also higher.[11]

Third, behavioural characteristics make them more predisposed to lead exposure. The risk of ingesting lead-contaminated soils and dust is higher due to the way children play outdoors and because they are closer to the ground, especially when they are learning to walk and crawl. Higher propensity to engage in hand-to-mouth behaviour and pica (persistent eating of non-nutritive substances, such as dirt, paint, etc.) also presents greater risks for children.[12] On average, it has been estimated a young child ingests between 100-400 mg of soil or house dust every 24 hours, and for children who engage in pica the amount ingested could be considerably higher.[13]

Fourth, the blood-brain barrier is still developing in children, especially at young ages. Therefore, neurological damage often occurs at higher levels for children than adults with similar levels of lead exposure.[14] A child's brain grows at its fastest rate during the early years of a child's life, when thousands of neural connections are made every second[15] – and lead exposure can substantially interfere with this complex, important and delicate process.

Fifth, deprivations that occur during the critical window of early childhood can potentially have lifelong socio-economic implications, including educational outcomes, violence, future wages and children's social and economic potential in life.[16]

Impoverished Children at Greatest Risk

Moreover, it is often the poorest children who are the most severely affected. It is the poorest children who:

- Live in areas where exposure risks are higher, such as in places where informal lead-acid battery recycling and smelting operations are more common or in homes that still contain lead in paint or pipes.[17]
- Have family members who are more likely to work in industries, such as informal lead-acid battery recycling, smelting, artisanal ceramic workshops and metals mines, without access to protective equipment.[18]
- Live in areas where identification of, and knowledge about, those risk factors is lower. Identification, awareness-raising and removal of lead can require resources that are frequently not available.
- Live in areas where access to health services to monitor, treat and prevent risks are lower. Many children who do not have access to good quality health services are not even tested.[19]
- Have lower overall health and nutritional outcomes, such as those who have iron- or calcium-deficient diets. These conditions can increase lead absorption.[20]

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Health Impacts

Lead, a highly poisonous element, affects almost every organ in a child's body.[21] Blood lead levels at the lowest measurable levels can compromise the reproductive, neurological and cardiovascular systems.[22]

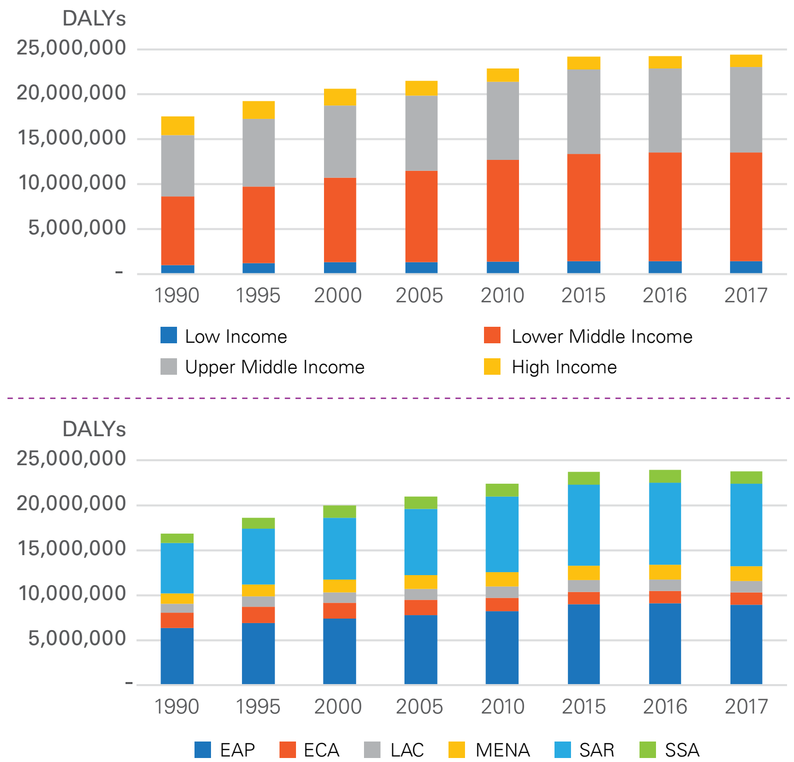
The impact of lead depends on the extent and duration of exposure. High-dose acute exposures can cause gastrointestinal disturbances, such as anorexia, nausea, vomiting and abdominal pain. It can cause hepatic and renal damage, hypertension and neurological effects, such as malaise and drowsiness.[23] At very high levels, lead can cause life-threatening encephalopathy, resulting in convulsions, seizure, blindness, mental retardation and even death.

Lead is typically a chronic or cumulative poison. Chronic lead exposure can cause haematological effects, such as anaemia, and neurological disturbances, including headache, irritability, lethargy, convulsions, muscle weakness, ataxia, tremors and paralysis.[24] The International Agency for Research on Cancer (IARC) has classified inorganic lead as probably carcinogenic to humans (Group 2A), meaning that there is limited evidence of carcinogenicity to humans, but that there is sufficient evidence in animals.[25] Lead has also been found to inhibit the body's use of vitamin D and iron, leading to delayed growth and stunting.[26]

Exposure to lead before and during pregnancy can also be extremely harmful. Lead stored in an expectant mother's bones from her earliest exposures can be released during pregnancy, especially when calcium in the bloodstream is low. This increases blood lead levels and poses risks to both the mother and unborn children. It has been shown to cause bleeding, miscarriage, still birth,[27] premature birth and low birth weight, as well as minor malformations.[28] Usually, the amount of lead in a mother's blood is similar to the levels found in the fetus. Lead exposure during pregnancy could affect the baby's growth as well as their future ability to hear, see and learn.[29]

> Lead is a cumulative toxicant that affects multiple body systems and is particularly harmful to young children. There is no level of exposure to lead that is known to be without harmful effects.
>
> – World Health Organization[30]

Figure 1 Health Effects of Lead Exposure Based on Countries' Income Levels, 1990 - 2017



Source: GBD 2017.
Notes: EAP = East Asia and Pacific; ECA = Europe and Central Asia; LAC = Latin America and the Caribbean; MENA = Middle East and Northern Africa; SAR = South Asia; SSA = Sub-Saharan Africa

Years of Productive Life Lost

The Institute of Health Metrics and Evaluation (IHME) estimated in 2019 that lead exposure accounted for 0.902 million deaths and 21.7 million years of healthy life lost (measured in Disability Adjusted Life Years or DALYs) worldwide due to long-term effects of lead exposure on health.[31] Lead exposure accounted for 62.5 per cent of the global burden of idiopathic developmental intellectual disability, 8.2 per cent of the global burden of hypertensive heart disease, 4.6 per cent of the global burden of ischemic heart disease, 4.7 per cent of the global burden of stroke, and 2.9 per cent of the global burden of chronic kidney disease.[32]

Today, 94 per cent of the disease burden (years of healthy life lost) from lead exposures occurs in low- and middle-income countries. Between 1990 and 2017, the health impacts of lead exposure grew by almost 40 per cent globally, with the lower tier of middle-income countries experiencing the highest growth, and high-income countries achieving a decline of more than 30 per cent (Figure 2). South Asia, East Asia and the Pacific are the regions where lead exposure causes the largest number of DALYs.[33]

The global death rate attributable to lead exposures has also increased steadily over the last 30 years and is now 21 per cent higher than in 1990.[34] This upward trend in the rate of deaths resulting from lead is most stark in upper-middle income countries, where the increase is 46 per cent since 1990.[35] Across East Asia, the death rate has increased by 53 per cent.[36] Today, 92 per cent of all deaths attributable to lead exposures occur in low- and middle-income countries.[37]

Cognitive & Neurological Development

A most troubling effect of lead on children is on the developing nervous system.[38] Even at very low levels, lead exposure in children has been linked with deficits in cognitive ability, lower IQ scores, diminished academic achievement and behavioural problems.[39] Children with blood lead levels as low as 5 μg/dL have been found to score 3-5 or more points lower on intelligence tests than do their peers without elevated blood lead levels.[40] These findings, together with others, have further supported the strong scientific consensus that any quantity of lead in blood is likely to impact health of both children and adults.

A meta-analysis of children's blood lead levels in India found that, on average, the children studied could be expected to lose 4 IQ points each as a result of lead exposures.[41] The analysis synthesized the results of 31 individual studies representing the blood lead levels of 5,472 people in nine states, finding a mean blood lead level of 6.86 μg/dL for children and 7.52 μg/dL for adults with no known occupational exposure.[42]

Even blood lead concentrations below 5 μg/dL have been associated with neurological damage in children.[43] Indeed, studies have consistently shown steeper declines in IQ in children with blood lead concentrations below 10 μg/dL.[44] One meta-review of the literature that examined blood lead levels below 5 μg/dL found no indication of a threshold at which adverse effects were guaranteed to not occur.[45]

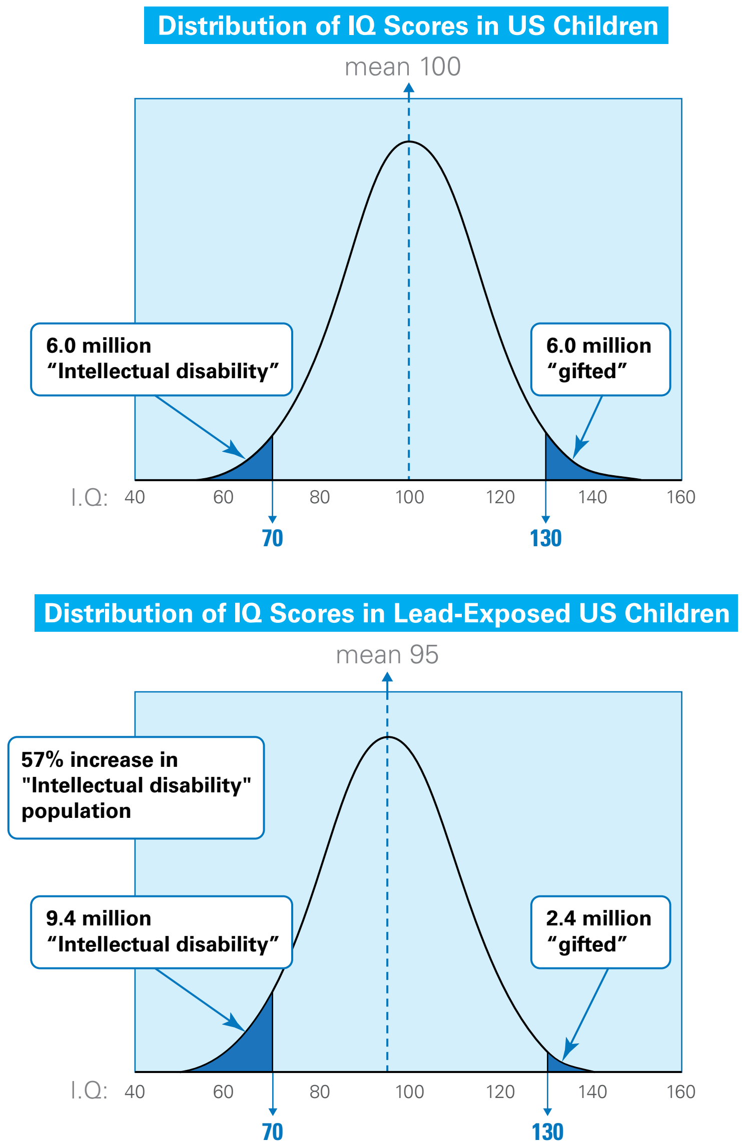
Globally, lead exposure is estimated to account for nearly 10 per cent of the burden of intellectual disability of unknown origin.[46] The effects are usually irreversible.[47] Treatments with pharmacologic agents (typically, chelating drugs) are available for the worst symptoms of acute high-level poisoning, but a rigorous multi-centre randomized controlled trial failed to show any improvement in intelligence in children with the chronic, moderate levels of exposure that are typical of most of the world's children.[48] Imaging studies of adults who have experienced high blood lead levels as children have found region-specific reduction in the brain's volume and alterations of its microstructure, as well as significant impact on brain reorganization,[49] the brain's ability to form new neural connections.

Some studies have found further negative effects beyond IQ, including shortening of attention span, disruptive behaviour, as well as well as aggression.[50] One 2009 study estimated that up to one in four cases of ADHD in 8- to 15-year-old children may be attributable to lead poisoning.[51] Studies also point to links between lead exposure and decreased hearing acuity, speech and language handicaps and anti-social and delinquent behaviours.[52]

Losses associated with a 5-point drop in IQ

A loss of five 5 points across an entire population could result in a 57 per cent increase in the proportion of the population determined to have intellectual disabilities. A decrease of more than 5 points can reduce the proportion of the population determined to have exceptional intelligence by more than 50 per cent.[53] This has tremendous implications for both the capacity of society to provide remedial or special education programmes, as well as for their future leadership.

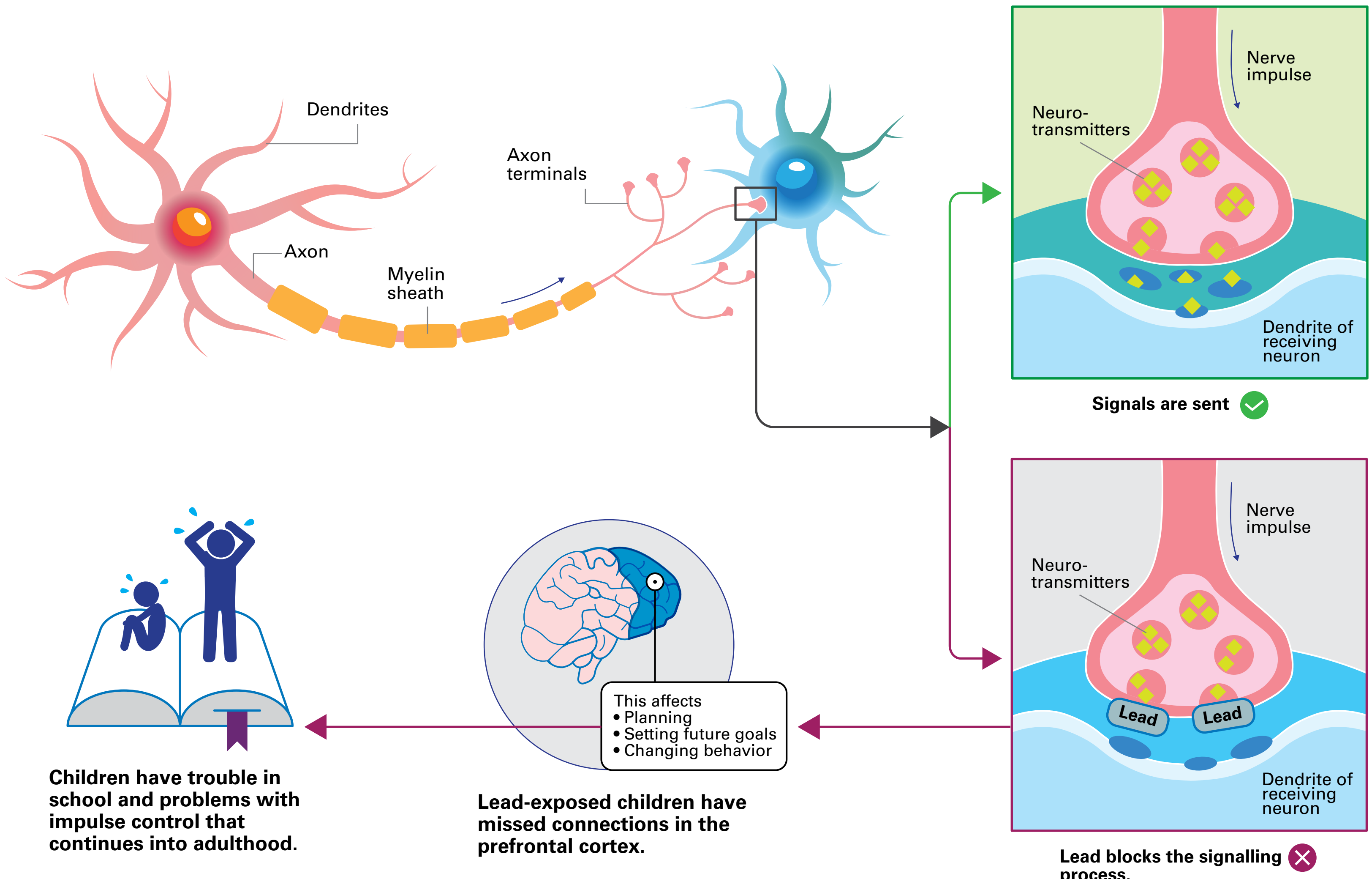
Figure 2 Losses Associated with a 5-Point Drop in IQ per 100 Million People



Source: The WHO and the Lead Paint Alliance[54], originally Weiss B. Neurobehavioral toxicity as a basis for risk assessment. Trends Pharmacol Sci. 1988;9(2):59-62.doi:10.1016/0165-6147(88)90118-6.

Figure 3 Lead Alters Neurotransmitter Release

When calcium (Ca2+) enters a neuron, the neuron releases neurotransmitters (green diamonds) to send a signal to the next neuron. Lead (Pb2+) can interfere with this process in two ways. When lead blocks calcium entry into the neuron, the neuron releases less neurotransmitter and sends a weaker signal to the next neuron. Lead can also cause aberrant neurotransmitter release when calcium is not present.



Source: http://sitn.hms.harvard.edu/flash/2016/deadly-biology-lead-exposure/#:~:text=Lead%20(Pb2%2B)%20can%20interfere,when%20calcium%20is%20not%20present.

Mental Health, Violence and Crime

Studies have postulated a relationship between early and prenatal lead exposure and subsequent criminal behaviour, recidivism and delinquency.[55] With its measurable effect on cognitive development, lead exposure can create learning disabilities and challenges that affect children's executive functioning, impulse control and levels of aggression. These conditions are often irreversible and, studies find, may affect the likelihood for violence and crime in adulthood. A variety of methods[56] have been used to examine the link between childhood lead exposure and propensity for crime, including highly localized ones in specific geographies to ones at the national scale, and from methodologies that span years to ones that span multiple decades, even a century.

Population studies in the United States have found that a significant amount of the regional and temporal variation in crime levels corresponds to varying levels of lead exposure. Indeed, studies have found that childhood blood lead levels were predictors of adult arrests for violent offenses and hypothesized that the still-poorly-understood 1990s decrease in crime rates in the United States was the result of a previous decline in blood lead levels[57]. A 2017 study of 12,000 children born from 1990 to 2004 in the United States found that a 1 unit increase in blood lead level (i.e. an extra 1 μg/dL) increased the probability of suspension from school by 6.5 to 7 per cent for boys and by 6.4 to 9.3 per cent for girls.[58] The findings are consistent with published findings that show children with higher bone lead levels are associated with more aggressive and delinquent behaviour when compared with young boys with similar IQ levels.[59] Blood lead levels in preschool children in the United States over the long term (1936-1990) explain 65 per cent of the variation in mental retardation rates, 45 per cent of the variation in average scholastic verbal achievement tests and 65 per cent of the variation in math achievement tests, according to yet another study.[60]

These trends mirror experiences across multiple countries in Europe and North America.[61] Other studies have conducted highly geographic-specific assessments on the links between lead exposure and crime. One such study found that children living near very busy roads where impacts to soil from leaded gasoline have been higher are more likely to be incarcerated when they become adults, compared with children from similar socioeconomic, gender and ethnic factors who did not live near very busy roads.[62]

But there is also reason for hope. Interventions, such as lead abatement and nutritional counselling to reduce the effects of lead exposure, can possibly lower the degree of cognitive inhibitions.[63] While there are no studies specifically examining the impact of early childhood educational interventions on cognitive or behaviour outcomes for childhood lead poisoning, one report suggests that approaches used to treat brain damage may be more appropriate for children with lead poisoning, compared with approaches for children with learning disabilities.[64]

Figure 4 Effects of Blood Lead Levels on Children and Adults

Blood Lead Levels in ug/dl (micrograms per deciliter)	Effects
Children & Adults	
<5 µg/dL	Decreased IQ, cognitive performance and academic achievement; increased incidence of problem behaviours and diagnosis of attention deficit/hyperactivity disorder; reduced fetal growth (based on maternal blood concentration); impaired renal function; reduced synthesis of aminolevulinic acid dehydratase (ALAD), contributing to anaemia
<10µg/dL	Delayed puberty; developmental toxicity
<20 µg/dL	Increased level of erythrocyte protoporphyrin; decreased vitamin D metabolism; decreased calcium homeostasis
>20 µg/dL	Anaemia
>30 µg/dL	Reduced nerve conduction velocity; increased vitamin D metabolism; increased risk of hypertension in adulthood
>40 µg/dL	Decreased hemoglobin synthesis
> 50 µg/dL	Severe neurological feature
> 60 µg/dL	Abdominal coli; features of acute poisoning but no encephalopathy
> 90 µg/dL	Encephalopathy
> 105 µg/dL	Severe neurological features
150 µg/dL	Death
Adults	
<5 µg/dL	Impaired renal function; reduced synthesis of delta-aminolevulinic acid dehydratase, contributing to anaemia
<10 µg/dL	Hypertension, increased cardiovascular-related mortality, spontaneous abortion, preterm birth
> 40 µg/dL	Peripheral neuropathy, neurobehavioral effects, abdominal colic
> 50 µg/dL	Decreased haemoglobin synthesis

Source: The World Health Organization[65]

"No safe blood lead level in children has been identified. Even low levels of lead in blood have been shown to affect IQ, ability to pay attention and academic achievement...Effects of lead exposure cannot be corrected".[66] The absence of an identified BLL without deleterious effects, combined with the evidence that these effects appear to be irreversible, underscores the critical importance of primary prevention.[67]"

– The US Centers for Disease Control and Prevention.

