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2015 World's Worst Pollution Problems

The New Top Six Toxic Threats: A Priority List for Remediation

World's Worst Pollution Problems 2015

This document was prepared by Pure Earth and Green Cross Switzerland with input and review from a number of experts and volunteers, to whom we are most grateful.

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Cover photo:
A man works in the chromium fields of Kanpur, India, an area that receives waste from, nearby tannery factories. Inhalation of chromium particles is the most common route of exposure on occupational settings. Observations documenting higher lung cancer rates in workers occupationally exposed to chromium date back to the 1930s.

Photograph by Sean Gallagher

Back cover photo:
On the Indonesian island of Sulawesi, a ball mill operation uses pure mercury to facilitate gold extraction form ore. The use of mercury in gold mining has been made illegal in Indonesia. However, its use continues in remote operations and as a result of existing black markets and corruption. Many industrial processes such as ASGM involve the heating of elemental mercury, resulting in the release of mercury vapors into the environment. These mercuric vapors can then settle as dust onto soil surfaces or surface water bodies through precipitation.

Photo by Larry C. Price

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Letter from Richard Fuller

In 1999, I founded Blacksmith Institute in New York—the result of an eventful decade of my life and a desire to make an impact on the world. At the time, very little was known about pollution in low- and middle-income countries. Indeed part of the impetus for the organization was a simple chart on a white board; four quadrants, "West" and "South" written down the Y axis, "Green" and "Brown" across the top.

West and South referred, roughly, to hemispheres; Brown and Green to environmental agendas. The chart was part of a series of retreats of sorts that I hosted at my home for like-minded people. The goal of the retreats was to identify the most underserved area in the environmental movement and determine a way to address that gap. In each quadrant, we listed organizations that worked in that area—World Wildlife Federation, Conservation International, Save the Whales—all impressive organizations engaged in powerful, transformative work.

When we were done filling in the names of every organization we could think of, we looked back at the board. Staring back at us was the bottom right quadrant: Brown/ South. We could think of no organization, government or otherwise working in this area. I drew a big "X" in the quadrant and wrapped my knuckles on the board. "This space has a big fat zero. We'll make our impact here."

Since that fateful series of retreats at my home, much has changed about our organization. Rather than being run by volunteers, we now have dozens of paid professionals working out of offices in New York, London, New Delhi, Jakarta, and many other cities around the world. We have developed an impressive portfolio of projects, impacting the lives of millions of people. We have changed our name to the more descriptive Pure Earth. And importantly, we have helped identify and single out a silent killer, pollution. Indeed, we now know that pollution accounts for 1 in every 7 deaths in low- and middle-income countries.

Each year, with our partner Green Cross Switzerland, we release a report on pollution and health. This series, "The World's Worst Pollution Problems," has been reported on widely from the *New York Times* to *National Geographic* and the *Times of India*. It has been downloaded thousands of times from our servers. In this way, it has made a significant impact on the public's awareness of the issue.

This year we report on six pollutants that pose an outsized threat to human health. The pollutants—Lead, Radionuclides, Mercury,

Pollution accounts for 1 in every 7 deaths in low- and middle-income countries. The Top Six Toxic Threats outlined in this report collectively affect the health of 95 million people.

Hexavalent Chromium, Pesticides and Cadmium— collectively affect the health of 95 million people and account for over 14.7 million Disability Adjusted Life Years in low and middle-income countries. These pollutants result in debilitating, life-threatening diseases, particularly in children.

We also report on some important advances in the pollution management area. The World Bank has launched the Pollution Management and Environmental Health program (PMEH) to focus on water, air and soil pollution. We expect to see some good results here. Elsewhere, UNEP has spearheaded the Minamata Convention on Mercury. The convention will prohibit new mercury mines and phase out existing mines by signatory countries. Finally, The Global Alliance on Health and Pollution (GAHP) has formed a special Commission on this issue. We report on this progress in special sections in the report.
We hope you find this document useful and informative. We also hope you'll join us in working on this important issue.

Sincerely,
Richard Fuller

President, Pure Earth
Co-chair, Global Commission on Pollution Health & Development

Introduction

The *2015 World's Worst Pollution Problems report* is the tenth in an annual series published by Green Cross Switzerland and Pure Earth (formerly Blacksmith Institute). Over the past decade, this series identified and drew attention to the worst, and most dangerously polluted places on the planet, while documenting and quantifying the startling health and human impacts of this neglected problem. The "World's Worst" series of reports has effectively raised global awareness about the extent and impacts of toxic pollution in low-and middle-income countries.

Last year's report looked at the "Top Ten Countries Turning the Corner on Toxic Pollution" profiling countries and projects making significant strides in saving lives, improving human health and restoring environments. Their successes were the result of perseverance by champions inside government agencies, civil society groups and individual communities. These countries provide examples of what can be achieved, even as pollution continues to pose a significant and credible risk to human health.

Revisiting the Top Six Toxic Threats from 2010

Defining The New Top Six Toxic Threats in 2015

This year we present an update on the six pollutants that pose an outsized threat to human health. The pollutants—lead, radionuclides, mercury, hexavalent chromium, pesticides and cadmium—collectively affect the health of 95 million people and account for 14,750,000 Disability Adjusted Life Years lost in low and

(Left) A farmer stands in a crop field in the Malwa region of Punjab, India. Pesticides are used extensively throughout the world to increase agricultural output and protect crops from pests and disease. However, many of these compounds pose harmful health risks and difficulty lies in striking a balance between food security and the desire to protect the health of populations and the environment.

Photo by Sean Gallagher

middle-income countries. These pollutants result in debilitating, life-threatening diseases and death.

The pollutants, which were highlighted in 2010, still clearly stand out among the others around the world. These affect more people at more sites at a greater dose than other pollutants. Their toxicological profiles are well defined and severe. In almost all cases, affordable interventions exist to mitigate the worst exposures from sites exhibiting these contaminants. There is one change in this year's top list: cadmium replaces arsenic.

This year's report also examines how advances in data gathering and analysis on the scope and impact of pollution, improve our understanding of the scale of these toxic threats. The 2012 Worst Polluted report established the first set of figures for the health burden of toxic pollution at contaminated sites, by estimating for this pollution—the basic parameter developed by the World Health Organization for assessing the Global Burden of Disease—the Disability Adjusted Life Year or DALY. In the years since then, these DALY estimates have been expanded and refined, resulting in broad acceptance by the international health community of this evidence of the impacts of toxic pollutants. Similar DALY estimates are now available for other forms of pollution, demonstrating the extent of overall damage caused by multiple substances. In this context, the number of people exposed to dangerous levels of pollution is increasing, with an estimated 1 in 7 deaths in 2012 resulting from exposure to soil, water, air and/or chemical pollution.

The improved data and analysis on pollution has resulted in some changes but little has happened in terms of significant cleanup. Strikingly, as progress is made on some of the classic communicable diseases in developing countries (malaria, HIV, Tuberculosis), the proportion of the overall burden of disease attributable to toxic threats is increasing. In some ways, this reflects a version of the "epidemiological transition" but it also emphasizes again the growing urgency of tackling toxic pollution.

Stubborn challenges remain in dealing with recycling lead from used batteries, while vehicle numbers continue to grow worldwide. Gold prices are still high and consequently emissions of mercury from small-scale gold mining will continue to increase and migrate globally. There has been very little progress in dealing with problems of heavy metals from poorly managed mining and processing or with dumps of obsolete or discarded pesticides.

In addition, the scale and health impacts of air pollution continue to multiply, and water quality issues worldwide show little improvement. For reasons such as these, it is important that we keep the focus on the call for remediation action.

However, the call is beginning to be heard resulting in new commitments from members of the international community—amplified by the Global Alliance on Health and Pollution. Some funders are beginning to recognize and to provide programmatic support for efforts to reduce the burden of pollution on mankind.

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Better Data Confirm the Impacts of Top Pollutants

Comparing Global Bads

A basic problem in making assessments across different types of health risks is the fundamental challenge of comparing the impacts of very different health conditions and disabilities. The approach that is most widely used is the Disability Adjusted Life Year (DALY). The DALY, developed by the World Bank and WHO in work that began in 1991, evaluates the consequences of different conditions in terms of both disease and early death and generates a single value representing overall impacts, thus allowing for direct comparison across different health conditions. This approach allowed worldwide comparisons across conditions and countries, now presented in the Global Burden of Disease reports, the most recent published being for 2010, where several hundred investigators collaborated to prepare consistent and comparable numbers. The mortality and burden attributable to 67 risk factors or clusters of risk factors behind the conditions were also assessed and reported.

DALYs can be thought of as lost years of "healthy" life and represent the sum of two separate calculations: years lived with disability (YLD), which corresponds to disease-related morbidity, and years of life lost (YLL), which represents premature mortality from disease.

(Left) Effluents from chromium industries may contain high concentrations of dissolved and suspended organic and inorganic solids, toxic metal salts, heavy metals, chrome and harmful electrolytes. These effluents often contaminate surface and groundwater sources, posing a serious hazard to nearby communities.

Photo by Sean Gallagher

A YLD is meant to capture the duration and severity of a given health outcome. The duration of an illness in years is multiplied by a numerical value meant to capture the severity of that illness. This numerical value, called a Disability Weight (DW), has been determined by WHO researchers for a long, though not comprehensive list of health outcomes. The higher the DW, the more severe the adverse health outcome; a DW of zero represents perfect health, while a DW of 1 represents death. Thus moderate hearing loss that is treated has been assigned a DW of .04, while AIDS that is not treated has a DW of .505, for each year. Because duration receives an equal waiting to severity, chronic illnesses can result in significant YLD contributions.

YLLs are an effort to capture the impact of premature death. The age of death for an individual is subtracted from the ideal life expectancy for that individual. The resulting number is his contribution to YLL. Thus if the ideal life expectancy is 85, and an individual dies prematurely at 50, then he has contributed 35 YLLs. In DALY calculations, YLDs are added to YLLs across a population for a given health outcome. The resulting DALY count can then be compared with other health outcomes to assess its overall societal impact.

This approach allows policy makers to make an assessment of the cost effectiveness of potential interventions, by estimating a cost per DALY saved. This approach has been used for interventions as varied as collapsible steering columns and mosquito nets.

DALY estimates from pollution are difficult to develop because the exposure of an individual to environmental pollution depends on the relative amounts of time spent indoors and outdoors, the proximity to sources of pollution, and the concentration of pollutants. The actual dose delivered to the lung or other organs in the body will depend on the type of pollutant, the breathing pattern and physical characteristics of the individual. Furthermore, assigned disability weights (DW) have yet to be agreed upon for several important sources of pollution. Despite these challenges, Pure Earth has updated DALY estimates for contaminated sites based on the approach developed and applied by Chatham-Stephens et al (2013),[1] which refined and has taken further the WWPP 2012 estimates.

The *2012 World's Worst Pollution Problems report* was the first to include the DALY metric. In that year, Pure Earth began to use its growing data on contaminated sites to estimate their disease burden. Since then, more has been learned about the extent of contamination and updated DALY estimates are provided in this report for each of the Top Six.

Extent of the Contaminated Site Problems

A key to determination of the global impacts of contaminated sites is the estimation of the total number of sites and of people affected. Since 2008, Pure Earth has identified over 3,200 contaminated sites in 49 countries and conducted in-country assessments at over 2,300 of those. These sites alone represent a potential health risk to more than 95 million people but they are certainly only a small fraction of the overall total of sites that need to be addressed as priorities. A study recently carried out by Pure Earth in Ghana suggests that the present databases may only cover perhaps ten percent of the actual sites. When the less urgent but still hazardous sites are included, the numbers in many countries will be much greater again: a review in the USA in 2004 by the EPA identified nearly 300,000 sites that would ultimately require remediation. Thus, the impacts identified in this report are necessarily an undercount.

FILLING IN THE GAPS: HOW MANY SITES ARE THERE?

In 2015 Pure Earth began a project to assess and extrapolate the number of heavy metal contaminated sites in Ghana. Using a visible site identification rubric a team of investigators based in Ghana mapped eight randomly selected administrative districts street by street. If a potential site met a minimum criterion on the rubric, a soil sample was taken and analyzed via x-ray fluorescence (XRF) to determine the content of heavy metals in soil. A 'key pollutant' at each site was selected based on the results of the analysis in relation to a recommended level such as screening levels set by the USEPA.