The Molecular Process that Causes Lead Toxicity

At a molecular level, lead alters very basic nervous system functions – such as calcium signalling. It does so by inhibiting, mimicking or displacing the actions of calcium.[68] It can then bind biological molecules, including sulphydryl and amide groups of enzymes, and alter their configuration as well as diminish and interfere with their functions, including the releasability of organelle stores.[69] In some cases, it prevents calcium-dependent release of several neurotransmitters, and in others it can augment calcium-dependent events, such as protein kinase C and calmodulin.[70] Each of these channels and processes inhibit major functions associated with neurological development and the healthy growth of a child.

Signs and Symptoms of Lead Poisoning

A challenge with childhood lead poisoning is that it is typically insidious. At low to moderate levels of exposure and blood lead levels, there are typically no symptoms at all and no physical signs that are apparent to a clinician. At moderate to high levels of exposure, children may complain of a variety of non-specific symptoms, such as headaches, abdominal pain, dullness, loss of memory, poor attention, loss of appetite or constipation.[71] The impacts of lead poisoning on neurological processes and the central nervous system may result in indications of clumsiness, agitation or decreased activity and drowsiness, which can proceed to vomiting, stupor and convulsions in more severe cases.[72]

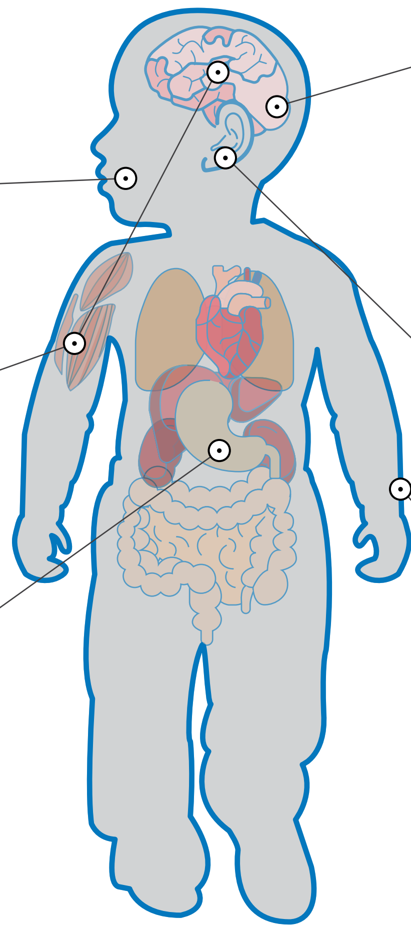
Figure 5 Lead Poisoning Symptoms in Children

General:
- Sluggishness
- Fatigue
- Malaise

Mouth:
- Slurred speech
- Blue line along the gum
- Pica activity

Neuro/Muscular:
- Seizures
- Convulsions
- Loss of coordination
- Weakness
- Coma

Stomach:
- Loss of appetite
- Weight loss
- Anaemia
- Abdominal pain
- Nausea and vomiting
- Diarrhoea or constipation
- Colic



Central Nervous System:
- Headaches
- Developmental delay
- Learning difficulties
- Behaviour and learning problems, or slowed growth
- Aggression
- Irritability
- Clumsiness
- Agitation
- Drowsiness
- Inattentiveness
- Hyperactivity
- Disorganization

Ear:
- Hearing problems
- Balance

Skin:
- Unusual paleness

Lead Poisoning Symptoms in Newborns from Prenatal Exposure:
- Premature birth
- Lower birth weight
- Slowed growth

Case Study:
Kathgora, Bangladesh

One night without warning, dark, acrid smoke began rising from the bamboo jungle near Sharmin Akhter's small house in Kathgora. Every night thereafter for more than a year, the fires glowed deep in the underbrush and the smoke rose. Black dust fell like rain, coating leaves, trees, houses, livestock with a fine inky powder. Akhter's buffalo began acting strangely, roaming aimlessly and foaming at the mouth before suddenly dying. Two goats also died.

As Akhter would tell Pure Earth investigators in November 2019, she did not know that the black smoke and dust from the fires in the jungle were a threat to her family and her livestock. Her children played in the jungle, running through the leaves and grass coated with the fine black powder and climbing onto the piles of broken battery cases.[73]

Only later did Sharmin Akhter and her neighbours learn that lead dust and fumes from informal used lead-acid battery recycling and open-air smelting furnaces had tainted their land and poisoned their children.

"We didn't realize how bad smelting was," Akher told a Pure Earth investigator. "If I knew the side effects, I would have prevented my children from going there." [74]

By the time that villagers understood what was happening in Kathgora, the small town of about 300 people 15 kilometres northwest of Dhaka had been badly contaminated by two informal operations that recycled used lead-acid batteries.[75]

Amzad Hossain had leased his land to the battery recyclers for 7,000 taka or roughly $83 USD a month without knowing how dangerous informal lead recycling could be. His neighbours complained to him about the smoke and claimed that their livestock were dying.[76]

"The people surrounding the smelting area, they do not live, they do not sleep, they do not eat," Hossain said in November 2019. When Hossain went into the jungle to inspect his land, he saw that the once prolific mango and jackfruit trees bore no fruit; he found a goat that had just given birth to a stillborn.[77]

With the complaints mounting and alarmed by what he'd seen, Hossain told the recyclers to leave his land. They refused, he said, until under more pressure from village leaders, he warned them, "Please leave this place or the local people will attack you."[78]

The recyclers fled, leaving behind acres of heavily contaminated land.

In 2017, Pure Earth and the Bangladesh Department of Environment selected Kathgora to be the site of a demonstration remediation project, believed to be the first of its kind in Bangladesh. The Department of Geology of the University of Dhaka and the International Centre for Diarrhoeal Disease Research, Bangladesh (icddr,b) were implementation partners.

Pure Earth team members found children playing on and around piles of broken batteries on the former recycling sites where soil testing showed lead concentrations of over 100,000 ppm – 250 times the US EPA limit of 400 ppm.[79] Early blood testing on a group of 75 children under the age of 7 found that all had elevated blood lead levels ranging from 8 μg/dL to 47 μg/dL with an average of 21.3 μg/dL.[80]

Some of the children had complained of itching skin after playing at the abandoned recycling site, probably from coming into contact with sulphuric acid spilled from broken batteries, but had otherwise seemed fine, their mother told Pure Earth investigators.[81]

Landowner Amzad Hossain, appalled by what had happened, joined the clean-up organized by Pure Earth, supervising the workers, housing team members, cooking for the clean-up crew and washing contaminated clothes at the end of the day.[82]

Local workers wearing masks and protective gear collected and disposed of abandoned lead-acid battery waste, then scraped and collected top-soil, which was buried in a pit. Clean soil excavated from the pit was used to cover the former ULAB sites. Roads were paved and homes were cleaned. Local workers carried out the clean-up, which was supported in part by UNIDO, the OPEC fund for International Development, the European Commission and USAID.[83]

Nine months after the clean-up, repeated testing found that children's blood lead levels had declined on average by 4.3 μg/dL. About 18 months after the clean-up was completed, children's blood lead levels had dropped by an average of 9.1 μg/dL - a 42 per cent reduction.[84]

While blood lead levels have come down, Akhter said her older son has become forgetful and is not doing as well in school as he did before the recyclers began burning lead in the jungle. He seems small for his age. Akhter asked if there is medicine that will help her son become as he was before; she was told there is not.[85]

According to the World Bank, an estimated 1,100 informal ULAB recycling sites put more than a million people at risk in Bangladesh.[86] The Kathgora sites are among 288 legacy informal battery recycling sites in Bangladesh that Pure Earth and and the Department of Geology of the University of Dhaka have identified and assessed since 2011.[87]

Informal ULAB recycling is a significant source of lead exposure in Bangladesh,[88] which, according to the Institute for Health Metrics and Evaluation, has the world's fourth-highest rate of death attributable to lead exposures.[89] Its population average blood lead level has been calculated at 11.65 μg/dL.[90]

Prevention and Treatment of Health Effects

Prevention:

There are a handful of activities that parents and caregivers can do to help prevent children's exposure to lead. While these vary considerably depending on contextual risk factors, the activities offer guidance that can be adapted to local conditions accordingly:

First, determine if there are lead-based risks in the house or around the community where children reside. Houses, schools and other buildings painted with lead-based paint, often before lead-based paints were banned, are potential sources of exposure, especially if the paint is cracking or peeling. Water pipes and fixtures are also potential sources of lead. Certified experts and professional cleaners who use proper stabilization techniques can reduce the risks.

Second, where risks are known, keep children out of contaminated areas. For example, children should be kept away from areas where paint known to contain lead is chipping or peeling; or away from toxic sites in communities, including backyards and common spaces where informal recycling of materials known to contain lead takes place. For areas and soils previously contaminated, and where it is difficult or impossible to prevent children from accessing, covering bare ground with sod can help reduce exposure and prevent children from inhaling or consuming lead dust.

Third, encourage good sanitation and hygiene practices, which can reduce exposure not only to lead but also other toxins and pathogens. Make sure children wash their hands and faces after playing outside or around areas where there could potentially be lead-based risks. Washing children's toys, which may become contaminated from soil or dust, also reduces exposure.

Fourth, encourage a healthy, balanced diet. Iron, calcium and vitamin C can help decrease the absorption of lead if a child is exposed. Healthier children have been shown to suffer less severe consequences from exposure to environmental toxins than counterparts presenting with comorbidities.[91]

Fifth, learn which products may contain lead and avoid using them. These products vary considerably by country and context; however, products that frequently contain lead include artisanal ceramics, some spices, traditional remedies and some cosmetics.

Sixth, prevent lead from being brought into the home. Parents and caregivers whose occupations include exposure to lead should take extra precautions not to bring lead dust into the home. Clothes and shoes should be changed after work. Regular hand-washing can help prevent transmission of leaded dust.

Seventh, seek medical care. If parents suspect their children have been exposed to lead, they should seek medical attention for their children and specifically request blood lead level tests.

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Treatment:

Unfortunately, there is no cure for lead poisoning. Once lead has been in the body for a prolonged period of time, it is very difficult to remove, as it is frequently deposited in bones. By this point, much of the neurodevelopmental damage has already been done.[92]

Treatment for acute and severe lead poisoning can include chelation therapy, a medical procedure that involves using chemicals known as chelating agents to bind to heavy metals, such as lead, iron, arsenic and mercury, in the bloodstream. The chelating agents enable the body to remove the metals from the bloodstream and excrete them through urine. However, chelation therapy does not undo damage that lead has already created – for example, to the child's developing brain. Chelation therapy is not recommended for cases where blood lead levels are below 45 µg/dL, as the side effects can also be severe. It does, nevertheless, save lives for children who have been acutely and severely exposed in the near-term. Importantly, care should be taken to identify the source of the initial lead exposure to prevent re-exposure after treatment.[93]

A nutritious diet high in iron, vitamin C and calcium can also reduce the body's absorption of lead.[94] With enough iron and calcium in the body less lead is absorbed; vitamin C helps to accumulate the iron, too. A good diet is not a replacement for mitigating exposure to a source of lead; however, it may help reduce the impacts of the exposure.

Improved and special educational services, including early childhood development (ECD), may mitigate some of the negative cognitive effects associated with exposure, but research in this area is lacking. In general, children with cognitive and developmental delays can benefit from a variety of interventions designed to address challenges that they are facing. In the case of lead poisoning, these interventions might not reverse the damage that lead poisoning has caused but they may optimize the child's abilities and performance given the circumstances and help the child to live as full and productive of a life as possible. Therefore, children exposed to lead who show behavioural problems would benefit from streamlined access to developmental assessment, intervention and special education services. Guidance and technical assistance should also be provided to teachers and educational systems on how to best provide for these children.[95]


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Children around the world are being poisoned by lead on a massive and previously unrecognized scale.

2 A DEVASTATING TOLL

While the scientific and medical communities have long documented the risks of lead, unfortunately many countries do not know the full extent of childhood exposure and have limited or no screening or surveillance systems that capture that data. Even fewer have implemented assessment and exposure prevention programs.[1,2] As such, the true picture of global childhood lead poisoning has been difficult to piece together. However, recent analysis from two parallel sources has helped to illuminate the breadth of lead exposures globally.

A New Understanding

A companion assessment to this report, conducted by the Institute for Health Metrics and Evaluation (IHME) and drawing on the substantive database from the latest edition of the Global Burden of Disease has found that across all countries globally **approximately 815 million children are estimated to have blood lead levels above 5 µg/dL.**[a] This analysis was undertaken using the Global Burden of Disease dataset for 2019 and includes all countries. In addition, IHME data gives estimates for average blood lead levels by country, premature deaths and DALYs from lead exposure by country.[3]

Supporting this result, a research paper,[4] with abstract accepted for publication in *Environmental Health Perspectives*, represents an additional comprehensive effort to determine the extent of lead exposure of children in lower- and middle-income countries, utilizing a systematic review of literature and independent papers across 34 countries for which reliable data were available. It has found that across those countries, which are predominantly high-burden, approximately 631 million children are estimated to have blood lead levels above 5 µg/dL.[b]

Lead poisoning is affecting children on a massive and previously unknown scale.

Annex A lists by country the number of children above **5 µg/dL and 10 µg/dL**, the average blood lead level and the number of deaths from lead exposure, utilizing the IHME dataset.

a. Data provided in annexes.
b. This finding is based on a meta-analysis of 476 independent papers encompassing 60 countries, more than any other study examining childhood lead poisoning completed to date. Efforts to review blood lead levels in low- and middle-income countries have relied on reports in peer-reviewed literature in absence of large government datasets like those available in high-income countries. Much of the available blood lead level data has also been gleaned through independent scientific research and by non-profit organizations, putting together a more holistic perspective. All of the countries included in the meta-analysis phased out leaded gasoline by 2010. The papers reviewed contained 978 sampled populations, comprising 699,209 individuals from which data were extracted and pooled to calculate national BLL estimates. Background BLLs could be pooled for children in 31 countries and adults in 36 countries. The team applied an established formula used by the World Health Organization to extrapolate countrywide exposures. The study focuses on disseminated exposures, such as those incurred by the general population from air pollution, water contamination, food and street dust, and excluded populations living near hotspots, such lead smelters and informal ULAB and e-waste recycling sites.

Table 1 Number of People (ages 0-19) with Blood Lead Levels > 5 µg/dL

	Mean	Lower -bound Estimate	Upper-bound Estimate
East Asia and Pacific	**77,675,947**	41,621,175	124,286,113
Europe and Central Asia	**12,501,133**	6,099,709	23,090,333
Eastern Europe and Central Asia	**10,027,028**	4,706,887	18,590,896
Western Europe	**2,474,105**	1,392,822	4,499,437
Latin America and Caribbean	**49,107,507**	29,270,540	71,601,467
Middle East and North Africa	**63,441,649**	40,514,465	88,791,458
North America	**1,359,412**	832,648	2,311,908
South Asia	**378,651,188**	309,826,991	450,840,325
Sub-Saharan Africa	**232,483,273**	134,894,930	343,448,826
Eastern and Southern Africa	**93,109,913**	49,946,531	146,414,745
West and Central Africa	**139,373,360**	84,948,399	197,034,081
Low- and Middle-Income Countries	**249,251,174**	158,564,810	345,066,610

Source: IHME 2019[5]

It should be noted that the exposure rates are not distributed evenly. The vast bulk of these exposures occur in low- and middle-income countries. Particularly worrying areas include Africa and South Asia.[6]

There are several reasons for this:

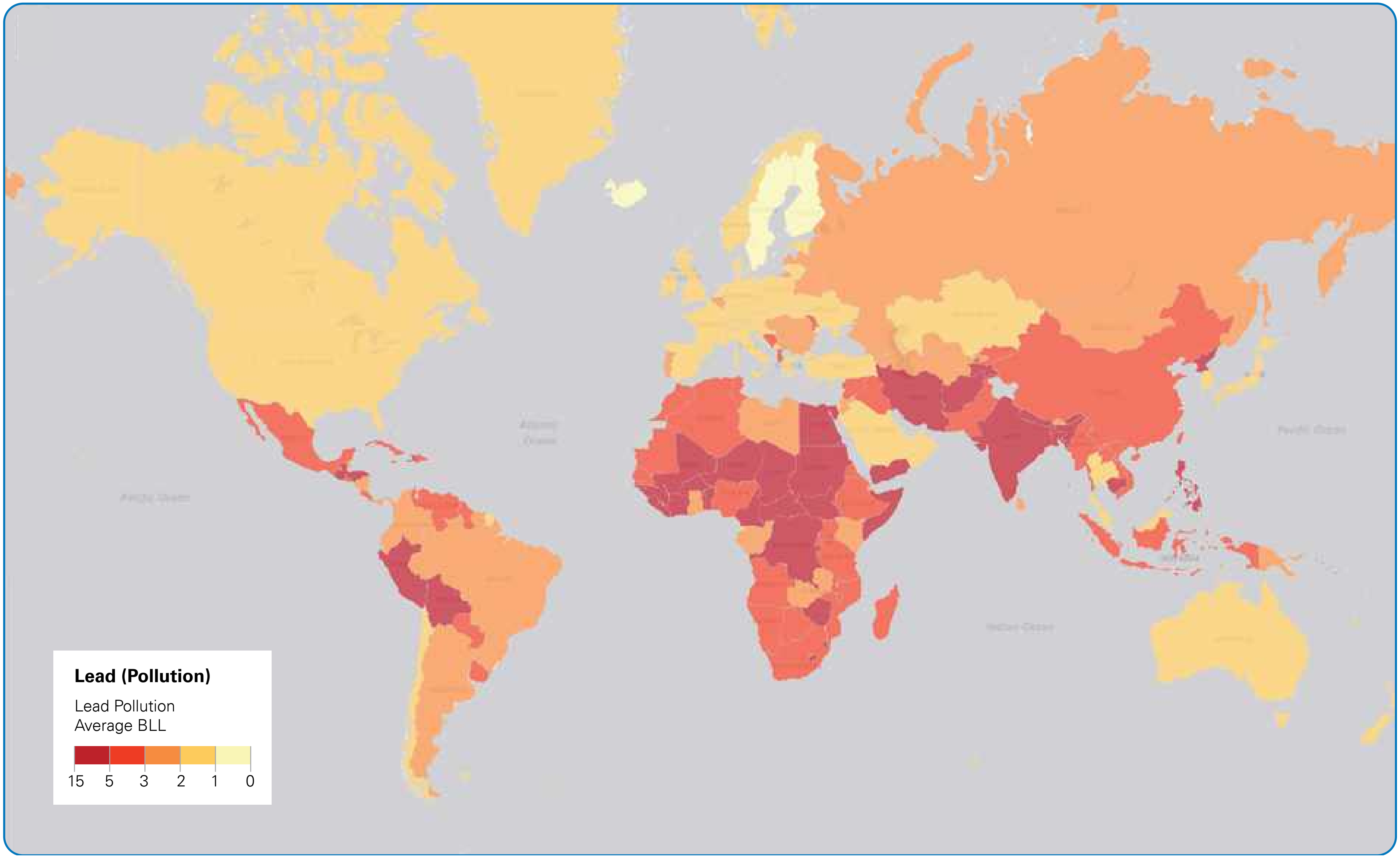
First, there are more opportunities for exposure given the comparatively higher prevalence of used lead-acid battery recycling, which represents one of the main exposure mechanisms. Even where children are exposed because of lead in spices, ceramics or other products, often that lead is still linked to local ULAB recycling facilities.