Seventy-two contaminated sites with results above a recommended level were identified in the project for an average of nine sites per district. Using a formula that gives an equal weighting to the number of sites found in each selected district, the area of each district and population found in each district, a weighted estimate was calculated to extrapolate the possible number of sites found in the country. In total, the team estimates that 1,944 sites contaminated by heavy metal pollution exist in Ghana. This is roughly nine times the current number of sites found in Pure Earth's database, and likely the best estimation of the number of heavy metal contaminated sites in Ghana.

This type of exercise will be replicated and refined elsewhere. In so doing we hope to develop more accurate estimates of the number of sites globally and the resulting burden of disease.

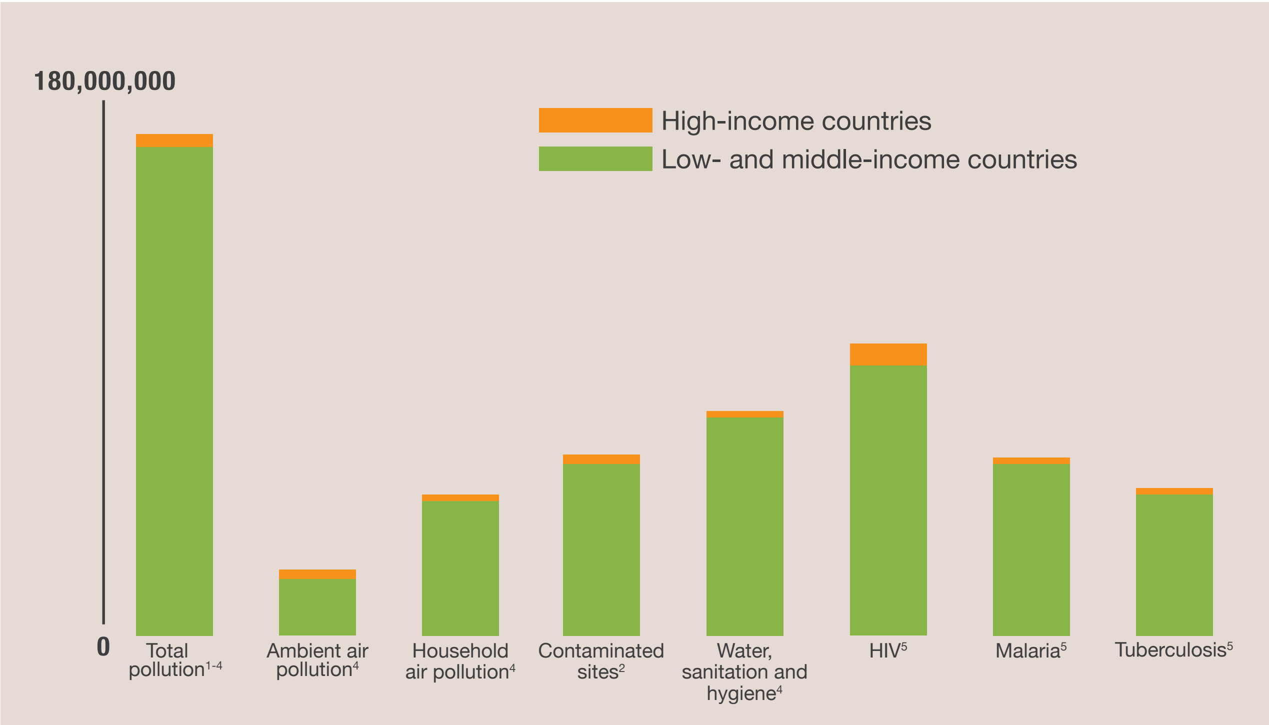
DALYs at Contaminated Sites

Chatham-Stephens calculated the DALYs for exposure to industrial pollutants at 373 toxic waste sites in India, Indonesia and the Philippines, building on data collected in the Toxic Sites Inventory Program. The team calculated Years Lived with Disability (YLD) and Years of Life Lost (YLL) for exposure to each contaminant through the relevant environmental media (air, soil and water) by combining estimates of disease incidence from these exposures with population data. For YLD, they used a consistent method to calculate disease incidence for all chemicals, except for lead where the availability of lead specific modelling tools and dose response relationships allowed more specific estimates.

The risk per person was determined for carcinogenic and non-carcinogenic effects. For carcinogens, the US EPA's Regional Screening Level Calculator for Chemical Contaminants was used to calculate long-term cancer risk per unit toxicant. For non-carcinogenic health effects, reference doses (RfD) and concentrations (RfC) from the US EPA's Integrated Risk Information System (IRIS) database were applied to the exposure pathways and contamination levels at each site. YLD for lead was calculated for mild mental retardation and anemia in children, and cardiovascular disease in adults. Additionally, Chatham-Stephens calculated YLL for carcinogens. They used cancer incidence and survival data to calculate the number of deaths. All cancers were assumed to last five years, before either going into remission or resulting in death. The risk numbers are then multiplied by the level of the contaminant in the relevant environmental medium.

These methods continue to be developed, given that gaps in data exist. Specifically, new analysis is being pursued to develop disability weights for a number of toxicants, including mercury.

GLOBAL POLLUTION DALYs VERSUS OTHER MAJOR CAUSES



1: Disease and injury regional mortality estimates 2011. http://www.who.int/entity/healthinfo/global_burden_disease/estimates_regional/en/index.html
2. Contaminated sites data extrapolated from GAHP database.
3. Population for 2013 - high income. Available at: http://www.tradingeconomics.com/high-income/population-total-wb-data.html
4 DALYs and deaths attributable to selected environmental risk factors, by WHO Member State, 2004. http://www.who.int/quantifying_ehimpacts/national/countryprofile/intro/en/
5. Estimated DALYs by cause, WHO Member States, 2012 http://www.who.int/healthinfo/global_burden_disease/estimates/en/index2.html

In addition, the methodologies to define the full extent and influence of contaminated sites need to be further refined so that more confident estimates can be prepared.