Second, there are also fewer regulations and enforcement mechanisms to ensure safe, environmentally sound practices in these industries.

Third, many children in low- and middle-income countries suffer from poor nutrition. Unfortunately, this is an additional risk factor – poor nutrition increases lead absorption.

Finally, there is often an absence of health screening programs in low- and middle-income countries,[7] making it difficult for authorities to identify hotspots and develop programs to prevent exposure and remediate toxic sites.

Figure 6 Children's Average Blood Lead Levels by Country



Source: IHME 2019. See Annex for full list by country. Lead exposure and health data is also visualized at www.lead.pollution.org

Lead can be found throughout the environment in which children live — in the air they breathe, the water they drink, the soil they walk and crawl on, the food they eat, the paint on the walls they touch, and even in some of the toys they play with.

3 SOURCES OF LEAD EXPOSURE

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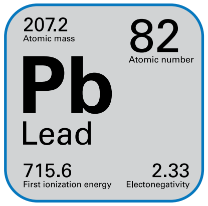

Lead is a naturally occurring element – a heavy metal – often denoted with the symbol Pb and atomic number 82. It is silvery with a bluish hue when freshly cut. It is denser than most common materials yet soft and malleable with a host of desirable chemical and physical properties, including a low melting point, corrosion resistance, conductivity, durability and the ability to form alloys with other metals. As such, it has been particularly useful for thousands of years and can be found in plumbing, batteries, construction materials, paints, glazes, gasoline additives, pewters, weights, ammunition, radiation shielding and cable covers.[1]

Sources of lead that result in exposures vary geographically. While lead occurs naturally in the environment, naturally occurring concentrations in air, water and soil do not pose significant human health risks.[2] Only as a result of human activity over the past few thousand years, including in mining and the use of lead in products, has it become more widely distributed and exposed people to harmful levels. Studies have shown that lead in the human body is now 500-1,000 times greater than it was in pre-industrial times.[3]

Today, unfortunately, lead can be found throughout the environment in which children live – including in the air they breathe, the water they drink, the soil they walk/crawl on, the food they eat, the paint on the walls that they touch, and even in some of the toys they play with. Lead enters the body through ingestion, through inhalation and through dermal contact.[4]

As there is no cure for lead poisoning, identifying local sources is a very important part of preventing exposure. In many cases, children are exposed to more than one source, making the challenge even more complicated. This is why source apportionment assessments, as well as comprehensive efforts to improve community knowledge, change risky behaviour, strengthen health systems and monitor blood lead levels, are critical to protecting children and preventing exposure.

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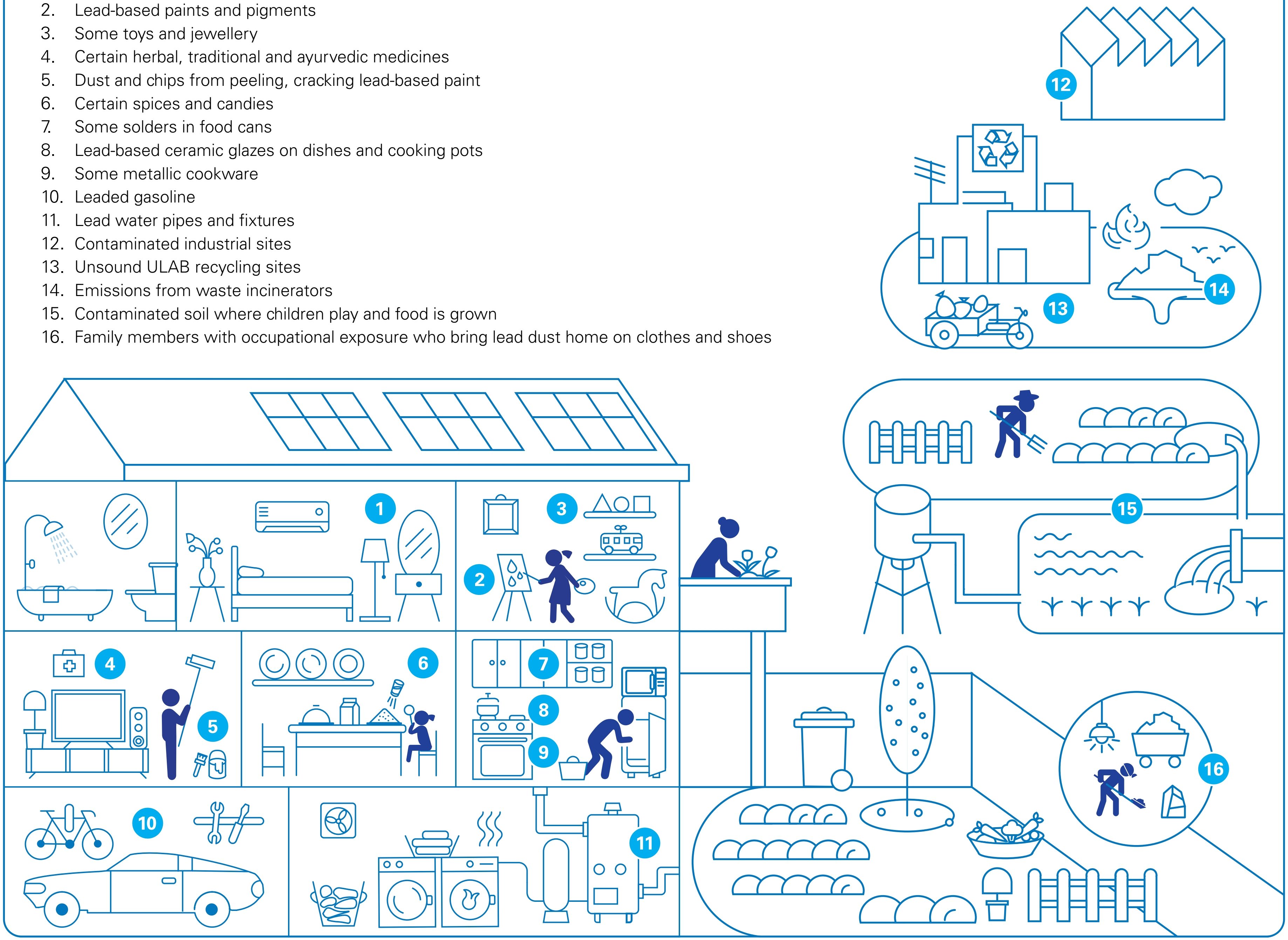
Figure 7 Where Lead Can be Found

1. Some traditional cosmetics
2. Lead-based paints and pigments
3. Some toys and jewellery
4. Certain herbal, traditional and ayurvedic medicines
5. Dust and chips from peeling, cracking lead-based paint
6. Certain spices and candies
7. Some solders in food cans
8. Lead-based ceramic glazes on dishes and cooking pots
9. Some metallic cookware
10. Leaded gasoline
11. Lead water pipes and fixtures
12. Contaminated industrial sites
13. Unsound ULAB recycling sites
14. Emissions from waste incinerators
15. Contaminated soil where children play and food is grown
16. Family members with occupational exposure who bring lead dust home on clothes and shoes



Note: The above infographic is an illustrative example only of likely sources of lead exposure. It is not meant to be fully comprehensive of all possible exposure pathways.

Lead-acid Batteries

Today, approximately 85 per cent of the lead used worldwide goes into the production of lead-acid batteries.[5] These batteries are used in traditional and electric vehicles, back-up power supplies for consumers, critical systems such as hospitals and telecommunications, and for green technologies, such as photovoltaic and wind turbine energy storage.[6] The demand for lead-acid batteries is growing rapidly, especially with the sheer increase in the number of vehicles in low- and middle-income countries, as well as in energy storage needs globally.[7] The ever-growing demand for lead has propelled prices for the heavy metal from $52.20 per metric tonne in 2005 to more than $106.96 in the last quarter of 2019.[8]

Between 2000 and 2018, the number of new vehicles sold in low- and middle-income nations more than tripled.[9] Altogether, propelled by rising rates of vehicle ownership in these nations, the number of cars, trucks and buses on the world's highways is expected to reach an estimated 2 billion in 2040.[10] Much of this increase in vehicle ownership, furthermore, has occurred in countries with warm and humid climates where batteries typically last only about two years, a rapid turnover that further accelerates the demand.[11]

Alternatives to Lead-acid Batteries

There are currently no readily available, economical and environmentally sound large-scale alternatives for lead-acid batteries, particularly for vehicles.[12] Nickel-cadmium (Ni-Cd) batteries, which are popular for some industrial applications, are much more expensive than lead-acid batteries because of the high costs of nickel and cadmium; Ni-Cd batteries have also been banned in the European Union because of concerns about the toxicity of cadmium. Nickel-metal hydride batteries, while growing in popularity for hybrid electric vehicles, are much more expensive than lead-acid batteries because of the use of expensive nickel and rare earth minerals. Lithium-ion cells are rapidly growing in popularity but are widely used in smaller batteries for portable electronics and at present are not practical for large vehicle batteries in part because of the cost of cobalt. Additionally, lithium-ion batteries with their high density and organic electrolytes are flammable.[13]

Almost all of the lead used in lead-acid batteries can be recovered and recycled.[14] In the United States and Europe, more than 95 per cent of the lead from used lead-acid batteries is recycled, where strict environmental regulations require that batteries be returned to the point of purchase or a collection centre for transfer to regulated recycling plants.[15] Since the closure of the last primary lead smelter in the United States in 2013, secondary lead production via recycling and residue recovery accounts for all of the lead produced in the United States and 74 per cent of the lead produced in Europe.[16] Legislation in the United States and European Union require that lead-acid batteries be recycled in regulated and monitored facilities with worker protections and environmental controls.

Many low- and middle-income countries, however, lack similar laws and the enforcement capacity necessary to ensure safe and environmentally sound ULAB recycling. As a result, an untold number of used lead-acid batteries are recycled in informal, uncontrolled and unregulated settings without the necessary processes and technologies to control lead emissions and prevent exposure of workers and surrounding communities.[17] Often, these activities are the principal source of livelihoods for poor families and communities. These informal recycling operations are often in backyards, where unprotected workers break open batteries with hand tools and remove the lead plates that are smelted in open-air pits that spread lead-laden fumes and particulate

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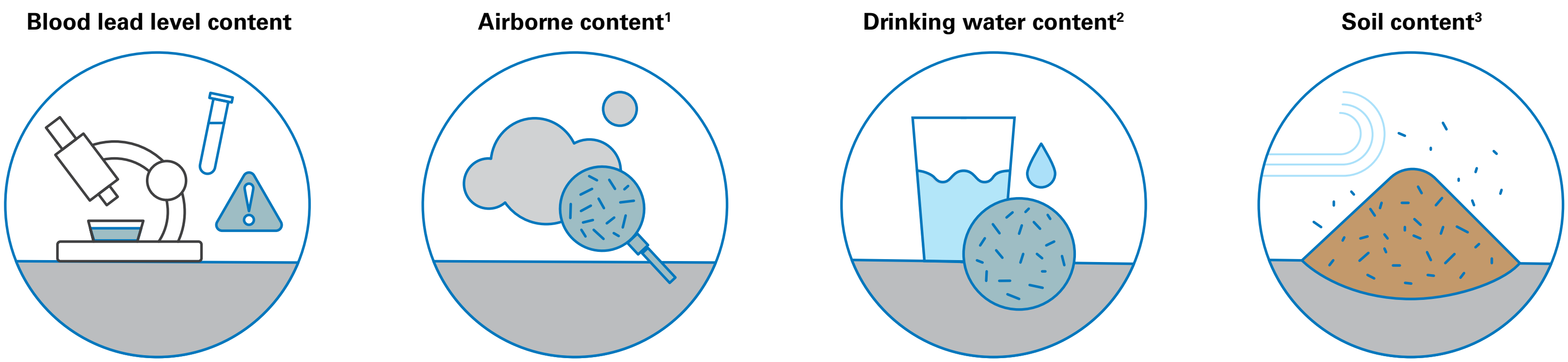
matter over wide swaths of surrounding neighbourhoods. Lead-laced acid from the batteries is often drained onto the bare ground or dumped directly into waterways, contaminating irrigation water and, ultimately, crops and fish.[18] Plastic battery cases are also frequently recycled, and, if inadequately washed, can contaminate other plastic items with lead.[19]

People, and especially children, living near recycling sites are at risk of lead exposure from the dust and fumes generated by the operations.[20] A 2011 literature review involving studies from 37 countries published from 1993 to 2011 found average blood lead levels in children living near lead battery manufacturing and recycling facilities to be 19 µg/dL – almost four times the US CDC reference level of 5 µg/dL requiring intervention.[21] Furthermore, the review found that workers had a mean blood lead level concentration of 64 µg/dL, with a range of 37.7 to 112.5 µg/dL. Airborne lead particles in these battery facilities were measured at an average of 367 µg/m^3, which is seven-fold greater than the US Occupational Safety and Health Administration's 50 µg/m^3 permissible exposure limit. Another comprehensive study in 2016 estimated there were 10,599 to 29,241 informal used lead-acid battery recycling sites in 90 countries.[22] The calculated mean BLL for exposed children (ages 0-4) at these sites was 31.15 µg/dL. The geometric mean BLL for adults was 21.2 µg/dL.

It is estimated that in Africa alone more than 1.2 million tonnes of used lead-acid batteries enter the recycling economy each year and much of that goes to informal operators.[23] Even formal battery recyclers have been known to pollute: breaking batteries with axes or machetes that expose workers to acid and lead dust and contaminate the surrounding areas and local watersheds with improperly stored lead.[24] While some secondary lead is used to make fishing weights and cookware, most of it does not meet purity requirements for battery production, and so is shipped to lead refineries primarily in Asia and Europe.[25] Soil samples taken from outside lead battery recycling plants across seven African countries, among them Nigeria, Ghana, Kenya and Tunisia, found lead levels that range from < 40 ppm to 140,000 ppm, with 81 per cent of soil samples having lead levels greater than 80 ppm and 64 per cent of samples having soil lead levels greater than 400 ppm.[26] By comparison, the US Environmental Protection Administration has established limits of 400 ppm for lead in bare soils in play areas and 1,200 ppm in non-play areas.

Figure 8



WHO and CDC state no safe level; CDC threshold for action 5 µg/L

0.5 µg/m3 (annual average)

10 µg/L

400 ppm (US EPA)

1. Air Quality Guidelines for Europe (2nd Ed) 2000 (https://www.euro.who.int/__data/assets/pdf_file/0005/74732/E71922.pdf) pg 152
2. Guidelines for Drinking-water Quality (First Addendum to the Fourth Edition) 2017. (https://www.who.int/water_sanitation_health/publications/gdwq4-1st-addendum/en/) pg 54
3. US EPA. 40 CFR Part 745, 2001 (https://www.govinfo.gov/content/pkg/FR-2001-01-05/pdf/01-84.pdf)

A 2013 study of China's lead-acid battery industry health hazards found that about 24 per cent of the 94,778 children tested between 2001 and 2007, after the phaseout of leaded gasoline in 2000, had blood lead levels that exceeded 10 µg/dL.[27] The study hypothesized that China's burgeoning lead-acid battery industry could be responsible for the persistently high blood lead levels among children and noted that China remains the world's leading producer, refiner and consumer of lead and lead-acid batteries.

Because ULAB processing is often the only means of livelihood for poor families and communities, improved regulations, guidance and good practices can go a long way to ameliorate conditions so that these facilities do not pose risks to the health and well-being of their workers and the surrounding communities.

ULAB Recycling Processes

In a typical automated enclosed process, the lead batteries are broken up in a hammermill or shredder and the pieces are fed into tanks filled with water. Here, gravity is used to separate the components: the lead and heavy materials sink to the bottom and the plastics rise to the top. The plastic materials are skimmed away and the liquid, including the sulphuric acid electrolyte, is drawn off. The metallic components are channelled to closed furnaces for smelting and refining and then piped into casting moulds. Waste from recycling is collected, treated and disposed of at a designated waste disposal site.[28]

Substandard manual processes, by contrast, release large amounts of lead particulate matter into the environment and pose greater risks to workers and communities. In a typical manual process, batteries are drained, then broken up with electric saws, machetes or axes. The components are separated by hand into piles. The lead components are carried to the furnace or taken on an open conveyer belt. The furnace may, in the worst case, be no more than an open pot on a fire. The molten lead is then poured into casting moulds. The electrolyte contains dissolved lead and, if the electrolyte leaks out or is poured onto the ground rather than into collection tanks, the lead becomes incorporated into soil particles, which subsequently become a source of lead dust.[29]

Toxic Sites Identification Program

Through its Toxic Sites Identification Program (TSIP), Pure Earth and its in-country investigators have identified 1,450 sites in over 50 countries where lead is the primary pollutant. Many children are directly affected by pollution from these sites, the vast majority of which are current and former smelters, mines and informal ULAB recycling operations. The site is publicly available at www.contaminatedsites.org.

The Toxic Sites Identification Program was established in 2005 to document polluted sites, collect data about pollution levels in air, soil and water, and correlate that information with effects on human health. Funded by the World Bank, UNEP, the European Commission, USAID and others, TSIP, with more than 4,000 listed sites covering a number of heavy metals and chemical contaminants, is recognized as the largest global inventory of toxic waste sites and is widely used by governmental and non-profit public health organizations to estimate toxic exposures and attendant health risks in specific population groups.[30]

Spices, Cosmetics and Toys

Lead can enter the supply chain at several different points. Spices grown near smelters, battery manufacturing plants and lead mines can absorb dust particles and remnants from these processes. Lead that is deposited in soil and water from airborne pollutants and fertilizer application can enter food systems and spices. Lead can also be part of the spice grinding machinery, contaminating foods that are put through it. In some cases, lead is added purposely to spices to enhance the colour and weight.

Given the interconnectedness of the global supply chain, lead in spices, cosmetics and toys in one country can affect children's lead exposure in another country. A US study of nearly 500 brands of infant formula and baby food found that over 30 per cent had detectable levels of lead.[31] There were a myriad of other contaminants present, too, such as arsenic, mercury, pesticides and acrylamides, among others. Another study found that more than 50 per cent of 1,496 samples of about 50 spices from 41 countries collected in New York had detectable levels of lead, with more than 30 per cent having concentrations greater than 2 ppm based on laboratory analysis.[32] The highest concentrations of lead were found in spices purchased in Georgia, Bangladesh, Pakistan, Nepal and Morocco. Another study in North Carolina, using data from 2011-2018, found that nearly 30 per cent of samples contained ≥1 ppm lead based on laboratory analysis.[33] The US Food and Drug Administration's action points at which an investigation is undertaken or recall is issued for products intended for consumption are 0.1 ppm for candy and 0.5 ppm for other foods.[34]

Moreover, the interconnectedness of the global supply chain works both ways: it can also mean waste, frequently electronic waste, is shipped from high-income countries to poorer countries for recycling and processing. Where safety standards and good practices in recycling these toxic materials are not in place, this poses risks to the communities involved in processing the waste. Pollution is inherently transboundary in nature and lead is no exception to this. Because of this, reducing exposure will require enhanced international cooperation.[35]

In April 2019, UNICEF reported the results of a nationally representative blood lead level survey in the Republic of Georgia, revealing that 41 per cent of children aged 2-7 had blood lead levels at or above 5 µg/dL; 25 per cent of the children had blood lead levels between 5 and 10 µg/dL; and 16 per cent had blood lead levels above or equal to 10 µg/dL. In three of the regions, more than 60 per cent of children had elevated blood lead levels, with one region, Adjara, reporting around 80 per cent of children tested with blood lead levels at or above 5 µg/dL and over 40 per cent with levels above 10 µg/dL.[36]

Turmeric

In Bangladesh, lead contamination of turmeric poses a significant health risk. Recently, Stanford researchers found lead-based adulteration in seven of the nine turmeric-producing districts.[37] Their evidence suggests manufacturers add lead to enhance the yellow colour consumers see as a sign of quality turmeric. Some concentrations exceeded the national limit by up to 500 times. Other studies have identified lead-contaminated spices in Pakistan, Libya, Poland, Ghana, Nigeria and Turkey. Given recent warnings about lead-contaminated spices exported to the United States from various origins,[38] this brief list of countries is not exhaustive.

Kohl

Traditional *kohl* or *surma* eyeliner worn by men, women and children in South Asian and African countries also has been found to contain high concentrations of lead despite regulatory efforts to remove lead-based makeup from world markets. Homemade kohl is still often made by grinding lead sulphide instead of the amorphous carbon or charcoal used by commercial manufacturers.[39] As much as half of the chemical composition of kohl may be lead sulphide.[40]

Toys

Toys, furniture and jewellery could contain lead-based paint or lead in the material from which it is made. In the United States, several recalls of toys have been issued over recent years, including 150 million pieces of metal toy jewellery in 2004 and 967,000 toys in 2007.[41] Other products that have been found to contain lead include crayons, chalk and clothing.

Lead has also been found in cosmetics and traditional remedies and ceremonial powders.[42] It is not possible to determine by looking at a substance whether it contains lead. Moreover, the sellers might not know if the products contain lead.

Lead can also be found in food. Contamination can happen in several points of the food chain.

According to the US Food and Drug Administration,[43] lead can enter our food supply, because:

- Lead in the soil can settle on or be absorbed by plants grown for fruits or vegetables or plants used as ingredients in food, including dietary supplements.
- Lead that gets into or on plants cannot be completely removed by washing or other food processing steps.
- Lead in plants or water may also be ingested and absorbed by the animals we eat, which is then passed on to us.
- Lead can enter food inadvertently through manufacturing processes. For example, plumbing that contains lead can contaminate water used in food production.
- Lead in pottery, storage containers, cooking pots and preparation surfaces can pass or leach into food or drinks.

Although the lead levels in the food supply decreased dramatically in the United States between the 1970s and the1990s, low levels of lead continue to be detected in some foods due to the continued presence of lead in the environment.[44]

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Folk Remedies and Cosmetics Known to Contain Lead[45]

- Ba-baw-san is a Chinese herbal remedy that contains lead. It is used to treat colic pain or to pacify young children.
- Daw Tway is a digestive aid used in Thailand and Myanmar (Burma). Analysis of Daw Tway samples showed them to contain as much as 970 parts per million (ppm) of lead, not to mention high arsenic levels (as high as 7,100 ppm).
- Greta and Azarcon (also known as alarcon, coral, luiga, maria luisa or rueda) are traditional Hispanic medicines taken for an upset stomach (empacho), constipation, diarrhoea and vomiting. They are also used on teething babies. Greta and Azarcon are fine orange powders with lead content as high as 90 per cent.
- Ghasard, an Indian folk medicine, has also been found to contain lead. It is a brown powder used as a tonic.
- Sindoor, a traditional red or orangish red cosmetic powder worn by women on the Indian subcontinent, can contain lead.

Case Study: Tbilisi, Georgia

Proudly pacing around the living room in fluffy pink bunny slippers, Barbare, aged 4, was eager to complete her outfit by adding some children's lipstick and sparkly nail polish. But her mother told her 'no'– fearing that using such substances would only do more harm than good for the girl who already had alarmingly high levels of lead in her blood.

In 2018, after discovering anecdotal evidence of high blood lead levels among Georgian children, UNICEF Georgia designed and, jointly with the National Statistics Office, conducted the country's largest nationally representative survey of the problem to date. The study, integrated in the Multiple Indicator Cluster Survey (MICS), collected more than 1,570 venous blood samples from children 2-7 years old.

Samples were sent to the Italian National Institute of Health in Rome and tested for toxic metals.

The results were alarming. Around Georgia, 41 per cent of children were found to have blood lead levels equal to or greater than 5 µg/dL - about ten times higher than the prevalence found in higher-income countries.[46] About 25 per cent of children had blood lead levels between 5 - 10 µg/dL while 16 per cent had blood lead levels greater than or equal to 10 µg/dL. Increased BLLs also strongly correlated with Wealth Index Quintiles, indicating social inequality aspects of the problem. The data presented below is from a nationally representative study measuring blood lead levels among children.

"I was completely shocked," said Giuli Zoidze, Barbare's mother.

"My first fear was that I was told that it hinders development," she said, adding that she had already noticed that Barbare had started talking quite late. Barbare's brother was born with cerebral palsy.

In the Adjara region of western Georgia, around 80 per cent of the children tested had blood lead levels higher than 5 µg/dL, with 50 per cent reporting BLLs of 10 µg/dL or more.

Dr. Irma Chikvaidze, a paediatrician at Lashvili Clinic in Batumi, the capital of the Adjara region, said that when the results first came out, little was known about the problem or its causes.

“We had some theoretical knowledge about it; that was all,” Dr. Chikvaidze said. “Everyone I know wanted to get tested.”

Georgia does not have a single public laboratory for such testing, and samples have to be sent abroad. Each test costs 120 lari ($42 USD), too expensive for most locals to afford, Dr. Chikvaidze said.

To tackle the problem, UNICEF developed a three-phase strategy.

“The first phase was understanding the problem, which was done through the MICS survey,” said Dr. Ghassan Khalil, UNICEF Representative in Georgia. “The second was to search for the sources and pathways (of lead contamination). Work on the third phase has already begun – the development and implementation of a national response plan.”

The strategy was endorsed and wholly adopted by Georgia’s Prime Minister, who officially requested UNICEF’s support. “We praise the government of Georgia for starting this and continuing the work,” he said.

“We felt there was a moral responsibility to continue, and this was nurtured by the very strong partnership we have with the National Centre for Disease Control (NCDC),” Dr. Khalil said.

UNICEF mobilized numerous other partners to work on the issue and received initial funding for the search for sources from the Estonian Embassy in Tbilisi, while the government provided the goodwill and readiness to acknowledge the problem and begin to work on a response straightaway, Dr. Khalil said.

Children and family members with elevated lead levels received all-inclusive medical attention free of charge. With improved nutrition and multivitamin supplements, children's BLLs improved substantially, with some reporting declines in lead concentrations of 40 to 50 per cent.

Yet, further challenges remain. Today, UNICEF, NCDC and partners are in the process of establishing a laboratory. UNICEF is planning to support the government in designing and establishing an environmental health surveillance system to collect data on pollution, human exposure to such pollutants and the prevalence of related diseases.

With time, NCDC would also like to develop the capacity to test for lead levels inside private homes, said Dr. Lela Sturua, head of the non-communicable diseases department in NCDC.

NCDC has developed a strategy plan 2020-2030 to address the issue of lead, while the Georgian government has already begun rolling out new regulations for toys, enforcing construction standards for kindergartens and providing full governmental funding for lead testing for every child if referred by a doctor, among other measures, Sturua said.

Doctors across the country have also received training to treat potential cases.

Dr. Chikvaidze and other medical personnel underwent three training modules in order to sharpen medical responses and pass on the knowledge to colleagues.

“Children with developmental issues are now being referred for lead tests,” Dr. Chikvaidze said.

“Now that I think about all the cases [of slow development] I couldn’t solve – maybe there is an explanation,” she added.

“In the meantime, the advice to families who are concerned is to wash hands, wash children’s toys, take care of the areas where children play and be careful in using certain spices,” NCDC’s Dr. Sturua said.

“I think we got lucky to be part of this survey because now we get special attention,” said Zoidze, Barbare’s mother. Other mothers in her daughter’s kindergarten now approach her for advice about how to protect their children.

Yet, the problem is far from solved, she says.

“Here, out of 40 families in the village, only one child was tested," said Zoidze. "I think there are more cases.”

Next Steps

UNICEF Georgia is embarking on a two-pillar project to scale up action:

Pillar 1: Conduct a study of the sources of lead exposures. The study of lead exposure sources was commenced by cross-sectional statistical analyses of blood lead level data and dozens of socio-economic and health indicators, which were collected along with venous blood samples.

Pillar 2: Build data, policy, regulatory and technical capacity to effectively combat prevalence of lead. UNICEF is supporting the government to elaborate a comprehensive, intersectoral, multi-year strategy and action plan. It includes allocation of needed resources from the state and local budgets, defining responsibilities and powers of relevant agencies considering OECD-wide best practices, as well as transposition of EU New Approach directives and regulations on food/ product safety and packaging, market surveillance and conformity assessment.

UNICEF and the government of Georgia have already taken the first steps to raise public awareness about the toxic effects of lead and have provided households with information about actions families can take to lower their risks. Medium- to long-term measures to effectively and sustainably address exposure to lead and other pollutants include the following:

1. ***Prevent market circulation of lead-contaminated products and materials,*** such as contaminated toys, spices, etc. by priming Georgia's technical and construction supervision and food and environmental agencies to properly control lead and other pollutants.

2. ***Identify, control and remediate hazardous sites*** such as landfills, battery recycling sites and lead-contaminated fields where animals graze or children play, etc.

3. ***Establish an environmental health surveillance system*** allowing systematic monitoring of product or environmental contamination, population exposure levels and associated disease burden. This will help the government to continuously readjust its interventions to existing and emerging challenges in the field of environmental health. This includes using existing systems to build on the country's future environmental health surveillance.

Figure 9 Prevalence of BLL ≥ 10 µg/dL by Wealth Index Quintile

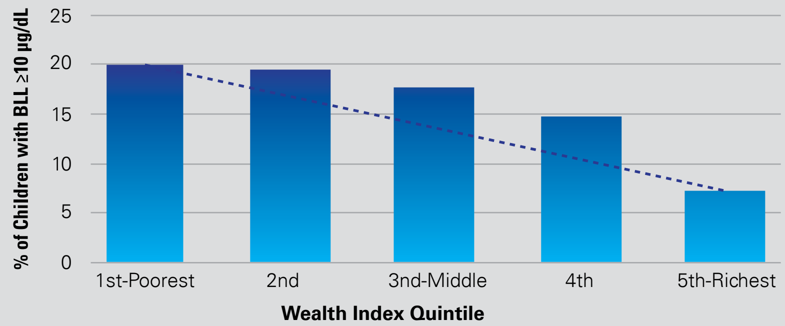
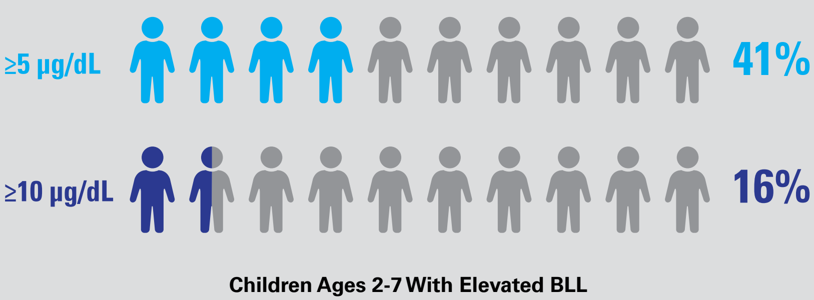


Figure 10 Percentage of Georgia Children with Elevated BLLs



Source: Andria Nadiradze, UNICEF Georgia

Ceramics and Cookware

Lead is often used in ceramics and cookware as a glaze, protecting the earthenware from corrosion over time. Leaded glazes provide a lustrous waterproof coating and have been traditional in many cultures. Originally brought to the Americas from Spain in the mid-1800s, leaded glazes have been in continuous use in traditional pottery in Mexico and elsewhere.[47]

However, using lead glaze presents a very large risk, especially when utensils are used in the preparation of food. Lead can easily leach from ceramic glazes and into food when fired at low temperature. Wood-fired kilns used by most artisanal potters often do not reach the fusing/sintering temperatures necessary to vitrify lead glazes to prevent lead from leaching into food.[48] Additionally, many of the potters work in and around their homes, exposing their families, and particularly young children, to lead dust. Acidic foods, such as lime and tomato juice, and high-heat cooking also cause lead to leach more readily from the pottery and cookware into meals and beverages.[49] In many low- and middle-income countries, locally-made aluminum cookware is common. Informal artisans use scrap metal from products such as waste engine parts. vehicle radiators, lead batteries and computer parts.[c] Consequently, whatever metals are present in this scrap will be incorporated, including lead, cadmium and even arsenic. Lead has also been found to migrate from cans into canned vegetables, despite the presence of internal coatings.[50]

In studies conducted in Mexico, soil sampling and blood lead level testing of children found high levels of exposure at home-based pottery workshops. Eleven children who lived in homes where pottery was made with lead glazes had an average blood lead level of 26.4 µg/dL.[51] Soil around the workshops, meanwhile, had a mean concentration of 1,098.4 ppm[52] -- more than two and a half times the level deemed acceptable for areas where children play by the US EPA.[53] Another recent health survey conducted by the National Institute of Public Health (INSP) in Mexico reveals that at least one million children between 1 and 4 years of age (representing 22 per cent of the study population) have elevated blood lead levels above 5 µg/dL.[54] When data from other areas of the country are analyzed, the number of children confirmed with elevated blood lead levels will most certainly go up, according to Daniel Estrada, head of Pure Earth Mexico and one of the co-authors of the report. They estimate that, based on extrapolation from the site assessments and including children under 14 years of age, approximately 13 million children have elevated blood lead levels as a result of lead-based glazing on ceramics and cookware.

The problem, however, is not unique to Mexico and Central America. In Cameroon, lead recycled from used lead-acid batteries also makes its way into cookware in the form of aluminium-lead alloys. The "macoccote" pots are widely used in homes, restaurants and open-air food stalls.[55]

c. Jeffrey D. Weidenhamer, Meghann P. Fitzpatrick, Alison M. Biro, Peter A. Kobunski, Michael R. Hudson, Rebecca W. Corbin, Perry Gottesfeld,"Metal exposures from aluminum cookware: An unrecognized public health risk in developing countries." (*Science of The Total Environment*, Vol 579, 2017) https://doi.org/10.1016/j.scitotenv.2016.11.023

Case Study:
Various Locations, Mexico

The main sources of lead exposure in Mexico include lead-glazed pottery/ceramics, metallurgical industry and mining. A study in the Mexico City area found a mean BLL of 2 μg/dL among children 1-5 years of age in 2008 to 2015, with 8 per cent of children having BLL > 5 μg/dL.[56] Outside of Mexico City, a measurement study was undertaken in 2018 of children ages 1-4 years in locations with less than 100,000 inhabitants. About half of children in Mexico in this age group live in such locations. The study found a mean BLL of 3.3 μg/dL with 22 per cent of the children having BLL > 5 μg/dL.[57]

Geographic-specific studies have found high BLLs in the last decade. A study in 2011 in two public schools in a small town in Morelos with no obvious source of lead from industry or mining found a mean BLL of 7.23 μg/dL.[58] The mean BLL among children 4 to 9 years old in a pottery-making community in the state of Tlaxcala was as high as 19.4 μg/dL in 2008-09.[59] Studies conducted between 2001 and 2009 found BLLs among children in communities with or near metallurgical industry and mining areas in the range of 6-11 μg/dL. More recent studies have confirmed that households continue to use lead-glazed ceramics, causing elevated BLLs. A study of 300 randomly selected mothers and newborn infants in Morelos in 2015 found that as many as 57 per cent of the families surveyed were using lead-glazed ceramics at least once a month.[60]

Based on the available information, a forthcoming report from the World Bank[61] estimates that children under 5 years of age in Mexico lost a total of 1.5 – 8.9 million IQ points in 2018, with a central estimate of 3.8 million. About 85 per cent of these annual losses are among children with a concurrent BLL of less than 5 μg/dL at the age of 5 years. Among adults, lead exposure caused 4,600 – 5,600 premature deaths in 2018, with a central estimate of 5,105. In addition, an estimated 9,000 – 11,000 disability adjusted years were lost from non-fatal cardiovascular and chronic kidney disease due to lead exposure, corresponding to 104-128 million days lived with illness.

As indicated by the accompanying table, lead exposure results in costs that are estimated to be equivalent to between 0.74 per cent and 2.68 per cent of GDP, with a central estimate of 1.37 per cent. The effects caused by lead exposure on children's intellectual development represent the largest share of these costs.

Table 2 Estimated Health Effects and Costs of Lead Exposure in Mexico, 2018

	Low	Central	High
Present value of future lifetime income (15-64 years) (MX$)	5,509,432	5,509,432	5,509,432
Lifetime income loss per IQ point lost (% of lifetime income)	1.66%	1.66%	1.66%
Labour force participation rate (15-64 yrs.)	65%	65%	65%
Cost per lost IQ point (MX$)	59,543	59,543	59,543
IQ points lost per year	1,530,526	3,838,340	8,876,783
Total cost of IQ losses (MX$ billion)	**91**	**229**	**529**
Total cost of IQ losses (% of GDP, 2018)	**0.39%**	**0.97%**	**2.25%**
Annual deaths from adult lead exposure	4,594	5,105	5,615
Estimated days of Illness from adult lead exposure (millions)	104	116	128
Cost of increased mortality of adult lead exposure	78.2	86.8	95.5
Cost of increased morbidity of adult lead exposure	4.8	5.3	5.8
Total cost of health effects of adult lead exposure (MX$ billion)	**82.9**	**92.2**	**101.4**
Total cost of health effects of adult lead exposure (% of GDP, 2018)	**0.35%**	**0.39%**	**0.43%**
Total costs (% of GDP, 2018)	**0.74%**	**1.37%**	**2.68%**

Source: The World Bank[62]

Pure Earth investigators have also found high levels of contamination from lead-glazed pottery in Morelos. At ceramics workshops, an average of about 1,098 ppm of lead was found in the soil, more than two and a half times the US EPA limit of 400 ppm, was common. The average blood lead level for children of ceramicists, 8 years and younger, was 26.4 µg/dL. Researchers estimated that those children could lose between 7 and 8 IQ points because of lead exposure.[63]

Throughout the country, Mexico's penchant for the traditional artisanal pottery made with lead glazes has been a persistent source of lead exposure -- despite educational campaigns warning of the dangers. Testing by the Instituto Nacional de Salud Publica found that about 14 per cent of the children tested, ages 1 to 4, had blood lead levels at or above 5 µg/dL with 3.2 per cent greater than 10 µg/dL. About 15.5 per cent of pregnant women tested had blood lead levels at or above 5 µg/dL.[64]

Pure Earth worked with the National Institute of Public Health to test the blood lead levels of 300 mothers and their newborns in the state of Morelos in 2015. During the screenings, a newborn was found with an astoundingly high blood lead level of 40 µg/dL -- eight times the CDC reference dose of 5 µg/dL, and a level far above that at which developmental toxicity, metabolic changes and cognitive damage occur.[65] Researchers pinpointed the family's use of lead-glazed cookware as the source of the baby's lead poisoning and worked quickly to educate the family about the dangers and to remove the contaminated pottery. The baby's blood lead level decreased to 13 µg/dL after the family stopped using lead-based pottery. A year later, the blood lead levels for the baby and his mother had declined 90 per cent. The child achieved major developmental milestones and was, at last encounter, a healthy kindergartener.[66]

In addition to the blood lead level and soil testing, Pure Earth's Barro Aprobado project conducts lead-free workshops for potters and seeks to raise awareness about the dangers of leaded pottery and works with the hospitality industry to drive demand for lead-free pottery. This work has been supported by industry as well; the world's largest lead-acid battery manufacturer has provided technical, coordination and governmental access support to the program.

Lead-based Paints and Pigments

Lead paint is another key source of exposure. Even though the harmful effects of lead in paint have been documented since at least the 1890s, only 73 countries, or 38 per cent of the world's nations, had legally binding controls to limit the production, import and sale of lead paints, as of September 30, 2019.[67] Even in countries that have taken steps to ban leaded paint, such as the United States and many European nations, lead-based paint is a continuing health hazard due to the deterioration of existing lead paint on walls and surfaces.