DALYs and This Year's Report

In the *2012 Top Ten Sources by Global Burden of Disease report*, we calculated DALYs for contaminated sites for the first time. Because this exercise was innovative, and extrapolated from a very limited dataset, the estimates were kept conservative. In 2012, the Toxic Sites Identification Program (TSIP) had assessed 1600 contaminated sites in 49 countries. These sites were visited, samples taken, and basic characteristics noted. Completed assessments were entered into a database for review and comparison. This database was then used as basis for initial efforts to estimate the number and type of contaminated sites globally. The overall assumed numbers of sites and the best estimate of the resulting DALYs were then presented. Importantly, this estimate was very likely an undercount of both the total sites and total DALYs. To illustrate this, note that the estimate used for the total number of sites in low and medium income countries with a total population of more than 5 billion people was less than one thirtieth of the estimate developed by the USEPA for the number of sites requiring remediation in the US alone, which has a population of 320 million.

Since the 2012 report, more than 800 additional sites around the world have been assessed and included in the database. These additional sites were identified through increased coverage and efforts and they turn out to be remarkably similar in scope and severity to those previously identified. The numbers affected are also in the same broad range already seen in previous surveys. Given this apparent consistency in the profiles of sites in the expanded database, the broad estimates of the total number of sites to be remediated have been held unchanged. Although it is clear that the estimated worldwide totals are only a lower bound, the data available does not yet allow better projections. More data collection and further research would be required, needing significantly more resources than are currently allocated. Preparing more precise and accurate estimates of total sites is probably best done on a country-by-country basis, with national authorities driving the efforts. Nevertheless, the estimated total disease burden resulting from contaminated sites presented in this report is staggering. It is comparable to other more well-known adverse health outcomes, and still receives remarkably little attention.

Revisiting the Top Six

The pollutants, which were highlighted in 2010, still clearly stand out among the others around the world. These affect more people at more sites at a greater dose than other pollutants. Their toxicological profiles are well defined and severe. In almost all cases affordable interventions exist to mitigate the worst exposures from sites exhibiting these contaminants. There is one

TOP SIX TOXIC CONTAMINANTS

- **Lead**

  Population at risk: 26m
  DALYs: 9m

- **Radionuclides**

  Population at risk: 22m*
  DALYs: N/A

- **Mercury**

  Population at risk: 19m
  DALYs: 1.5m

- **Chromium**

  Population at risk: 16m
  DALYs: 3m

- **Pesticides**

  Population at risk: 7m
  DALYs: 1m

- **Cadmium**

  Population at risk: 5m
  DALYs: 250,000

- **Total**

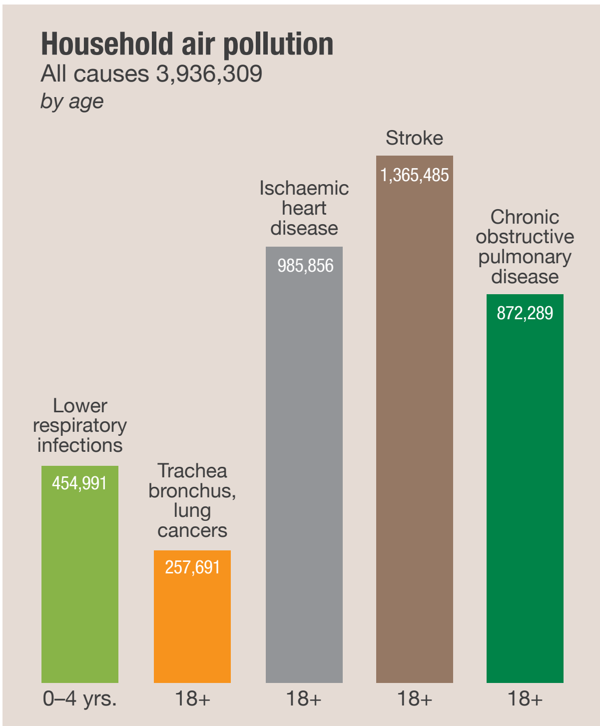
  Population at risk: 95m
  DALYs: 14,750,000 years of lost life

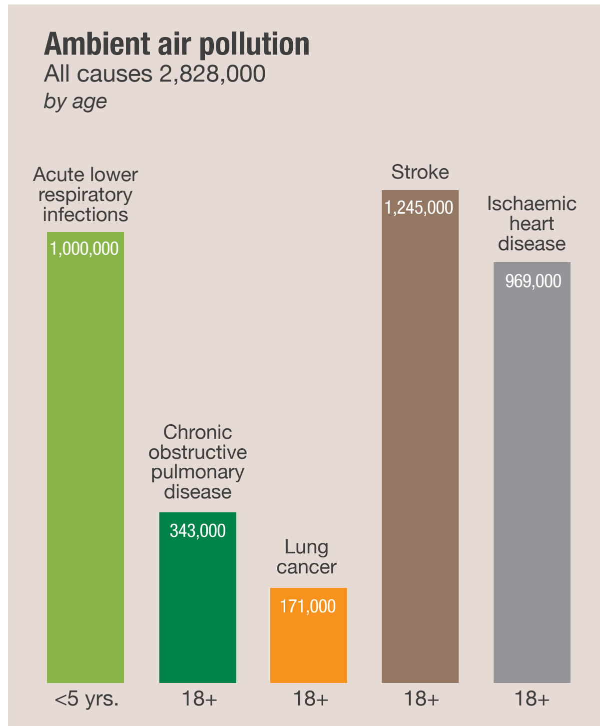
DALYs—Disability Adjusted Life Year

*Estimate includes 800k to 1 million at risk based on point source exposure to radionuclides derived from 91 identified sites in the Toxic Sites Identification Program

HOUSEHOLD & AMBIENT AIR POLLUTION ATTRIBUTABLE DEATHS IN FOUR LOW- AND MIDDLE-INCOME WHO REGIONS

Africa, America, South-East Asia, Western Pacific





change in this year's top list: cadmium replaces arsenic. Both are very serious toxic pollutants, but the story of arsenic is much complicated by the enormous extent of the problems caused by use of groundwater from aquifers contaminated by naturally released arsenic. This problem is most well known from the impacts on countless millions of rural villagers in Nepal, Bangladesh and parts of India, but also occurs in other parts of the world. This is a major issue, but now deemed to be outside the scope of these reports on polluted hot spots. Cadmium has long been recognised as a significant health threat, with numbers at risk similar to those affected by arsenic pollution, and is another heavy metal whose persistence and ubiquity makes it a real worldwide health problem.