Lead is added to paint to increase drying capacity and durability, as it resists moisture and helps prevent corrosion.[68] Children can be poisoned if they chew on surfaces coated with lead-based paint, such as windowsills and door edges.[69] It is especially dangerous to children because it tastes sweet, and when lead paint peels and cracks over time, it creates flakes and dust which children can ingest. Toys painted with lead-based paints also can taste sweet, which further encourages children to mouth them.[70]

In the United States, lead paint for household use was banned in 1978.[71] In 2007, the European Union passed EU REACH, which restricts imports and the use in manufacturing of certain specific lead compounds for use in paints.[72] Individual EU countries acted even sooner. France passed legislation in 1948 providing the complete ban of white leaded paint for household use, and in 2000 Denmark restricted the marketing and import of lead paint.[73]

Despite international efforts to eliminate lead paint globally, many countries still lack regulations. Current regulations on lead paint also do not necessarily prohibit its sale, manufacture, or trade entirely.[74] Most countries with controls for lead paint regulate its manufacture export, import and sale. However, eight countries with lead paint controls do not regulate the manufacture of lead paint, 17 do not regulate exports, 10 do not regulate lead paint imports and eight do not regulate the sale of lead paint.[75] Architectural and decorative paints still contain significant concentrations of lead, while "industrial" paints generally have lead concentrations that are up to 10 times greater.[76] For example, road-marking paints can contain up to 20,000 ppm lead.[77] As of 2015, an increasing number of countries, including Cameroon, China, Ethiopia, India, Israel, Kenya, the Philippines, Tanzania and Thailand have put in place laws on lead paint for industrial uses.[78,79]

More countries need to take action to stop the manufacture and sale of lead paint. By ceasing the use and manufacture of all lead-based paints, countries can prevent significant and long-term sources of lead contamination for future generations, while continuing to mitigate and remediate legacy sources of lead paint on older homes and buildings. In the United States, for example, the 2006 American Healthy Homes Survey found that up to 37.1 million homes (34.9 per cent) had lead-based paint somewhere in the building of which 23.2 million (21.9 per cent of all homes) had one or more lead-based paint hazards.[80] The US CDC reports that 24 million homes have significant hazards; nearly 4 million of these are homes with young children.[81]

A comprehensive international initiative to promote the phase-out of lead in paint is being led by WHO and UNEP and chaired by the US EPA. *The Global Alliance to Eliminate Lead in Paint* promotes model laws and guidelines to regulate lead levels in new paint to governments around the world. It is modeled after the successful Partnership for Clean Fuels and Vehicles, which helped eliminate leaded gasoline.

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Case Study: Pesarean, Tegal, Indonesia

For the past several decades, metalworking fed families in the village of Pesarean in the Tegal Regency on the island of Central Java, even as the smelters and factories contaminated homes, school yards, public streets and a cemetery with lead and other heavy metals. In the late 1970s, as plastics began to replace some of the metal products made in Pesarean, metalworkers began recycling used lead-acid batteries and smelting the recovered lead for resale, often working in their homes or yards, unaware of the danger to themselves and their families.[82] With no designated disposal sites, recyclers dumped slag from lead smelting in a mound in the middle of the village, creating an enormous toxic site of lead-infused charcoal ash and metal waste. Children played in the slag piles and walked through them to school; residents tracked lead dust into their homes and shops while breezes wafting through the village carried lead particles out from the village center.[83]

In 2010, the Government of Tegal Regency created an industrial zone one kilometre outside of Pesarean for smelting activity. The remaining informal smelters moved to the zone where they have set up a co-op and work in open sheds outside a formal lead smelting factory.[84]

However, the massive slag heap in the center of the village remains a source of intense lead pollution. Lead levels in soil samples tested by Pure Earth have measured at more than 54,000 ppm in some areas.[85] Blood lead levels, too, have been consistently elevated, even dangerously so.[86]

A 2011 Mer-C study found that 88 per cent of 400 adults tested had blood lead levels about of 10 µg/dL and 16 per cent had blood lead levels at or greater than 45 µg/dL,[87] the level at which the US Centers for Disease Control recommend urgent medical intervention with chelation therapy. A 2013 study of women of child-bearing age found an average blood lead level of 28 µg/dL among the women, with a maximum BLL of 45.8 µg/dL.

In 2015, with support from the Asian Development Bank (ADB), Pure Earth began a project to identify lead-contaminated sites in and around Pesarean and to assess the risk to the community. After hosting focus groups with former smelter owners, workers and their female partners, Pure Earth conducted blood lead level sampling of residents who lived near former smelters. Of the 46 people tested, 41 per cent had blood lead levels at or greater than 45 µg/dL.[88] Although no blood samples were taken from children, Pure Earth investigators heard repeatedly from parents and school administrators that children were struggling with their schoolwork. Several reported overt physical deformities and mental handicaps, as well as developmental delays. With support from the Danish aid agency (DANIDA) in 2016, Pure Earth developed a remediation plan for the village.[89]

In an effort to mitigate the risks from lead contamination, the government of Indonesia, at both national and sub-national levels, has taken action to respond to the crisis. In 2018, the first phase of a clean-up of a village school yard with high concentrations of lead in the soil was completed. Government officials are currently working on the next phase of the remediation plan.[90]


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Leaded Gasoline

Tetraethyl lead was used extensively to improve engine performance in automobiles from its market entrance in 1923.[91] Between 1926 and 1985, 7 million tonnes of lead was combusted as gasoline additive in the United States.[d] As a result, lead particulate matter was released into the air and became a major historical source of lead exposure for both children and adults. However, once it became clear to scientists and policymakers that leaded gasoline posed significant risks, most countries successfully phased out the product, resulting in a dramatic reduction of blood lead levels across the globe. In the United States alone, the geometric mean of blood lead levels dropped from 12.8 μg/dL in 1976 when the phase-out of leaded gasoline began, to an average today of less than 1 μg/dL.[92] The United Nations Environment Programme *Partnership for Clean Fuels and Vehicles* reported in May 2019 that only Algeria has not enacted legislation banning leaded gasoline.[93]

© Envato Elements

d. Nriagu, Jerome O. "The rise and fall of leaded gasoline," (Science of The Total Environment,Vol 92,1990): https://www.sciencedirect.com/science/article/pii/004896979090318O

Lead in Soil

Lead can be found in soil and dust, especially where activity relating to lead operations has taken place, such as industrial operations, smelting or ULAB recycling. Areas where pesticides containing lead arsenate was used and land where coal ash has been dumped often are contaminated with lead residue. High levels of leaded soil can be found where leaded paint used on houses has chipped, flaked and peeled into the soil. Moreover, while lead is no longer used in gasoline, years of deposits from its use, as well as industrial sources, may still contaminate soil. Artificial turf playing fields may also contain potentially unhealthy levels of lead dust, especially older ones that are exposed to weather and are more likely disintegrate.[94]

Lead residue from the combustion of leaded gasoline remains in the environment in very large quantities, especially in urban areas and around highways.[95] A study in the United States found that soil near building foundations and next to streets plural have higher lead content than soils in the middle of yards or playgrounds, due to the exposure to building debris containing leaded paint and to traffic emissions.[96] A review of soil contamination in China from 1979-2016 shows the patterns of soil contamination changing together with the economic development of the country, policies on leaded fuel and coal burning patterns.[97] In China after the use of lead in gasoline was banned in 2000, coal burning remained a major source of soil contamination.

When lead is added to the soil surface, it tends to accumulate in the upper 1 to 2 inches of soil unless the soil has been disturbed by activities such as excavation or tillage. Added lead also will become most concentrated in very fine soil particles, which tend to stick to skin and clothing and form airborne soil dust, constituting another exposure route for humans.[98]

The other exposure route is the consumption of food grown in contaminated soil. However, the availability of soil lead depends on how tightly it is held by soil particles and on its solubility. At low soil pH (pH<5, acidic conditions) lead is held less tightly and is more soluble. At near neutral or higher pH (pH>6.5, neutral to basic conditions) soil lead is held more strongly and its solubility is very low. Lead is held very tightly by organic matter, so as organic matter increases, lead availability decreases.[99]

Where soil is known to be contaminated, it is important to prevent children from playing in it or accessing it altogether, and to avoid using the soil for any kind of fruits or vegetables meant for consumption. It is often recommended to plant grass on areas of bare soil or to cover the soil with seed, mulch or wood chips, if possible.[100] A common conventional remediation for lead-contaminated soil is to dig it up, haul it away to a landfill and then truck in "clean" soil mined from elsewhere. Other remediation techniques involve capping the soil with grass or concrete. There are also bio-redmediation routes. Bioavailability of lead in soil can be decreased by increasing the pH of the soil, i.e. by adding phosphorus or iron and then covering with grass or other types of vegetation that act as hyper-accumulators of lead.[101]


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Lead in Water

Lead in drinking water, most commonly from decaying or corroding pipes and fixtures or from solder that connects pipes, continues to be a risk. Installation of lead pipes in the United States on a major scale began in the late 1800s, particularly in the larger cities. By 1900, more than 70 per cent of cities with populations greater than 30,000 used lead water lines. Although lead was more expensive than iron (the material of choice until that time), lead pipes had two significant advantages over iron ones: they lasted much longer than iron (about 35 years compared with 16) and, because lead is more malleable, the pipes could be more easily bent around existing structures.[102] The degree to which lead dissolves into water depends on the temperature, pH, and time that water has been in touch with corroding lead pipes.[103] In the United States, an estimated 6.1 million homes still use lead pipes.[104]

Countries should include strict parameters on lead in their drinking water quality standards.The World Health Organization provides a provisional guideline value of 10 µg/L in drinking water for analytical purposes, but, in regard to health, the organization suggests lead levels should be as low as possible.[105] Canada has updated the drinking water guideline to reduce the maximum acceptable concentration as low as possible, but to a maximum of 5 µg/L.[106] The US Environmental Protection Agency has a zero-exposure limit.[107]

The long-term solution to eliminating the source of exposure is replacing pipes. However, replacing the pipes and mains of entire water systems is very expensive and in lower-income countries might be prohibitive. Hence, water providers can introduce additives (orthophosphate and pH) that reduce the corrosion of pipes and over time reduce the likelihood of lead getting into the water as it passes through the customer's service line, indoor pipes and plumbing to the faucet.[108]

Drawbacks to using orthophosphate include the ripple effects of adding this nutrient into the larger water supply that, under the right conditions, can set off a chain of problematic events such as accelerating the growth of algae. Areas of intervention can include the regulation and the capacity of service providers to manage the lead-related risks of drinking water safety.[109]

On the user side, mitigation strategies can be promoted, such as using cold tap water for drinking and cooking, as well as letting water run for a few minutes before collecting it.[110]

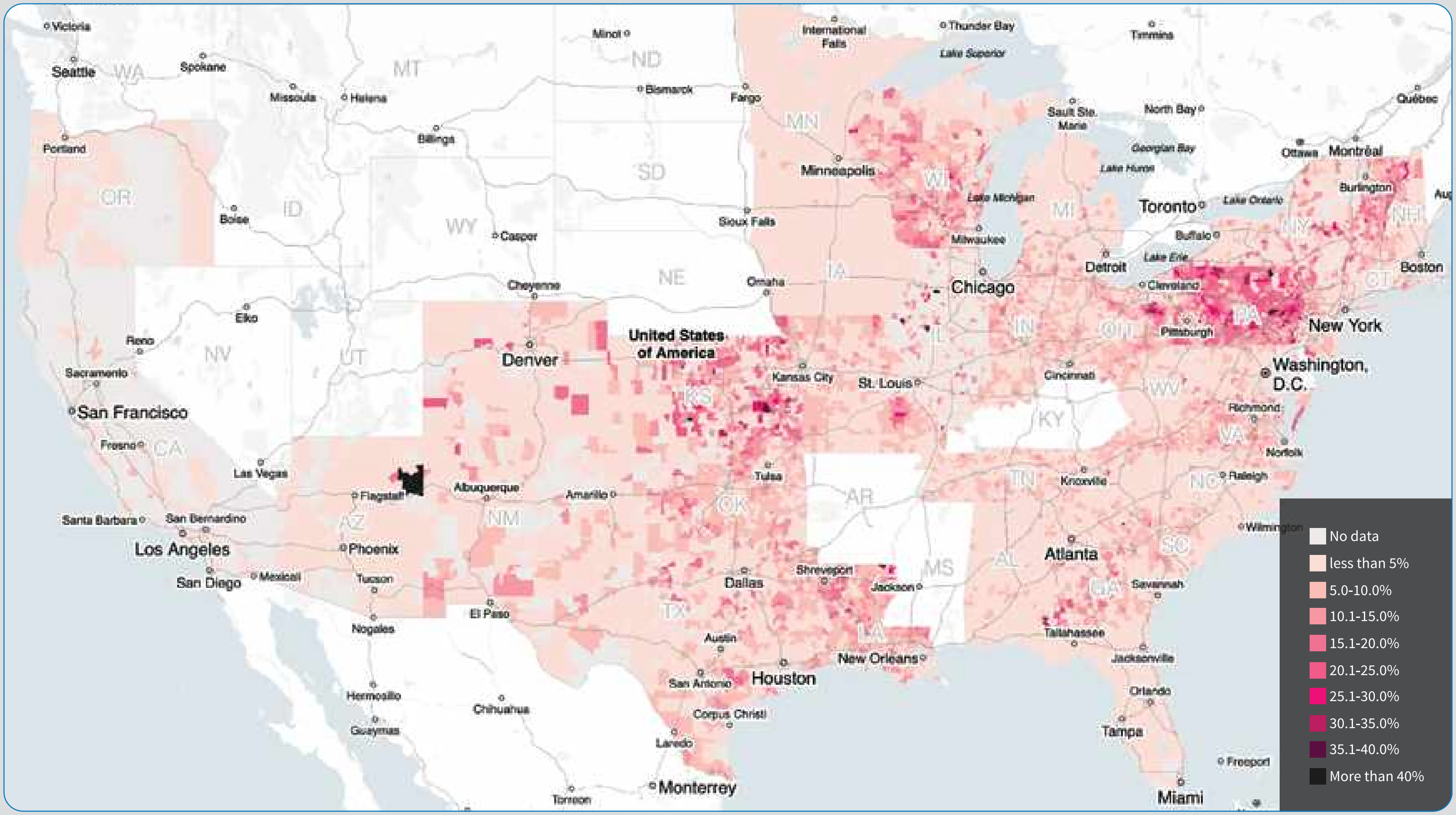
Case Study:
Flint, Michigan, US

In Flint, Michigan, public water supplies were found to contain high levels of lead after the city switched water sources from Lake Huron to the Flint River. The river water, which contained more corrosive minerals, began to rapidly erode aging lead pipes. The water in one home tested contained 13,200 ppb of lead, more than two and half times the level of lead that could be classified as "hazardous waste" by the US EPA.[111] Average blood lead levels for children under 5 years, which had been declining steadily since 2006, spiked during the crisis with an estimated increase in mean blood lead levels of 0.5 ug/L and an increased likelihood of a child presenting with a blood lead level greater than 5 ug/L by a factor of 1.91-3.5.[112]

Since the 1970s, efforts to reduce lead in paint, gasoline, water, yards and even playgrounds have resulted in considerable success in reducing blood lead levels amongst children in the United States. Nationwide, only 2.5 per cent of children under 5 are estimated to have elevated levels. Studies found, however, that among children tested in Flint, Michigan, 5 per cent had elevated blood lead levels above 5 µg/dL – double the national average – during the crisis, with some children and residents experiencing more severe poisoning.[113]

The challenges are not limited to Flint, Michigan. A 2017 investigation by Reuters,[114] which examined lead testing results across 34 US states and the District of Columbia, found that 3,810 neighbourhoods and areas have poisoning rates that are far higher than those in Flint and in some cases are at least double those measured during the peak of city's water crisis. About a third of these areas have poisoning rates that are four times higher. In some areas, up to 30-40 per cent of surveyed children are living with blood lead levels that are above the CDC threshold of 5 µg/dL. The map in Figure 11, produced by the Reuters investigation, indicates lead poisoning that exceeds limits by county. The data has been obtained by local health authorities and the CDC, providing a granular assessment of exposure rates of children. While progress across the United States in reducing childhood lead exposure has improved markedly over recent decades, progress has been very uneven, with many neighbourhoods and children still at risk for high exposures to lead.[115]

Figure 11 The Thousands of US Locales Where Lead Poisoning is Worse than in Flint, Mich.[116]



© Mapzen, OpenStreetMap, and others

Source: https://www.reuters.com/investigates/special-report/usa-lead-testing/

Electronic Waste

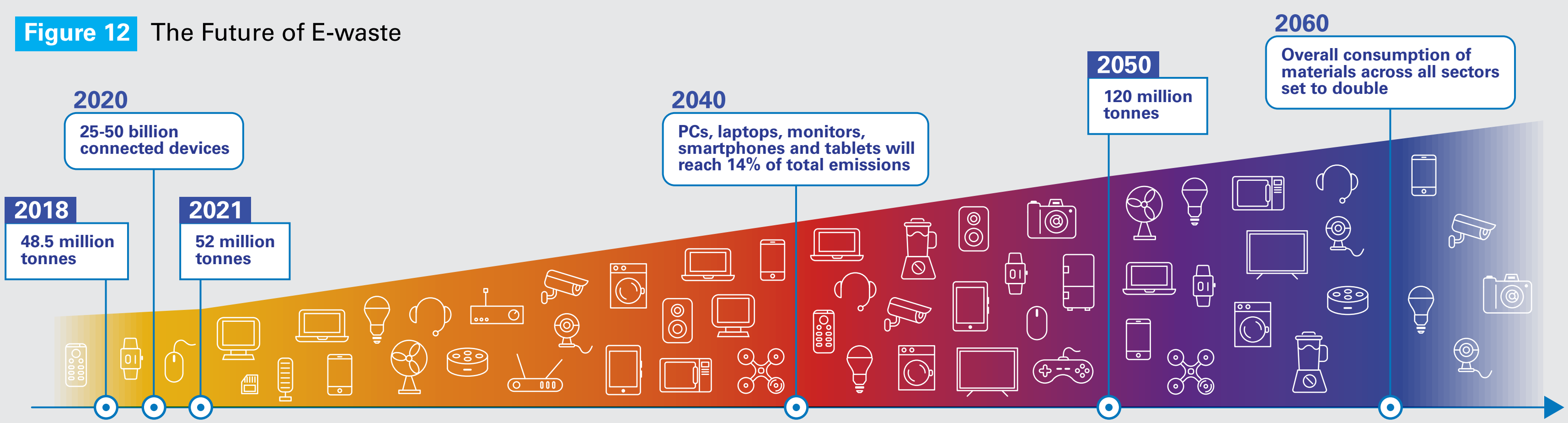
E-waste is currently the world's largest growing form of waste.[117] E-waste (or 'electronic waste') refers to anything with a plug, electric cord or battery[118] that has been used and disposed as waste. E-waste includes computers, televisions and mobile phones, among other electronic devices. The world currently produces up to 50 million tonnes of e-waste per year. By comparison, 50 million tonnes is equivalent to 125,000 jumbo jets, which is more than all the commercial aircraft ever created.[119] It is projected that e-waste could top 120 million tonnes per year by 2050.[120]

It is hazardous, complex, and expensive to safely recycle or dispose of e-waste. Approximately 80 per cent of e-waste is shipped to low- and middle-income countries, often illegally,[121] where thousands of informal workers, often including children, pick through, dismantle and/or burn the e-waste to obtain valuable metals and materials. These practices expose them to toxic substances, including, but not limited to, lead. The poorest residents are usually the most affected in these informal recycling industries, which typically have limited workplace protections.[122] Moreover, children living near these sites[123] are forced to breathe air that is toxic as a result of the burning of e-waste and dust that has been swept up in the wind, to eat food that may have been grown in contaminated soil, and to drink water which is potentially full of harmful chemicals from e-waste sites.

Along with lead, there are dozens of valuable materials embedded in e-waste, including gold, copper, nickel, indium and palladium.[124] Up to 60 elements in the periodic table can be found in e-waste.[125] Lead is found in multiple different forms of e-waste, including many of the older products, such as lead-lined cathode ray tubes in old TVs and computer circuit boards.[126] Additionally, lead is still commonly added to plastic electrical wire insulation to improve durability. The lead content in electrical wires often ranges up to 4,000 ppm. Burning the plastic wire generates high quantities of lead-containing smoke. Other techniques used to obtain the materials, such as melting down e-waste in open pots or dissolving circuit boards in acid, can cause severe toxic exposure.[127]

On average, every person in the United States and Canada produces about 20 kg of e-waste annually, while in the European Union that figure is 17.7 kg per person. In Nepal, by comparison, the annual per capita e-waste generation is about 0.8 kg; in Afghanistan it is 0.6 kg; and in Niger it is 0.4 kg.[128] E-waste is growing rapidly in low- and middle-income countries; however, only 67 countries have legislation in place to manage e-waste.[129] The Basel Convention on the Control of Transboundary Movements of Hazardous Wastes and Their Disposal is a multilateral treaty aimed at suppressing environmentally and socially detrimental hazardous waste trading patterns and has been signed by 186 countries.

Figure 12 The Future of E-waste



Source: UNU, 2018; OECD, 2018; E-waste Monitor 2017

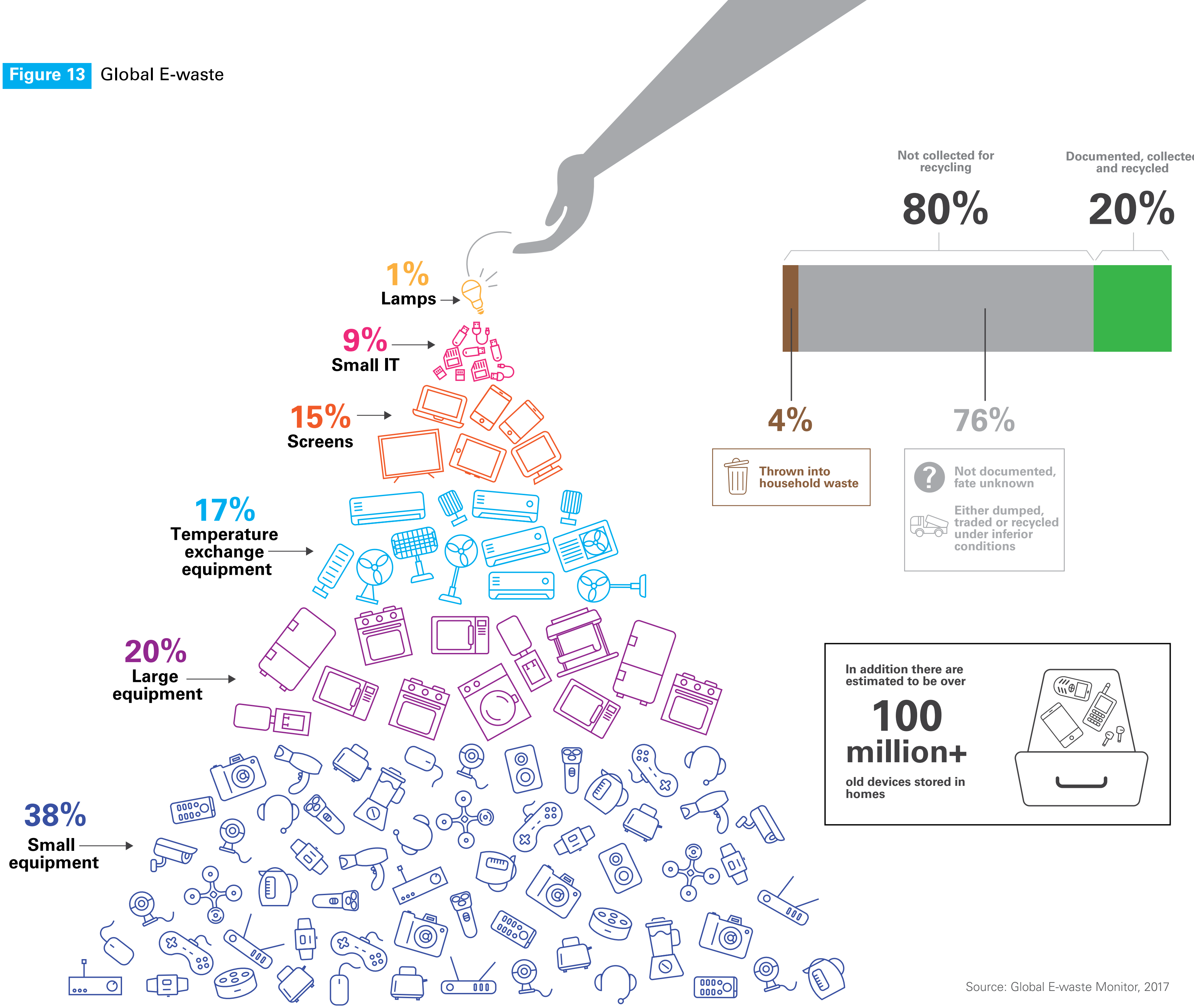
Case Study:
Accra, Ghana

In a small corner of Agbogbloshie, a former wetland notorious as "the world's largest e-waste dump",[130] a pilot project offers tantalizing possibilities for safer e-waste recycling. Using mechanized stripping machines, workers learned to remove lead-infused plastic coatings from copper wire, a safer alternative to the common practice of burning the wire. While this centre was operating, the model e-scrap facility produced an estimated 450 pounds of recycled copper and 40 pounds of aluminium for export in a month.[131] Plastic coatings were also recycled.

Initiated by Pure Earth and GreenAd Ghana with funding from the United Nations Industrial Development Organization (UNIDO), the recycling facility demonstrated the possibilities: cleaner and economically viable recycling, cooperation among stakeholders in the informal recycling economy, and less exposure to toxic pollution and heavy metals for both the workers and nearby residents. The National Youth Authority, a local government department, provided the land for the pilot project facility, which was created using three 40-foot ISO Intermodal Containers and four mechanized wire-strippers. The Agbogbloshie Scrap Dealers Cooperative, which is owned by GASDA, GreenAd and the National Youth Authority, managed the recycling facility with oversight by the Ghana Environmental Protection Agency.[132]

It is a drop in the bucket, to be sure. Black smoke from burning e-waste still darkens the sky above the Ghanaian scrap yard. But piloting a mechanized wire-stripping facility is a significant step in the right direction. Agbogbloshie, which occupies a 20-acre industrial section of Ghana's capital Accra, is home to hundreds of informal recyclers who break open used lead-acid batteries and electronic products from computers to telephones to retrieve the valuable metals inside. The vast majority of recyclers, including children, work without protection, breaking apart components with their bare hands and burning off plastic coatings infused with lead to recover copper wires.[133] This is often done over fires fuelled by tyres, which are similarly burned to recover the metal bands.[134] High levels of heavy metal contamination have been found in soil and ash mixtures collected in Agbogbloshie.[135, 136]

Figure 13 Global E-waste



Source: Global E-waste Monitor, 2017

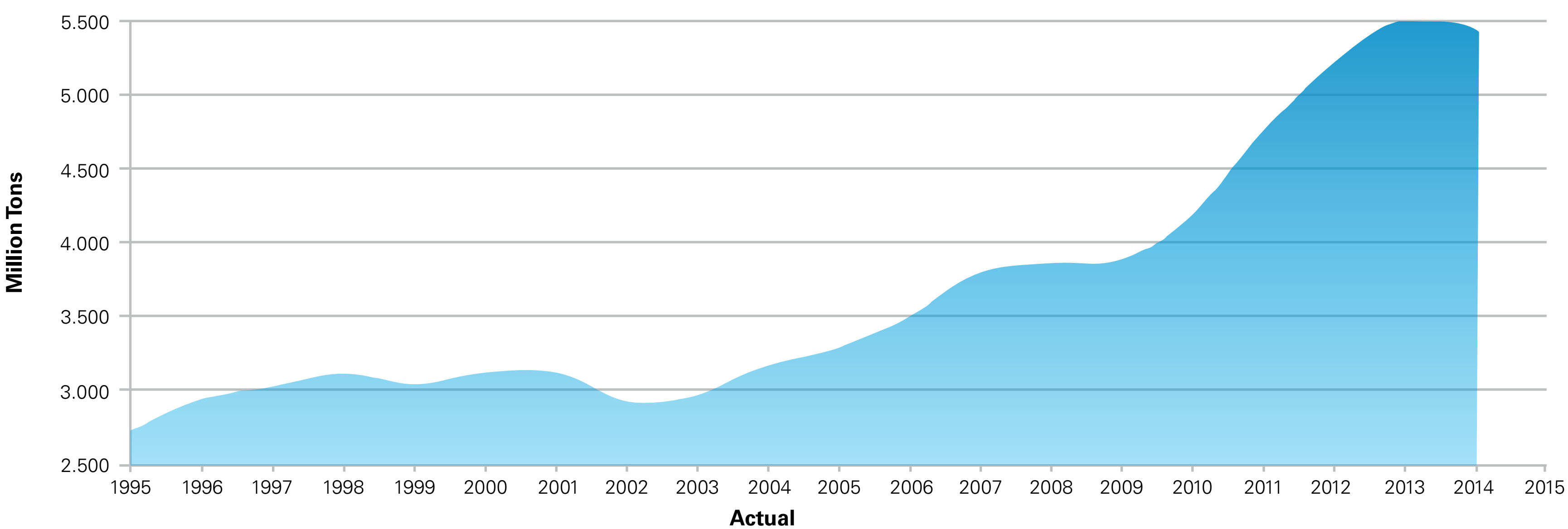
Occupational Exposure

There are many professions in which workers can be exposed to dangerous levels of lead. Moreover, there is potential for the worker to extend contamination beyond the workplace and into areas where families and children live and play.

Historically, exposure to lead was extremely high amongst those working in lead mines, especially where adequate protection for workers was not provided or available.[137] Moreover, mining of lead has grown considerably over recent years. According to the US Geological Survey, global mined lead production approximately doubled between 1994 and 2019 (see graphic below).[138] However, the increase in lead mining does not necessarily translate into exposure. Safe standards and procedures can prevent occupational exposures – and reduced occupational exposures means reduced exposures for children, especially as many workers can inadvertently carry home lead on their clothes and hands, carry home lead on their clothes and hands..

But exposure can also occur in professions that work with materials that contain lead. These include abatement and clean-up of residential and commercial buildings, steel structures or environmental sites; demolition of buildings and structures; work that entails handling ceramic glaze, glasswork or stain-glass windows; manufacturing of products containing or coated with lead (e.g., metal equipment parts, batteries, etc.); melting of products containing lead (e.g., scrap metal smelting; incinerators, foundries/ casting); industrial mineral processing activities, such as mining extraction or smelting; painting or sanding on industrial equipment and steel structures; recycling materials, including batteries and e-waste; and repair, renovation or remodelling of buildings, among other activities.[139]

Figure 14 Global Mined Lead Production (1995-2014)



Source: US Geological Survey 'Lead 2015"
http://minerals.usgs.gov/minerals/pubs/commodity/lead/

The total economic costs caused by lead exposure underscore the importance of tackling lead exposure as a priority environmental, health and development challenge.

4 BROADER ECONOMIC IMPLICATIONS

Pervasive childhood lead exposures are a drain on a country's economy. Quantifying the impacts of lead exposure and assigning them a monetary value can help raise awareness about the severity of this environmental risk, enable comparisons of costs and benefits of interventions and inform efforts to set environmental priorities and policies to reduce or eliminate lead exposure. Following, we review some of the literature at both the national/subnational levels, as well as the global level estimates and provide updated assessments.

Estimates of National/Subnational Economic Effects

Table 3 summarizes the results of the studies conducted in Argentina, Bolivia, Lao People's Democratic Republic (PDR) and Mexico. In all countries, lead exposure results in increased mortality and morbidity among adults and in significant neuropsychological effects in children.

Similar studies have also been conducted to estimate the health effects and costs of lead exposure at the sub-national level, as summarized in Table 4. While these studies have covered geographic areas with very different characteristics, lead consistently represents a significant health risk and causes significant economic costs.

Table 3 Summary of National-Level Estimates of the Cost of Lead Exposure[1]

	Argentina (2012)	Bolivia (2014)	Lao PDR (2017)	Mexico (2018)
Total population (in millions)	41.1	11	6.86	126
GDP per capita (US$)	11,573	3,150	2,500	9,763
Labour force participation rate (15-64 years)	68%	74%	81%	65%
IQ points lost per birth cohort	619,581	345,576	341,615	3,838,340
Cost of IQ loss (% of GDP, 2018)	0.60%	1.35%	1.9%	0.97%
Annual deaths from adult lead exposure	2,082	371	562	5,105
Days of illness from adult lead exposure (in millions)	9.7	2.2	2.2	116
Cost of increased mortality and morbidity of adult lead exposure (% of GDP)	0.31%	0.21%	0.65%	0.39%
Total Cost (% of GDP)	**0.91%**	**1.56%**	**2.55%**	**1.36%**

Source: (Larsen and Skjelvik, 2014), (Larsen, 2016), (Larsen, 2017)

Table 4 Summary of Subnational-Level Estimates of the Cost of Lead Exposure[2]

	Apurimac, Peru (2012)	Sindh, Pakistan (2009)	Hidalgo, Mexico (2012)	Yucatan Peninsula, Mexico (2013)
Total population	452,000	36,000,000	2,800,000	4,300,000
GDP per capita (US$)	$1,931	1,279	$6,980	8,967
IQ points lost per 1 year birth cohort	11,200	1,984,840	55,200	142,000
Cost of IQ loss as % of GDP, 2018	1.34%	2.54%	0.63%	1.14%
Annual deaths from adult lead exposure	11	--	63	138
Days of illness from adult lead exposure	58,000	--	232,000	505,000
Cost of increased mortality and morbidity of adult lead exposure	0.15%	--	0.13%	0.18%
Total Cost (% of GDP)	**1.49%**	**2.54%**	**0.76%**	**1.33%**

Source: (Larsen and Skjelvik, 2014), (Larsen and Skjelvik, 2015), (Larsen and Skjelvik, 2012), (Larsen, 2015).

Estimates of Global Health Economic Effects

Attina and Trasande (2013) extracted data from 68 articles published from 2000-2012 to calculate what childhood lead exposure would cost low- and middle-income countries in Africa, Asia, Latin America and the Caribbean. Using an environmentally attributable fraction model, they estimated that the loss of lifetime earnings (attributable to childhood lead exposure) represented a total cost of $977 billion (with a range of between $729.6 billion and $1,162 billion) annually in low- and middle-income countries. Their estimate of the economic burden associated with childhood lead exposure in low- and middle-income countries was equivalent to around 1.20 per cent of world GDP in 2011.[3]

Figure 15 COST AS A % GDP BY REGION

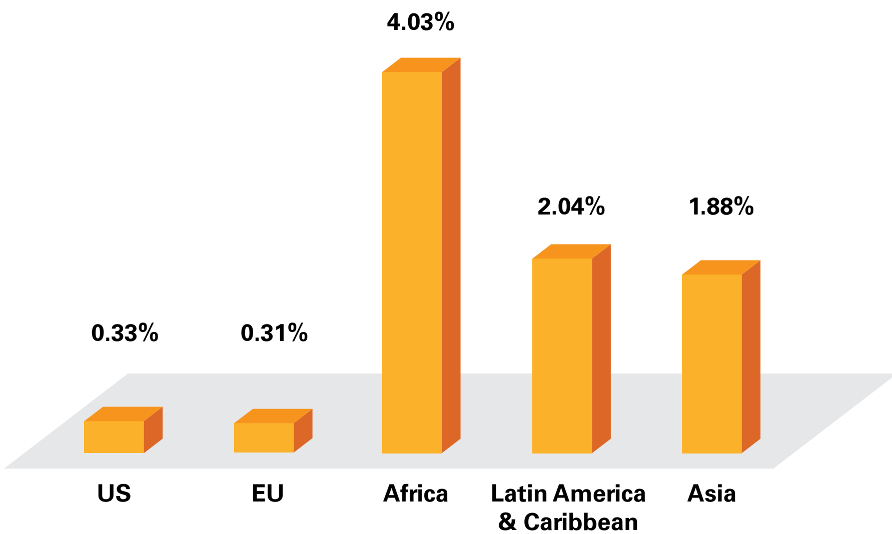
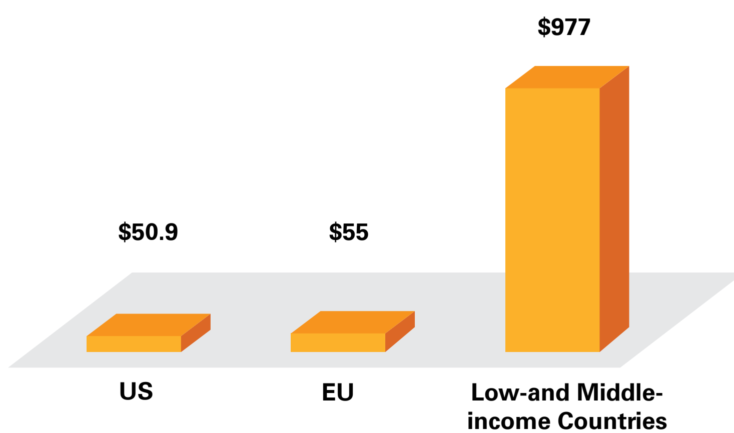


Figure 16 COST IN BILLIONS OF DOLLARS (USD)



Source: NYU: Economic Costs of Childhood Lead Exposure in Low- & Middle-Income Countries. https://med.nyu.edu/departments-institutes/pediatrics/divisions/environmental-pediatrics/research/policy-initiatives/economic-costs-childhood-lead-exposure-low-middle-income-countries [accessed July 28 2020]

Source for Asia, South and Central America, and Africa: Attina, Teresa M., and Leonardo Trasande. "Economic costs of childhood lead exposure in low-and middle-income countries." (*Environmental health perspectives* 121, no. 9, 2013): 1097-1102. Retrieved from: https://med.nyu.edu/departments-institutes/pediatrics/divisions/environmental-pediatrics/research/policy-initiatives/economic-costs-childhood-lead-exposure-low-middle-income-countries

Source for US: Trasande L, Liu Y. "Reducing the staggering costs of environmental disease in children, estimated at $76.6 billion in 2008." (Health Aff, Millwood, 2011) 30(5):863-70. DOI: 10.1377/hlthaff.2010.1239. https://med.nyu.edu/departments-institutes/pediatrics/divisions/environmental-pediatrics/research/policy-initiatives/economic-costs-childhood-lead-exposure-low-middle-income-countries

Source for EU: Bartlett ES, Trasande L. "Economic impacts of environmentally attributable childhood health outcomes in the European Union." (*Eur J Public Health*, 2014) 24(1):21-6. DOI: 10.1093/eurpub/ckt063. https://med.nyu.edu/departments-institutes/pediatrics/divisions/environmental-pediatrics/research/policy-initiatives/economic-costs-childhood-lead-exposure-low-middle-income-countries

Benefits and Costs of Interventions to Reduce Lead Exposure

A few studies have estimated the cost and benefits of interventions to reduce lead exposure. Gould (2009)[4] concluded that for every $1 invested to reduce lead paint hazards in the United States, there is a benefit of between $17 and $221. The benefits considered in the study include the costs of medical treatment, lost earnings, tax revenue, special education, lead-linked Attention-Deficit/Hyperactivity Disorder cases, and criminal activity.

Grosse et al (2002)[5] quantified the benefits from improvements in worker productivity resulting from the reduction in children's exposure to lead in the United States since 1976. They estimated that reduced exposure to lead resulted in 2.2- to 4.7-point increases in IQ for preschool-age children in the late 1990s. Estimating that each IQ point raises worker productivity 1.76-2.38%, the reduction in lead exposure resulted in benefits for each year's cohort of 3.8 million 2-year-old children of between $110 billion and $319 billion.

A 2017 report assessed the benefits and costs of various interventions that could be implemented to reduce or eliminate lead exposure. The report found that the benefits of all these interventions would outweigh their costs.[6]

Table 5 Benefits and Costs of Interventions to Reduce Lead Exposure

Intervention	Benefits per each $1 invested
Removing leaded drinking service lines from homes	$1.33
Eradicating lead paint hazard from older homes for low-income families	$1.39
Lead-safe renovation, repair and painting practices	$3.10

Source: Health Impact Project 2017.