Population estimates for contaminated sites are notoriously difficult to calculate. Myriad factors contribute to any individual's exposure profile, such as the length and the route of exposure. Moreover, each individual responds differently to toxics. While one person may fall ill from drinking contaminated water, another may suffer no negative effect. Determining the number of people whose health is at risk at a given site therefore requires a number of assumptions.

The numbers presented below are based primarily on accumulated experience in assessing sites. Over the past seven years our teams have visited some 2,300 sites in 49 countries. This experience has given us a unique insight into the pollution profiles of certain industries and sites. This experience has been used to develop basic estimates of the total number of sites and people exposed in the regions where the data have been collected. Those estimates are then tested by targeted site assessment and extrapolation exercises (for example, the Ghana mapping discussed above). These estimates are further buttressed through literature review, consulting industry data, and through consultation with relevant experts. Nevertheless the numbers presented here should be taken as indicative rather than definitive estimates of the human health impact of pollution. Further information on the estimates for each pollutant is included with the discussion of the pollutants later in this report.

It must be noted that our estimates regarding the population at risk of exposure to radionuclides has increased significantly since the 2010 report. We believe that incorporating data from additional sources illustrates a more accurate representation of the burden it places on low- and middle-income countries. The population at risk estimates for radionuclides generated by Pure Earth is derived from 91 sites involving the mining and processing of uranium identified through the Toxic Sites Identification Program (TSIP). To date, the TSIP Program has not had the resources to assess health impacts resulting from nuclear power plant disasters and those affected by their associated fallout. However, studies conducted by Green Cross Switzerland in coordination with the University of Southern California estimate a much larger additional population at risk for exposure to radionuclides. This literature review estimates that 10 million individuals are at risk of health effects resulting from the Chernobyl nuclear disaster (1986) alone. We also include a lower level estimate of 500 thousand for the population affected by the Fukushima Daiichi nuclear disaster (2011). Other populations not accounted for through TSIP include those exposed to low-dose radiation, nuclear industry personnel, as well as those suffering from the psychological effects resulting from the threat of radionuclide exposure.

As these populations are no less affected by radionuclides, we include them along with population estimates at risk generated through TSIP data. Taking those figures into account, an additional 20 million or more individuals may be at significant risk of exposure to radionuclides.

This year, it is possible to provide both Population at Risk figures (as for 2010) and estimated DALYs (given for some industries in 2012) for each of these Top Six contaminants.

The six pollutants are summarised here and presented in more detail later. Possible interventions and some recent case studies of interventions in action are also included.

Lead

Lead (Pb) is a heavy metal and powerful neurotoxin that occurs naturally in the environment. This metal has been mined for centuries for use in a variety of products and is combined with other metals to form alloys. Lead is often released into the environment during mining, smelting, and lead recycling processes. Exposure to lead through inhalation of contaminated dust, ingestion of contaminated soil, water or food and through dermal contact can result in a variety of health effects including neurological damage, IQ decrement, anemia, nerve disorders and a host of other health problems. The effects of lead are most severe in children, and at high concentrations, lead poisoning can result in death.

Radionuclides

Radionuclides occur either naturally in soil and rocks (e.g. uranium, thorium, potassium) or have been artificially produced by men since the discovery o the atom (e.g. plutonium, americium). Most environmental releases of radionuclides are the result of industrial processes such as uranium mining, mine waste disposal, nuclear weapons production and testing, nuclear energy production and creation of radiological products used in medicine. Exposure to radionuclides through ingestion and inhalation may result in

(Left) Sukhbeer Kaur (19) holds a portrait of her father, Pippal Singh, who died in 2010 of cancer at the age of 40. Excessive pesticide use in the region is thought to contribute to an increase incidence of cancer. Exposure to pesticides is a known risk factor for cancer development affecting the prostate, pancreas, liver, lungs and other organs.

Photo by Sean Gallagher

acute health effects such as nausea, vomiting and headaches to chronic health effects such as fatigue, weakness, fever, hair loss, dizziness, disorientation, diarrhea, blood in stool, low blood pressure and death. Ionizing radiation resulting from exposure to radionuclides may cause cell damage in humans that results in cancer development or genetic aberration.

Mercury

Mercury (Hg) is a heavy metal that occurs as elemental mercury, or in chemical compounds as inorganic mercury or organic mercury. Elemental mercury is used in a variety of industrial processes such as the extraction of gold from gold-containing ores and is also found in products such as thermometers and dental fillings. Exposure to elemental mercury may cause brain, kidney and immune system damage, as well as impair fetal development. While inorganic mercury is found in a number of industrial compounds, exposure to harmful levels is unlikely. However, organic mercury is produced when elemental mercury combines with carbon and is most commonly found in the environment as methylmercury, another potent neurotoxin. Methylmercury is known to cause Minamata disease, a severe neurological syndrome.

Hexavalent Chromium

Chromium (Cr) is a naturally occurring heavy metal that is often used in industrial processes. Although it can be released into the environment through natural processes, it is often released as a result of industrial activities, particularly those related to leather processing. Chromium is found in one of two forms: chromium III (trivalent) and chromium VI (hexavalent). While trivalent chromium is a mostly stable form that occurs naturally, hexavalent chromium tends to result from industrial processes and has a number of deleterious health effects. Depending on the route of exposure, chromium can cause damage to the respiratory and gastrointestinal systems. Additionally, hexavalent chromium is a known human carcinogen and can increase the rate of various cancer types based on the exposure route. While lower in toxicity, trivalent chromium may still cause negatively health effects and may cause damage to DNA.

Pesticides

Pesticides are substances, often chemical in nature or heavy metals, that have been used extensively the last hundred years throughout the world to protect crops by eliminating pests and thereby increasing agricultural output or control disease vectors. However, a significant amount of these pesticides are washed away by rainfall into surface and groundwater, allowing the nearby population to be exposed. Some of the old pesticides (so called POPs, like DDT) are even migrating globally, affecting communities thousands of kilometres away from where they have been used. General acute effects from pesticide exposure include headaches, nausea, dizziness and convulsions. Chronic exposure to pesticides may result in neurological, reproductive and dermatological health impacts.

Cadmium

As assessment activities are expanded, particularly in Asia, this issue is beginning to be more common. Cadmium is a byproduct of zinc mining and processing and can be released to the environment from smelting and from mining wastes. Cadmium also occurs in some phosphate rock and therefore in some fertilizers. It limited industrial use—mainly in electroplating and batteries. It can be transported long distances from smelters associated with small airborne particles and then deposited on the soil. Cadmium is readily taken up from the soil into the food chain, by plants, including leafy vegetables and cereals, and can also be dissolved in water and affect fish. Human exposure is typically through a contaminated food chain or from (active or passive) smoking. Even small amounts of cadmium can cause significant human health impacts.