The total costs caused by lead exposure underscore the importance of tackling lead exposure as a priority environmental, health, and development challenge. The estimates presented in this chapter are based on very conservative assumptions and consider only some of the health effects of lead exposure; yet, they point to a significant loss of life and healthy years, and to the millions of children who were robbed of the opportunity to have a brighter future. It should be noted that not all interventions have been shown to be effective at reducing children's blood lead levels or behavioural outcomes. A recent Cochrane review of 14 intervention studies found little evidence of effectiveness for some of these interventions and called for further studies to establish the most effective interventions for preventing lead exposure, especially in low- and middle-income countries and in at-risk groups in high-income countries.[7]

In light of recent evidence of the severity of impacts of lead in children, studies should be undertaken across the world to confirm BLLs among children, map geographic pockets of high BLLs ("hotspots"), and identify and control sources of lead exposure. This information could help to better define interventions to reduce lead exposure, which based on available evidence, are likely to generate benefits that clearly outweigh their costs.

Proven solutions exist and they can be implemented now.

5 SOLUTIONS TO ADDRESS CHILDREN'S LEAD EXPOSURE

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> You will observe with Concern how Long a useful Truth may be known, and exist, before it is generally received and practiced on.
>
> – Benjamin Franklin, *Letter on Lead Poisoning*, 1786

The issue of lead poisoning is not new, but our understanding of the scope and scale of its impacts and of feasible solutions has never been better. Proven solutions exist for low- and middle-income countries, those most burdened by this challenge. Those solutions can be implemented today.

Blood lead levels in the general population dropped dramatically with the transition from leaded to unleaded gasoline. Removal of lead-based paints for household use and improved remediation (and education) also has resulted in demonstrably improved blood lead levels. Management and remediation of lead hazards and hotspots and regulation and control of recycling and smelting operations in some areas has produced demonstrably favourable results. Lead, which is so highly recyclable, can be recovered, refined and repurposed safely without polluting the environment and exposing workers, their children and surrounding neighbourhoods to the dangers inherent in informal recycling and smelting operations. Lead-contaminated sites can be remediated and restored. People can be educated about the dangers of lead and empowered to protect themselves and their children.

UNEP Survey[1]

The United Nations Environmental Programme surveyed 102 countries seeking information about current ULAB recycling regulations, monitoring and manufacturing processes, along with any needs that the countries might have in improving their processes and reducing lead pollution. From the 40 responding countries that completed surveys, results showed the following needs:

- The Asia and the Pacific region expressed the need for technical and capacity building as most required.
- The Latin American region expressed more need for monitoring systems, national strategy, technical and capacity building, legislation and regulation building.
- The Africa region expressed the need for monitoring systems, public private partnerships, technology and legislation and regulation building.

The countries, almost universally, said that they need technological help and capacity building to improve ULAB recycling. Latin American and African countries also expressed the need for help with monitoring systems, legislation, regulation building and public-private partnerships. The UNEP survey results underscored the findings of numerous university and governmental studies, interviews with residents and local government officials, and the observations of non-governmental organizations working on the ground to address lead pollution.

Addressing lead pollution and exposure among children requires a coordinated and concerted six-pronged approach across the following areas: improving monitoring and reporting systems; improving prevention and control; improving management, treatment and remediation; improving public awareness and behaviour change; improving legislation and policies; and global and regional action. Achieving these goals will require international action by governments, public-private partnerships and industry. Following, we examine them in more detail.

Monitoring and Reporting Systems

- *Develop country-level monitoring capacity for blood lead testing.* A first step in addressing any problem is understanding the scope of the situation – including who is affected and to what degree, so that effective support can be provided. There is an enormous need for improved blood lead testing; monitoring mechanisms; data and analysis; and reporting on children who have been exposed in all countries, especially in low- and middle-income countries. The companion study to this report put together the most comprehensive assessment to date; however, much more data is needed, especially at a local level where efforts can be targeted towards the most at-risk children. Improved and expanded monitoring and reporting, through inclusion of blood testing in household surveys or through sentinel monitoring in health care facilities, will help identify poisoned children, so that preventative measures can be quickly implemented to reduce the toxic effects of lead.

- *Conduct source apportionment assessments at local levels to determine how children are being exposed.* Assessments should be conducted at the household, school and community level. The more we know about the true sources of exposure, the faster we can target interventions.

- *Identify contaminated sites.* This entails setting standards and providing guidance to local authorities on criteria as well as management of the response. Once sites are identified, communities will be aware of the danger and will most likely start avoiding the site. Social media can be an effective tool.


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Prevention and Control Measures

- *Prevent children's exposure to high-risk sites.* This includes preventing children from accessing or playing around ULAB recycling facilities, waste sites (especially e-waste) and smelting and former smelting sites, as well as other locations. This includes safe disposal of ULABs used in renewable energy systems, as well safe disposal of solar panels and related products which may contain lead. It also includes actions to develop and promote safe practices for informal pickers and informal miners, especially if they are pregnant or lactating (or children themselves).

- *Prevent children's exposure to products that contain lead.* This includes eliminating the use of lead in paint compounds; gasoline (in countries where it is still in use); ceramics and pottery used for cooking, eating or drinking; children's toys and school materials; cosmetics; and in spices and medicines.

- *Prevent children's exposure to lead paint.* Encourage countries to adopt lead paint laws or set legally binding lead paint limits. Adopting lead paint laws has been shown to be the most effective way of eliminating lead paint, hence, preventing exposure from lead in paint. Reformulate lead paint to be lead-free. It is technically possible and feasible to reformulate paint – many paint producers have already phased out lead paint from their production.

- *Ensure children are receiving adequate health services and nutrition.* Good nutrition is essential not only in reducing lead absorption, but also in treating children who already have elevated blood lead levels. Iron, vitamin C and calcium have been shown to help limit lead absorption. A balanced age-appropriate diet can help limit the full effects of lead poisoning. Conversely, calcium and iron deficiencies, as well as malnutrition in general, increase lead absorption.[2] Good quality healthcare can also help identify exposures, provide guidance to reduce absorption and initiate treatment to remove lead from the blood if levels are very high. This can greatly help limit any long-term damage that lead can cause children, both in terms of overall health and cognitive development.

- *Address risks that occur during the prenatal period.* Pregnant and lactating mothers are at particular risk from lead exposure. Pregnant women exposed to lead dust or fumes can readily pass the toxin to the developing fetus via placental transfer. In addition to the usual lead health effects of cognitive damage, it seems that such exposure may be associated with low birthweight offspring. The science on this observation is still developing. Lead exposure continues as the child breast feeds and quickly absorbs the material since it is a calcium analogue. Given the nature of the rapidly developing central nervous system of fetuses and newborns, lead exposure at this stage of development is particularly damaging.[3,4] Pregnant mothers should be provided with blood lead level testing if risk factors are present. Sources of exposure should be identified, and mothers and caregivers should receive counselling and support to prevent further exposure. Mothers should be provided with improved nutrition and overall health, including calcium and iron supplementation if required. Mothers should also be provided with support once the child is born to ensure the best possible health and development (including cognitive development) during the first thousand days of a child's life – a critical window for growth.

- *Improve recycling practices and collection systems of ULABs.* Ensure used lead-acid battery and e-waste recycling operations have controlled and environmentally sound operations that support local economies and protect workers and local neighbourhoods from toxic emissions and dust. Improve collection systems of ULABs to ensure proper and safe recycling. Private sector and industry have already shown positive support for this work; large lead producers and battery manufacturers have given technical and other assistance.

- *Replace lead in pottery glazes and cookware with safer alternatives.* There are plenty of alternatives to leaded glazes in pottery. Education is key for both consumers and artisanal potters who can be trained to use non-toxic glazes. Additionally, laws discouraging the sale and use of lead glazes in dishes and cookware can be effective in removing this source of exposure from the market.[5]

Management, Treatment and Remediation

- *Strengthen health systems so that they are equipped to detect, monitor and treat lead exposures among children.* This includes setting up blood level monitoring pre- and post-remediation with referral and treatment programs for lead-poisoned children.[6]

- *Provide children with enhanced educational interventions.* Access to high quality education and developmental interventions is important for children who suffer developmental delays caused by lead poisoning. While it is impossible to fully reverse the effects of lead poisoning on cognitive development, families can discuss lead exposure with their children's teachers and doctors. Children with lead poisoning may be eligible for developmental screening at school and for disability or special education services. Children with elevated lead levels who are at high risk for developmental delays benefit most from interventions that start at an early age. Mental health and cognitive behavioural therapy in particular can help children manage conditions such as ADHD, which has been strongly associated with lead exposure in children. Lead exposure is estimated to account for a significant increase in ADHD cases in the United States.[7]

- *Contain and clean up toxic sites.* Each toxic site has unique requirements, but in general there are common procedures and methodologies that have proven successful in remediating contaminated areas. These can include removing contaminated soil and waste, installing barrier cloths and paving or covering areas with clean fill, and planting with grass and vegetation.[8]

- *Encourage the use of non-lead compounds in the manufacture of paint.* Support innovation and knowledge sharing among local business on alternative paint manufacturing techniques. Promote alternative paint manufacturing techniques.

- *Remove lead completely from areas where children live, play or learn.* Wet-wipe surfaces and test for continued presence of lead using established cleaning and testing resources.[9]


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Public Awareness and Behaviour Change

- *Create continual public education campaigns about the dangers and sources of lead exposure with direct appeals to parents, schools, youth associations, community leaders and healthcare workers.* Anecdotal interviews and formal studies have repeatedly demonstrated that parents of children found to have high blood lead levels had no idea that their families were at risk -- whether from nearby backyard recycling operations, lead-glazed pottery, home-based workshops or adulterated spices. Likewise, workers in informal recycling and smelting operations often are unaware of the inherent dangers of lead exposure or measures that they should take to protect themselves and their families. Identification of lead in food and spices and public dissemination of that information can greatly help develop appropriate actions to be taken at both policy and household levels. Community education; public awareness; and the knowledge, technology and skills to replace dangerous procedures are essential to the success of all other efforts to eliminate lead poisoning worldwide.

- *Utilize existing media and communications resources.* Build media and communication campaigns for severely affected areas. This includes identifying media that are most used within different communities, including internet, TV, radio, SMS or other media.

- *Educate workers and owners of ULABs and smelters about the risks of lead exposure and ways to protect themselves, their families and their communities.* Create industry and worker education campaigns modelled on the 2018 UNEP-ILA guidelines for the environmentally sound management and recycling of used lead-acid batteries.[10]

- *Provide training for healthcare workers* about the symptoms of lead exposure, along with the provision of blood lead level test kits and chelation therapy drugs, following guidelines issued by the World Health Organization.[11]

- *Educate children and teachers about the risks.* Teaching children about lead risks is challenging because lead is often invisible and the effects are not immediately felt or even recognized. It is important to educate children about lead risks in ways that they can understand, including telling them where dangerous areas are located. Often teachers in the community can best impact sustainable change. Numerous community health education programs (malaria prevention, vaccinations, pregnancy prevention) are teacher-driven and based within school systems.

Legislation and Policy

- *Develop, implement and enforce environmental, health and safety standards for lead battery manufacturing and recycling.* Implementing and enforcing these standards through strong legislation and policy will help ensure the appropriate industrial hygiene and occupational measures are in place; improve awareness of the risk factors; eliminate bad practices; and help reduce children's exposure to harmful and toxic substances that can affect their health, well-being and potential.

- *Develop legislation and policies to regulate e-waste recycling.* Legislative systems have not kept pace with the rapid growth of this new type of waste. It will be necessary to assess the unique risks that this type of waste poses to prevent creating toxic environments for children.

- *Develop and reinforce legislation and policies to eliminate use of lead compounds in paint and gasoline (where it is still in use); in ceramics and pottery that are used for cooking, eating or drinking; in children's toys; and in cosmetics, spices and medicines.* This should be done with mechanisms to enable better monitoring and enforcement.

- *Enforce environmental and air-quality regulations for smelting operations*. While lead has been removed from gasoline, it can still enter the air through smelting operations – and so air quality regulations that prevent lead from being emitted into the air are very much still needed.

- *Ensure that national drinking water quality standards include lead parameters.* Regulation of water providers also should promote risk management approaches to water safety.

- *Advocate for the inclusion and enforcement of e-waste recycling and metals mining as a worst form of child labour* (hence prohibited by convention 182).

Global and Regional Action

- *Support action in affected countries with development assistance, technical capacity building, and measurable results in reducing blood lead levels.*

- *Prevent children's exposure to lead by avoiding future sources of lead exposure, such as by eliminating the use of lead compounds in the manufacture of toys, paint and other products.*

- *Create global standard units of measure to verify the results of pollution interventions on public health, the environment and local economies.*[12]

- *Build an international registry of anonymized results of blood lead level studies.* This could be maintained by an international organization to track the extent of global lead pollution and the efficacy of remediation efforts over time.[13]

- *Create and reinforce international standards and norms around recycling and transportation of used lead-acid batteries.* With the growth of lead-acid batteries, these standards and norms will be very important in helping countries develop national legislation, policies and good practices to better protect children.

- *Establish funding mechanisms and technical assistance, including from the private sector and industry, and foster research to close evidence/ research gaps.*

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International Treaties, Conventions, Declarations and Agreements Linked to Children's Exposure to Lead Pollution

There are several treaties and conventions that link children's exposure to lead pollution and form an important basis for informing policy and accountability mechanisms to ensure that children live in a safe and clean environment.

- **1989:** The Convention on the Rights of the Child, which includes the importance of a safe and healthy environment for children. Exposure to lead pollution undermines the effective enjoyment of the rights enshrined in the Convention on the Rights of the Child, including the rights to life, survival and development (art. 6), the highest attainable standard of health (art. 24), adequate standard of living (art. 27), education (art. 28), among others.[14]

- **1992:** Agenda 21 adopted by the United Nations Conference on Environment and Development addressed the need to protect children from toxic chemicals.[15] This includes Section 19: Environmentally sound management of toxic chemicals, including prevention of illegal international traffic in toxic and dangerous products; 6.27.iv: Protect children from the effects of environmental and occupational toxic compounds; 6.41.i.ii: Incorporate appropriate health risk analysis in all national programmes for pollution control and management, with particular emphasis on toxic compounds such as lead; 16.11; 17.28; among others.

- **1997:** The Declaration of the Environment Leaders of the Eight on Children's Environmental Health acknowledged lead poisoning as a major environmental hazard to children and committed to reduce and improve monitoring of blood lead levels in children, as well as to fulfil and promote internationally the OECD Declaration on Lead Risk Reduction.[16]

- **2002:** The Bangkok Statement on Children's Health and the Environment called for the reduction or elimination of exposure to toxic metals such as lead, as well as to advocate for the removal of lead from all gasoline, paints, water pipes and ceramics.[17]

- **2002:** In the Plan of Implementation of the World Summit on Sustainable Development, governments agreed to "phase out lead in lead-based paints and in other sources of human exposure, work to prevent, in particular, children's exposure to lead and strengthen monitoring and surveillance efforts and the treatment of lead poisoning".[18]

- **2006:** The Declaration of Brescia on Prevention of the Neurotoxicity of Metals recommended the immediate elimination of tetra-ethyl lead from the gasoline supplies of all nations; the review of all uses of lead, including recycling, in all nations; and the urgent reduction of current exposure standards.[19]

- **2009:** The Busan Pledge for Action on Children's Health and Environment acknowledged the chronic and acute health risks associated with children's exposure to lead and further affirmed the commitment of the global community to end childhood lead poisoning.[20]

- **2009:** The Resolution II/4 of the second International Conference on Chemicals Management (ICCM 2) identified lead in paint as an emerging policy issue and endorsed a global partnership to promote phasing out the use of lead in paints. Among others, one of the objectives of the Global Alliance to Eliminate Lead Paint is to share guidance and promote assistance to identify and reduce potential lead exposure in and around housing, childcare facilities and schools in which paint containing lead and paint dust is present and in industrial facilities producing or using paint containing lead to reduce workers' lead exposure.

- **2015:** The Sustainable Development Goals. Sound management of chemicals and waste are key factors for achieving the SDGs[21]. See figure 17.

- **2017:** Third UN Environment Assembly Resolution on Lead Paint: Member States passed a resolution calling for the global elimination of lead paint through the establishment of lead paint laws.[22]

Figure 17

Sustainable Development Goals[23]

SDG 1-No Poverty: Poor populations are most vulnerable to exposures from hazardous substances. It is estimated that 99% of children affected by lead exposure live in low- and middle-income countries.

SDG 2-Zero Hunger: Lead is sometimes ingested in food grown in contaminated soil or seasoned with spices adulterated with lead. Lead is also more readily absorbed by the body when a child is malnourished, especially when iron and calcium intake is deficient.

SDG 3-Good Health and Well-being: Lead is a major cause of poor health and well-being of children and adults, creating kidney, liver, and neurological conditions, among other health effects.

SDG 4-Quality Education: Lead can cause neurological impairment, reducing a child's ability to learn.

SDG 5-Gender Equality: Chemicals impact men and women differently due to both sociocultural and physiological differences. For lead, this includes different types of occupational exposure as well as how lead affects pregnant women in particular. For women, vulnerability to chemicals is exacerbated by power imbalances.

SDG 6-Clean Water and Sanitation: Water scarcity and quality are determined by many factors, including polluting of water supplies by toxic chemicals, such as lead.

SDG 7-Affordable and Clean Energy: Lead is a major component of batteries which collect and store power from many renewable energy platforms that conserve and deliver clean, affordable energy and reduce greenhouse gases. Proper recycling of lead-acid batteries will be especially important given the growth of the renewable energy sector.

SDG 8-Decent Work and Economic Growth: The health and safety of people whose work results in occupational exposure to lead needs to be ensured. The risk of children's lead exposure in mines or waste recycling activities makes it one of the worst forms of child labour. (ILO Convention 182 Article 3d)

SDG 9-Industry, Innovation and Infrastructure: Innovation in the replacement and sound management of chemicals, including lead, can reduce exposure and hazardous waste and support the development of new

SDG 10-Reduced Inequalities: The poorest, most marginalized members of society tend to be exposed to higher levels of lead.

SDG 11-Sustainable Cities and Communities: Reducing exposure to toxic chemicals, including lead pollution, is part of creating safe and healthy communities. This is particularly critical where lead is used in paint on buildings and homes and in areas where lead-acid batteries are recycled informally and without the right precautions and practices. Otherwise, lead particulate matter can enter the soil, water and air of those cities and communities.

SDG 12-Responsible Consumption and Production: Good practices, safety procedures and innovation in managing lead production, use and recycling can contribute to the development of circular economies and promote more sustainable patterns of production and consumption.

SDG 13-Climate Action: Improper recycling of lead-acid batteries can release chemicals which degrade the environment and ecosystems, which are crucial to addressing climate change, both in terms of adaptation and mitigation.

SDG 14-Life Below Water: Toxic pollutants discharged into oceans and rivers are later absorbed by some of the fish we eat.

SDG 15-Life On Land: Improper recycling of lead-acid batteries can release chemicals and waste, causing severe environmental degradation and disruption of ecosystems via contamination of water, soil, air, flora and fauna.

SDG 16-Peace and Justice and Strong Institutions: Institutional frameworks and coordination mechanisms among relevant stakeholders have been recognized as essential to the attainment of the sound management of chemicals and waste.

SDG 17-Partnerships for the Goals: Sound management of chemicals can contribute to enhanced policy coherence for sustainable development through public-private partnerships, capacity building and technology innovation.

Source: Adapted from IOMC 2018 'Chemicals and Waste Management: Essential to

It is clear from the body of evidence compiled that lead poisoning is a much greater threat to the health of children than previously understood. The under-recognized threat of lead exposure takes an enormous toll on the physical and neurological health of children globally. Although much more research needs to be conducted, enough data has recently emerged that decisive action must begin – and it must begin now.

ANNEX

Number of Children with Blood Lead Levels (BLLs) Above 5 µg/dL and Above 10 µg/dL Per Country from IHME

	AREA/ COUNTRY	Number of Children with BLL > 5 µg/dL	Number of Children with BLL > 5 µg/dL (lower-bound estimate)	Number of Children with BLL > 5 µg/dL (upper-bound estimate)	Number of Children with BLL > 10 µg/dL	Number of Children with BLL > 10 µg/dL (lower-bound estimate)	Number of Children with BLL > 10 µg/dL (upper-bound estimate)
1	Afghanistan	19,452,102	18,274,876	20,016,234	12,248,563	8,521,159	15,310,596
2	Albania	170,795	78,923	304,775	24,291	9,125	55,805
3	Algeria	2,910,421	1,286,116	5,629,753	335,968	131,464	819,093
4	Andorra	173	107	282	25	18	35
5	Angola	4,738,129	2,183,204	8,358,612	691,877	251,283	1,620,559
6	Antigua and Barbuda	892	283	2,045	13	2	45
7	Argentina	951,816	431,672	1,879,939	91,040	43,810	178,490
8	Armenia	72,562	32,669	140,915	8,473	4,141	16,713
9	Australia	116,404	66,856	208,953	14,019	9,201	22,152
10	Austria	26,669	15,301	44,249	3,462	2,348	5,214
11	Azerbaijan	227,940	101,208	439,132	26,862	12,970	50,666
12	Bahamas	2,933	1,004	6,837	35	6	128
13	Bahrain	24,348	10,527	49,104	2,541	1,215	5,109
14	Bangladesh	35,527,671	23,639,658	45,959,260	9,675,388	4,207,907	17,832,455
15	Barbados	1,979	650	4,525	25	4	87
16	Belarus	208,448	96,063	404,567	24,739	11,814	50,740
17	Belgium	204,097	89,877	412,420	19,526	9,118	40,770
18	Belize	9,836	3,518	22,533	199	34	628
19	Benin	3,148,829	1,669,885	4,795,096	607,993	211,459	1,363,161
20	Bhutan	24,975	11,440	46,285	3,273	1,584	6,177
21	Bolivia (Plurinational State of)	3,231,154	1,685,516	4,414,206	521,801	84,640	1,449,816
22	Bosnia and Herzegovina	92,648	42,214	175,329	11,075	5,001	23,115
23	Botswana	216,886	102,018	384,031	30,852	11,850	71,290
24	Brazil	4,403,642	3,347,298	5,666,961	98,266	66,158	142,543
25	Brunei Darussalam	2,765	1,519	4,977	324	209	523
26	Bulgaria	66,826	30,554	130,749	8,193	4,169	15,084
27	Burkina Faso	9,077,888	6,441,902	10,920,624	3,218,541	1,340,372	5,552,306
28	Burundi	3,053,133	1,604,294	4,622,476	626,214	207,235	1,425,906
29	Cabo Verde	17,440	7,731	33,381	2,051	980	3,944
30	Cambodia	3,171,259	1,177,856	5,174,199	188,670	7,792	860,159

	AREA/ COUNTRY	Number of Children with BLL > 5 µg/dL	Number of Children with BLL > 5 µg/dL (lower-bound estimate)	Number of Children with BLL > 5 µg/dL (upper-bound estimate)	Number of Children with BLL > 10 µg/dL	Number of Children with BLL > 10 µg/dL (lower-bound estimate)	Number of Children with BLL > 10 µg/dL (upper-bound estimate)
31	Cameroon	7,534,476	4,030,583	11,048,855	1,620,490	534,307	3,586,082
32	Canada	128,854	78,976	221,044	16,534	11,464	25,327
33	Central African Republic	1,736,399	1,090,246	2,271,734	483,546	177,033	945,156
34	Chad	7,873,733	6,107,127	8,913,448	3,298,713	1,548,238	5,182,799
35	Chile	143,928	68,819	271,449	15,459	8,444	26,447
36	China	31,237,708	22,945,417	41,910,725	41,133	-	132,356
37	Colombia	588,648	205,603	1,402,236	10,157	1,651	34,600
38	Comoros	36,396	16,205	70,751	4,289	1,948	8,955
39	Congo	279,774	126,167	538,290	32,907	15,390	67,030
40	Cook Islands	14	8	28	-	-	-
41	Costa Rica	191,502	59,486	442,071	6,437	930	22,273
42	Côte d'Ivoire	5,252,219	2,642,258	8,352,664	964,392	324,885	2,225,641
43	Croatia	28,823	14,403	55,727	3,741	2,132	6,619
44	Cuba	880,044	326,322	1,620,183	61,587	9,254	216,930
45	Cyprus	5,206	3,022	9,081	635	420	996
46	Czechia	69,909	37,166	134,476	9,231	5,564	16,191
47	Democratic People's Republic of Korea	4,875,085	2,499,693	6,314,223	589,871	40,652	2,023,855
48	Democratic Republic of the Congo	23,943,664	12,991,380	34,641,958	5,275,931	1,738,077	11,476,988
49	Denmark	27,731	16,151	51,452	3,254	2,151	5,343
50	Djibouti	58,699	26,508	113,772	6,926	3,223	14,327
51	Dominica	1,017	328	2,486	18	3	65
52	Dominican Republic	1,342,729	464,381	2,521,817	83,761	12,241	288,301
53	Ecuador	601,756	189,035	1,466,237	16,389	2,488	58,027
54	Egypt	25,402,579	16,992,842	32,721,993	5,994,338	2,534,024	11,346,111
55	El Salvador	690,408	239,400	1,348,381	40,779	6,109	144,067
56	Equatorial Guinea	36,536	16,844	69,982	4,498	2,337	8,120
57	Eritrea	495,266	224,235	947,933	59,364	26,349	127,275
58	Estonia	10,715	5,097	20,340	1,370	743	2,428
59	Eswatini	208,825	108,534	323,947	40,267	13,763	91,878
60	Ethiopia	18,028,525	8,393,173	30,561,004	2,738,325	971,062	6,194,661
61	Fiji	2,229	898	4,924	-	-	-
62	Finland	11,217	7,236	17,112	1,688	1,211	2,356
63	France	332,322	202,934	588,296	38,929	26,621	61,073
64	Gabon	42,890	19,843	81,671	5,188	2,630	9,381
65	Gambia	537,876	290,616	803,089	111,518	38,479	243,235
66	Georgia	65,025*	28,517	125,018	7,703**	3,675	14,361

* Data does not include recent analysis by UNICEF Georgia showing 41 percent of children aged between 2 and 7 have BLLs above 5 µg/dL. This report will be integrated into IHME GBD processes and be reflected in the 2020 GBD.
* Data does not include recent analysis by UNICEF Georgia showing 16 percent of children aged between 2 and 7 have BLLs above 10 µg/dL. This report will be integrated into IHME GBD processes and be reflected in the 2020 GBD.

	AREA/ COUNTRY	Number of Children with BLL > 5 µg/dL	Number of Children with BLL > 5 µg/dL (lower-bound estimate)	Number of Children with BLL > 5 µg/dL (upper-bound estimate)	Number of Children with BLL > 10 µg/dL	Number of Children with BLL > 10 µg/dL (lower-bound estimate)	Number of Children with BLL > 10 µg/dL (upper-bound estimate)
67	Germany	333,259	178,982	619,634	38,909	24,197	64,429
68	Ghana	1,731,786	792,455	3,376,580	204,359	95,060	429,802
69	Greece	66,517	31,501	129,963	6,925	3,679	12,366
70	Grenada	2,976	1,020	7,305	74	12	254
71	Guatemala	4,249,599	2,046,138	6,330,075	559,874	89,994	1,651,653
72	Guinea	4,490,705	2,938,292	5,760,738	1,347,908	517,687	2,574,000
73	Guinea-Bissau	548,447	319,718	758,096	135,970	47,431	278,469
74	Guyana	67,527	21,176	149,402	2,884	441	10,649
75	Haiti	4,564,819	3,158,146	5,230,944	1,250,092	272,269	2,740,026
76	Honduras	2,118,430	892,155	3,415,397	210,693	31,450	691,812
77	Hungary	101,570	47,310	192,285	12,371	6,339	22,198
78	Iceland	944	602	1,540	139	102	206
79	India	275,561,163	242,633,715	309,462,889	64,378,274	49,850,518	82,033,908
80	Indonesia	8,271,863	5,486,754	11,998,982	17,017	-	58,127
81	Iran (Islamic Republic of)	10,291,577	5,058,898	16,424,484	1,712,100	550,034	4,057,976
82	Iraq	5,410,843	2,855,274	8,862,091	727,281	301,079	1,566,680
83	Ireland	26,445	15,386	46,996	3,161	2,097	5,022
84	Israel	86,431	47,048	170,444	9,530	5,841	16,853
85	Italy	160,862	98,027	269,585	20,963	14,530	31,669
86	Jamaica	132,746	41,732	311,095	4,233	662	14,207
87	Japan	319,061	264,846	379,489	42,580	35,619	50,603
88	Jordan	490,487	212,189	987,238	50,837	23,502	107,081
89	Kazakhstan	306,647	140,117	587,074	37,798	19,246	67,520
90	Kenya	2,831,808	2,063,095	3,815,927	326,521	238,535	445,902
91	Kiribati	11,386	2,836	24,635	248	-	1,353
92	Kuwait	35,004	17,995	68,926	4,078	2,399	7,259
93	Kyrgyzstan	493,397	221,143	952,997	61,632	25,587	141,865
94	Lao People's Democratic Republic	578,053	124,625	1,433,087	7,485	-	43,874
95	Latvia	22,240	10,275	43,020	2,694	1,370	4,993
96	Lebanon	29,835	17,744	51,735	4,074	2,839	6,451
97	Lesotho	566,723	380,655	718,443	185,182	74,253	331,128
98	Liberia	1,519,897	984,012	1,948,446	453,303	171,937	849,599
99	Libya	108,559	47,831	216,265	11,658	5,802	21,891
100	Lithuania	20,996	9,817	40,019	2,690	1,446	4,766
101	Luxembourg	1,677	1,004	2,678	233	161	337
102	Madagascar	4,850,537	2,339,254	8,152,558	801,784	277,020	1,911,645

	AREA/ COUNTRY	Number of Children with BLL > 5 µg/dL	Number of Children with BLL > 5 µg/dL (lower-bound estimate)	Number of Children with BLL > 5 µg/dL (upper-bound estimate)	Number of Children with BLL > 10 µg/dL	Number of Children with BLL > 10 µg/dL (lower-bound estimate)	Number of Children with BLL > 10 µg/dL (upper-bound estimate)
103	Malawi	3,431,433	1,638,020	5,697,855	562,726	194,393	1,289,147
104	Malaysia	56,949	24,320	122,095	-	-	-
105	Maldives	6,510	1,567	20,298	7	-	79
106	Mali	9,715,463	7,407,368	11,179,194	3,880,528	1,818,826	6,223,184
107	Malta	6,399	2,849	12,715	639	294	1,383
108	Marshall Islands	1,140	269	3,399	2	-	22
109	Mauritania	483,045	219,525	880,818	66,223	25,259	155,529
110	Mauritius	4,494	1,443	12,113	-	-	-
111	Mexico	13,856,064	11,107,542	16,961,117	637,721	429,683	923,151
112	Micronesia (Federated States of)	2,308	547	7,125	4	-	41
113	Monaco	99	58	158	13	9	20
114	Mongolia	140,540	62,993	270,570	16,416	7,690	33,249
115	Montenegro	6,926	3,187	13,227	860	451	1,529
116	Morocco	1,867,720	945,447	3,291,506	209,212	99,236	422,005
117	Mozambique	5,732,981	2,740,667	9,565,358	927,028	322,040	2,146,321
118	Myanmar	4,695,777	1,111,990	10,792,839	84,419	-	465,329
119	Namibia	361,079	178,891	586,559	62,043	21,645	143,539
120	Nauru	54	18	147	-	-	-
121	Nepal	6,719,235	3,934,651	9,331,520	1,741,952	638,139	3,512,007
122	Netherlands	58,886	34,515	95,824	7,638	5,093	11,119
123	New Zealand	47,673	21,760	94,720	4,826	2,469	8,943
124	Nicaragua	234,283	77,718	567,812	6,351	990	21,710
125	Niger	12,500,267	11,002,269	13,271,618	6,774,183	4,041,648	9,277,497
126	Nigeria	43,178,214	22,897,294	68,349,470	7,295,704	2,811,434	15,804,939
127	Niue	2	-	4	-	-	-
128	North Macedonia	46,163	20,990	88,280	5,404	2,600	10,605
129	Norway	22,627	13,029	39,855	2,785	1,845	4,362
130	Oman	53,065	24,708	106,056	5,892	3,141	10,843
131	Pakistan	41,121,401	21,271,107	65,265,365	7,718,106	2,880,748	16,850,708
132	Palau	15	8	30	-	-	-
133	Palestine	126,574	55,417	247,080	13,571	6,785	24,940
134	Panama	141,233	44,945	344,218	3,752	543	12,837
135	Papua New Guinea	103,499	30,597	294,673	-	-	-
136	Paraguay	485,405	151,307	1,043,645	21,777	3,083	79,634
137	Peru	7,132,941	3,588,904	10,206,503	867,968	153,795	2,532,764
138	Philippines	20,024,201	6,771,216	34,771,527	932,894	32,769	4,367,214

	AREA/ COUNTRY[1]	Number of Children with BLL > 5 µg/dL	Number of Children with BLL > 5 µg/dL (lower-bound estimate)	Number of Children with BLL > 5 µg/dL (upper-bound estimate)	Number of Children with BLL > 10 µg/dL	Number of Children with BLL > 10 µg/dL (lower-bound estimate)	Number of Children with BLL > 10 µg/dL (upper-bound estimate)
139	Poland	267,632	135,185	497,796	34,852	20,218	59,791
140	Portugal	97,745	42,259	196,510	9,560	4,580	18,129
141	Qatar	22,984	10,517	45,631	2,525	1,332	4,667
142	Republic of Korea	219,179	132,968	375,060	24,969	16,863	38,411
143	Republic of Moldova	193,045	89,492	342,986	28,132	10,395	66,296
144	Romania	402,440	181,534	782,724	47,462	22,433	96,156
145	Russian Federation	3,113,839	1,424,244	5,928,361	367,890	178,790	719,439
146	Rwanda	1,327,355	602,192	2,443,172	175,460	69,592	398,041
147	Saint Kitts and Nevis	432	147	1,010	5	-	19
148	Saint Lucia	2,604	867	6,310	50	7	172
149	Saint Vincent and the Grenadines	4,561	1,446	11,170	137	20	479
150	Samoa	2,598	669	8,151	1	-	20
151	San Marino	121	70	202	16	11	23
152	São Tomé and Príncipe	20,201	9,175	37,100	2,658	1,060	6,018
153	Saudi Arabia	368,766	184,566	729,532	41,538	23,546	75,513
154	Senegal	1,896,621	878,328	3,380,318	265,894	101,231	611,797
155	Serbia	164,391	77,828	314,038	19,685	9,696	38,684
156	Seychelles	495	145	1,365	-	-	-
157	Sierra Leone	2,297,191	1,329,283	3,210,974	557,770	193,226	1,166,481
158	Singapore	41,699	19,464	83,620	4,192	2,114	7,740
159	Slovakia	39,588	19,708	73,182	5,130	2,901	8,869
160	Slovenia	8,005	4,657	14,200	1,182	797	1,911
161	Solomon Islands	95,053	27,482	180,159	3,113	45	15,555
162	Somalia	8,141,711	5,613,810	9,947,692	2,731,229	1,105,507	4,840,500
163	South Africa	4,750,794	2,235,464	8,368,352	692,063	259,962	1,619,975
164	South Sudan	2,326,421	1,207,126	3,587,487	451,970	152,387	1,039,253
165	Spain	254,139	139,874	512,480	27,358	17,075	49,422
166	Sri Lanka	238,131	59,977	738,474	162	-	2,005
167	Sudan	12,525,390	7,550,683	16,617,314	3,165,459	1,052,544	6,664,349
168	Suriname	14,228	4,715	35,937	317	43	1,122
169	Sweden	27,912	17,799	43,151	3,984	2,860	5,650
170	Switzerland	54,701	26,907	108,394	5,798	3,250	10,514
171	Syrian Arab Republic	1,905,840	871,811	3,318,221	271,737	90,260	670,836
172	Tajikistan	1,704,817	867,486	2,706,863	304,651	105,943	702,577
173	Thailand	128,384	46,519	304,469	-	-	-
174	Timor-Leste	273,898	84,480	488,717	11,626	216	57,160

1. More information can be found at lead.pollution.org

	AREA/ COUNTRY	Number of Children with BLL > 5 µg/dL	Number of Children with BLL > 5 µg/dL (lower-bound estimate)	Number of Children with BLL > 5 µg/dL (upper-bound estimate)	Number of Children with BLL > 10 µg/dL	Number of Children with BLL > 10 µg/dL (lower-bound estimate)	Number of Children with BLL > 10 µg/dL (upper-bound estimate)
175	Togo	1,509,799	736,098	2,409,937	270,562	89,358	619,311
176	Tonga	669	211	1,913	-	-	-
177	Trinidad and Tobago	5,230	2,319	11,730	57	19	163
178	Tunisia	467,758	205,940	928,732	49,389	21,687	108,882
179	Turkey	643,762	321,545	1,195,588	77,084	44,424	131,081
180	Turkmenistan	113,062	50,897	218,949	13,631	6,769	25,093
181	Tuvalu	74	22	217	-	-	-
182	Uganda	5,243,550	2,463,734	9,534,505	695,697	283,703	1,577,996
183	Ukraine	263,193	133,799	504,459	35,416	20,999	62,387
184	United Arab Emirates	41,924	21,839	81,178	5,040	3,032	8,785
185	United Kingdom	213,702	186,117	281,542	29,036	25,099	42,470
186	United Republic of Tanzania	7,278,659	3,438,673	13,064,052	985,553	394,413	2,235,313
187	United States of America	1,230,558	753,672	2,090,864	159,679	111,735	243,749
188	Uruguay	178,744	80,199	333,111	19,283	7,531	45,148
189	Uzbekistan	1,642,279	750,074	3,179,138	193,682	89,600	406,318
190	Vanuatu	14,216	2,972	38,546	99	-	675
191	Venezuela (Bolivarian Republic of)	2,873,401	1,026,749	5,562,780	171,429	27,145	591,060
192	Viet Nam	3,242,192	711,362	8,993,910	22,775	-	154,780
193	Yemen	13,796,934	11,647,756	14,861,489	6,895,768	3,802,496	9,978,608
194	Zambia	1,190,789	528,363	2,302,307	140,715	63,534	294,771
195	Zimbabwe	5,709,835	4,306,145	6,617,160	2,361,645	1,097,113	3,735,569
	REGION	**Children above 5 µg/dL BLL mean**	**Children above 5 µg/dL BLL lower**	**Children above 5 µg/dL BLL upper**	**Children above 10 µg/dL BLL mean**	**Children above 10 µg/dL BLL lower**	**Children above 10 µg/dL BLL upper**
1	South Asia	378,651,188	309,826,991	450,840,325	95,765,725	66,100,055	135,547,935
2	East Asia and Pacific	77,675,947	41,621,175	124,286,113	2,006,683	155,639	8,342,141
3	West and Central Africa	139,373,360	84,948,399	197,034,081	36,880,830	15,848,344	68,660,469
4	Eastern and Southern Africa	93,109,913	49,946,531	146,414,745	18,463,189	7,093,354	38,228,300
5	Middle East and North Africa	63,441,649	40,514,465	88,791,458	16,347,077	7,609,714	29,259,583
6	Eastern Europe and Central Asia	10,027,028	4,706,887	18,590,896	1,308,404	589,960	2,702,653
7	Latin America and Caribbean	49,107,507	29,270,540	71,601,467	4,702,663	1,253,461	11,879,307
8	North America	1,359,412	832,648	2,311,908	176,213	123,199	269,076
9	Low-Income Countries	249,251,174	158,564,810	345,066,610	73,811,735	34,963,414	129,469,651
10	Western Europe	2,474,105	1,392,822	4,499,437	294,198	186,147	494,057
11	Sub-Saharan Africa	232,483,273	134,894,930	343,448,826	55,344,019	22,941,698	106,888,769
12	Europe and Central Asia	12,501,133	6,099,709	23,090,333	1,602,602	776,107	3,196,710

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Map Source: Mapzen, OpenStreetMap, and others
Graphic: Charlie Szymanski, Christine Chan, Matt Weber, M.B. Pell
Data Sources: State agencies or CDC. Some states did not include data for census tracts and zip codes if the testing numbers were small, usually below five, to protect patient privacy.
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Pure Earth
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