Overall Pollution Burden

Recently, there has been much increased attention to the health impacts of all types of pollution, driven in part by the publicity given to new data on the impacts of air pollution. The most striking fact information emerging from these recent analyses is the huge and previously unrecognised role of pollution on the health of the world's population. The *2012 World's Worst report* concluded that industrial pollution was a health problem of the same order as notorious diseases such as malaria, based on estimated DALYs.

Recently released WHO figures calculated that in 2012, exposures to pollutants in air, water and soil resulted in an estimated eight million deaths in low and middle-income countries. By comparison, HIV/AIDS causes 1.5 million deaths per year and malaria and tuberculosis fewer than 1 million each. The result is that about one death in seven worldwide is a consequence of environmental pollution.

FOOTNOTES

1. Chatham-Stephens K, Caravanos J, Ericson B, et al. Burden of disease from toxic waste sites in India, Indonesia, and the Philippines in 2010. *Environ Health Perspect*. 2013;121(7):791-796

2

The Growing Share of Pollution-related Diseases

Transition from Communicable to Chronic

This year's report specifically addresses an important shift in the burden of disease around the world: as progress is made on dealing with communicable diseases such as HIV or tuberculosis, the relative importance of chronic diseases is on the rise. Pollution is now widely accepted as one of the key risk factors for non-communicable disease (NCD). This shift is happening while improved knowledge is being developed about the number of sites globally and the scale of the related burden of disease—both of which are larger than previously known.

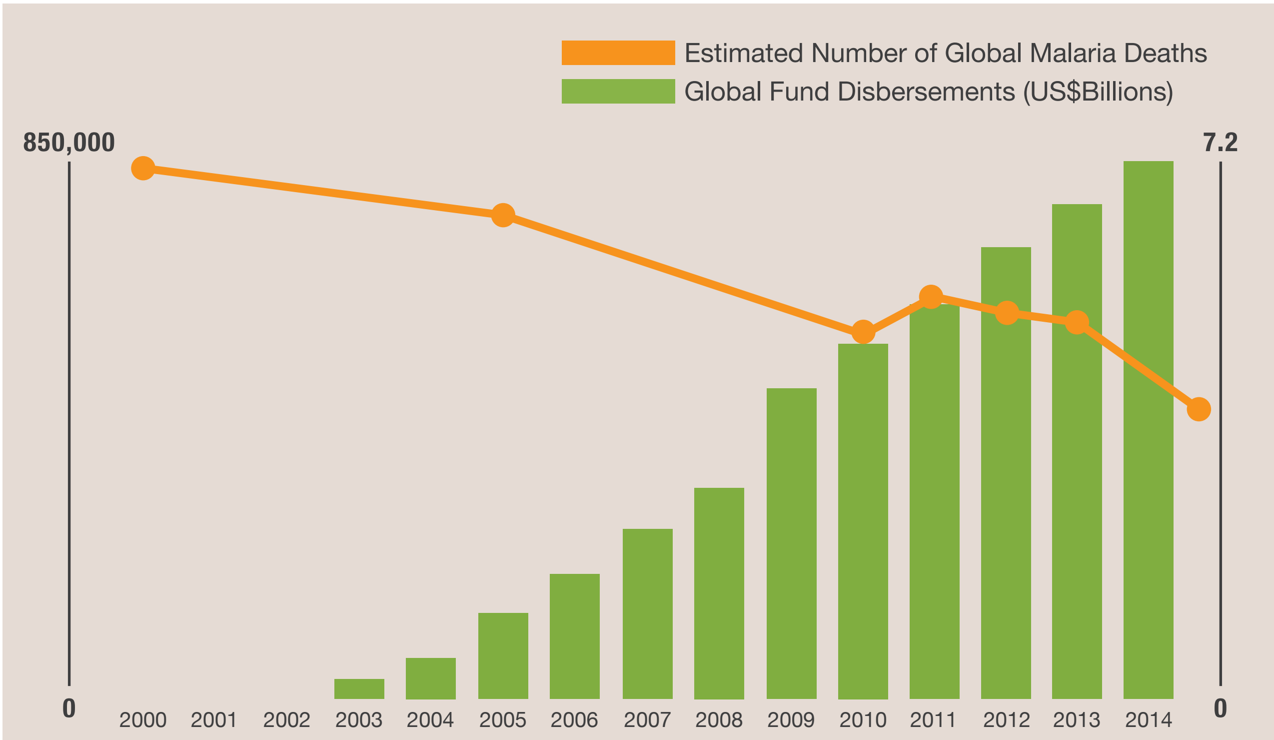
Recently, the burden of illness resulting from non-communicable diseases (NCDs) has played a larger role impacting the health of populations in low and middle-income countries (LMICs).[2] While significant progress has been made in lessening the burden of communicable disease, the incidence of chronic illnesses continues to surge. A number of factors have contributed to this transition including an increase in the popularity of processed foods, decreases in physical activity and shifting cultural norms.

The World Health Organization has estimated that by 2020, NCDs will be responsible for 80 percent

(Left) Chromium-contaminated wastewater from leather tanneries often finds its way into nearby water sources used for drinking, bathing and irrigation. Due to the relatively inexpensive cost of labor and materials, almost half of the world's tanning and leather industries are located in low- and middle-income countries.

Photo by Sean Gallagher

ESTIMATED GLOBAL MALARIA DEATHS AND GLOBAL FUND DISBURSEMENTS



Source: Achieving the malaria MDG target: reversing the incidence of malaria 2000-2015; WHO & Unicef, The Global Fund

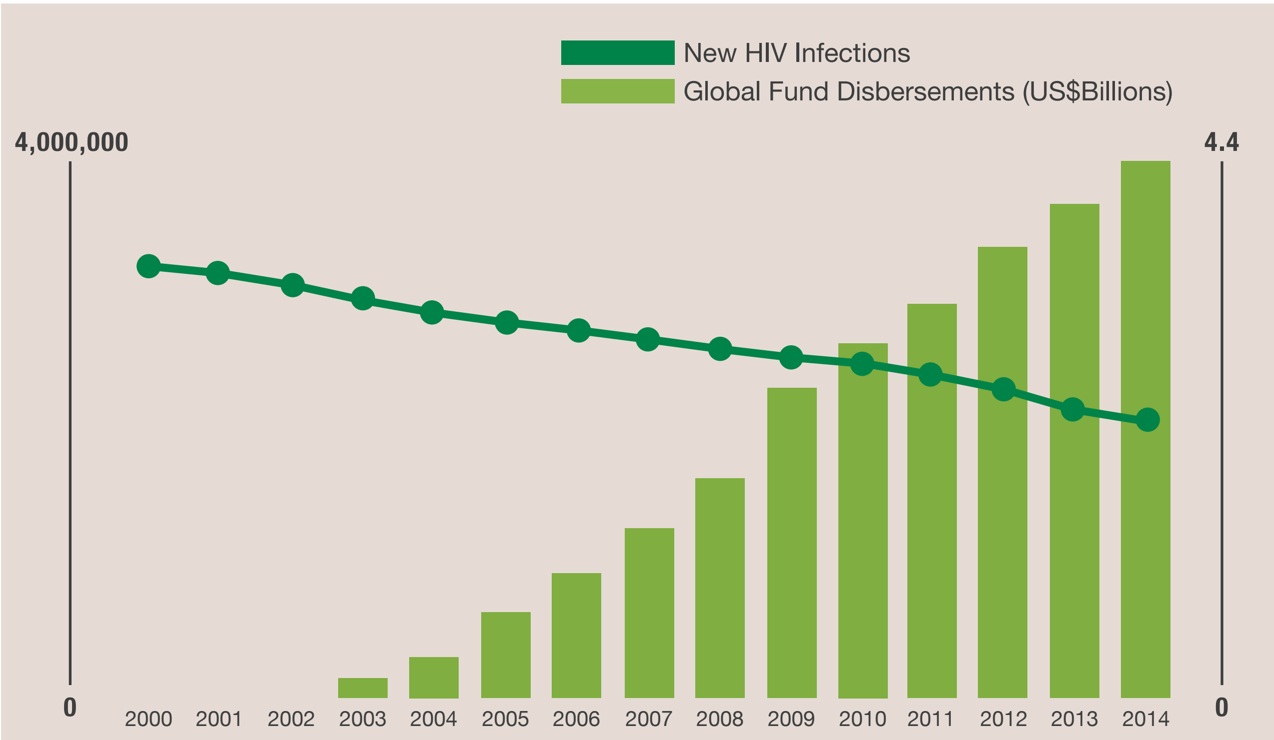
of the global burden of disease.[3] As globalization and urbanization continue to accelerate in LMICs, governments have had difficulty expanding efforts to prevent NCDs. A significant factor is toxic pollution, which is responsible for the death of one in seven people in LMICs. As detailed in our 2014 report, 94% of the burden of disease from pollution falls on LMICs that are ill equipped to ameliorate these issues. Exposure to toxic pollution largely contributes to the prevalence of chronic diseases in affected populations. Due to their persistence in the environment, heavy metals and other toxic pollutants used in industrial processes find there way into the bodies of nearby residents.

Exposure to Pollutants, Chronic Illness and the Burden of Disease in LMICs

Exposure to lead and resulting elevated blood lead levels have been associated with hypertension.[4] Increases in hypertension are associated with concurrent increases in risk of both cardiovascular and cerebrovascular disease, chronic diseases that place a large burden on LMICs. Aside from being the second leading cause of global mortality, more than 80% of cardiovascular disease cases were found in LMICs.[5]

IQ decrement and mild mental retardation (MMR) are also known to result from exposure to lead. This may be attributed to lead's ability to inhibit biochemical processes involving the regulatory action of calcium, and its ability to interact

TRENDS IN NEW HIV INFECTIONS IN GLOBAL FUND-SUPPORTED COUNTRIES



Source: UNAIDS, The Global Fund

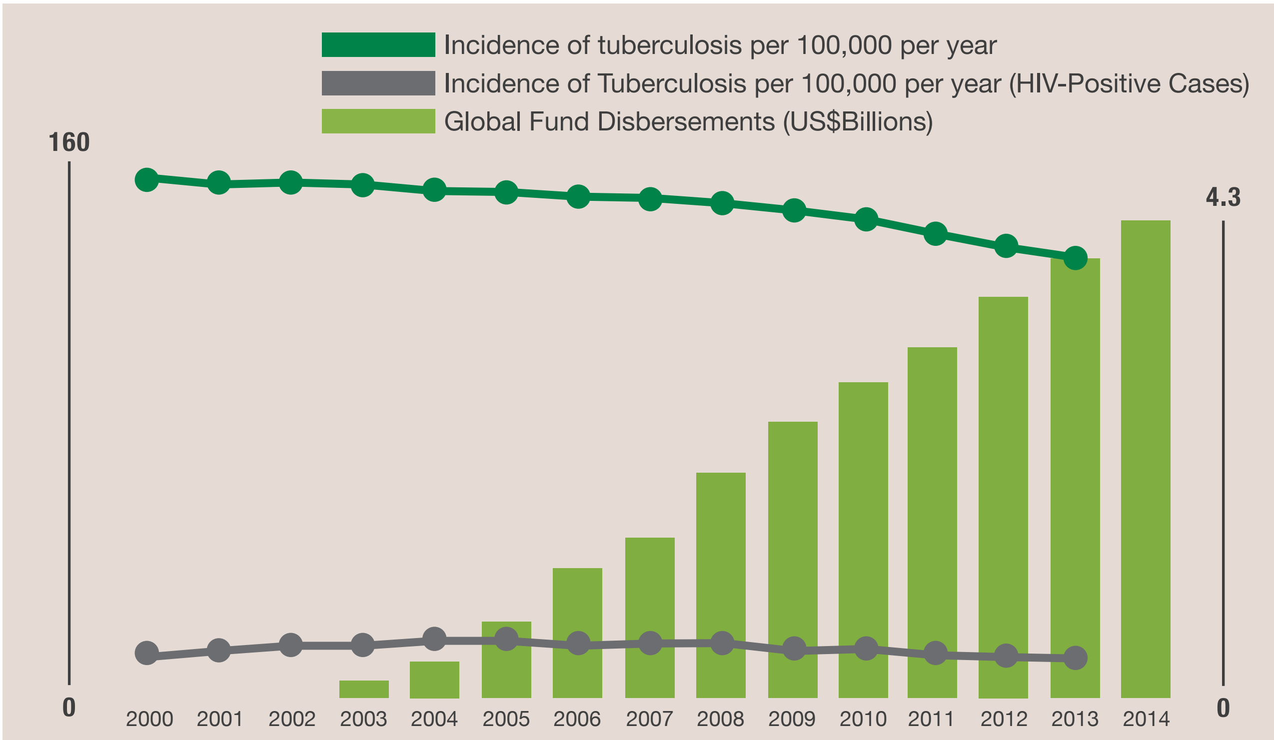
with proteins.[6] Both cardiovascular and MMR outcomes that have resulted from lead exposure have been estimated to account for .6% of the global burden of disease.[7]

Exposure to lead is also known to cause anemia through the process of heme synthesis impairment and the destruction of red blood cells.[8] Anemia in children results in a number of negative health effects including kidney dysfunction, mental retardation and impairment of psychomotor development.[4] Anemia has been estimated to account for 8.8% of total disability from all conditions, with young children and women shouldering the largest burden.

Exposure to mercury and pesticides in their various forms has been known have severe implications on the neurological system, including death. Perhaps the best documented of these neurological impacts is the neurological syndrome known as Minamata that results from exposure to methylmercury. High levels of pre- or postnatal exposure to methylmercury have been found to cause symptoms mimicking cerebral palsy in the developing fetus, while chronic psychiatric symptoms including intelligence impairment, shifting mood and erratic behavior has been documented in adults.[9] Additional neurological symptoms include mental retardation, delayed development, memory loss, language disorders, vision and hearing loss and seizures.[10]

An increase in life expectancies for individuals in LMICs have resulted from improved reproductive health, childhood nutrition and a reduction

TUBERCULOSIS INCIDENCE AND GLOBAL FUND DISBURSEMENTS



Source: Global Tuberculosis Report, WHO, The Global Fund

in communicable diseases. As a result, more individuals are living to the age where neurological disorders are more prevalent.[10] Compounding this issue is the reality that that treatment rates for neurological disorders have found to be lowest in LMICs, where treatment gaps greater than 90% have been found.[11]

Additionally, inhalation of mercury vapor, typically in its elemental form, is known to produce adverse effects on the digestive, nervous and immune systems and at times can be fatal, while exposure to inorganic mercury compounds, pesticides and uranium can cause kidney damage.[12] Such pollutants are known contributors to the burden of chronic kidney disease in developing countries. A treatment gap exists in LMICs not only due to low awareness among patients and care providers, but also as a result of reduced availability of renal replacement therapy.[13] Health expenditures for chronic kidney disease continue to place an insurmountable financial burden on LMICs.

Exposure to chromium and radon by inhalation may cause damage to the respiratory system, and are known causes of lung cancer. As lung cancer is one of the leading causes of death world wide, causing 1.5 million deaths annually, its contribution to the burden of disease in LMICs is significant. Additional health effects include damage to the gastrointestinal and immunological systems. More recent studies have shown that hexavalent chromium is a stomach carcinogen in humans.[14] Stomach cancer is one of seven cancer types accounting for two-thirds of the estimated total cancer burden in low- and middle-income countries.[15]

FOOTNOTES

2. Islam SMS, Purnat TD, Phuong NTA, Mwingira U, Schacht K, Fröschl G. Non-communicable diseases (NCDs) in developing countries: A symposium report. *Globalization and health*. 2014;10(1):1-8
3. World Health Organization. Global action plan for the prevention and control of noncommunicable diseases 2013-2020. 2013
4. Fewtrell L, Prüss-Üstün A, Landrigan P, Ayuso-Mateos J. Estimating the global burden of disease of mild mental retardation and cardiovascular diseases from environmental lead exposure. *Environ Res*. 2004;94(2):120-133
5. Bowry AD, Lewey J, Dugani SB, Choudhry NK. The burden of cardiovascular disease in low-and middle-income countries: Epidemiology and management. *Can J Cardiol*. 2015;31(9):1151-1159
6. Sanders T, Liu Y, Buchner V, Tchounwou PB. Neurotoxic effects and biomarkers of lead exposure: A review. *Rev Environ Health*. 2009;24(1):15-46
7. World Health Organization. Global health risks: Mortality and burden of disease attributable to selected major risks. World Health Organization; 2009
8. Jain NB, Laden F, Guller U, Shankar A, Kazani S, Garshick E. Relation between blood lead levels and childhood anemia in india. *Am J Epidemiol*. 2005;161(10):968-973
9. Driscoll CT, Mason RP, Chan HM, Jacob DJ, Pirrone N. Mercury as a global pollutant: Sources, pathways, and effects. *Environ Sci Technol*. 2013;47(10):4967-4983
10. Gibb H, O'Leary KG. Mercury exposure and health impacts among individuals in the artisanal and small-scale gold mining community: A comprehensive review. *Environ Health Perspect*. 2014;122(7):667-672
11. Whiteford HA, Ferrari AJ, Degenhardt L, Feigin V, Vos T. The global burden of mental, neurological and substance use disorders: An analysis from the global burden of disease study 2010. *PloS one*. 2015;10(2):e0116820
12. Park JD, Zheng W. Human exposure and health effects of inorganic and elemental mercury. *J Prev Med Public Health*. 2012;45(6):344-352
13. Jha V, Garcia-Garcia G, Iseki K, et al. Chronic kidney disease: Global dimension and perspectives. *The Lancet*. 2013;382(9888):260-272
14. Welling R, Beaumont JJ, Petersen SJ, Alexeeff GV, Steinmaus C. Chromium VI and stomach cancer: A meta-analysis of the current epidemiological evidence. *Occup Environ Med*. 2015;72(2):151-159
15. Bray F, Jemal A, Grey N, Ferlay J, Forman D. Global cancer transitions according to the human development index (2008–2030): A population-based study. *The Lancet Oncology*. 2012;13(8):790-801

3

The Top Six: Striving to Make Progress

Introduction

Presented in the following pages are the Top Six toxic threats affecting the health of populations in low- and middle-income countries. There has been little real change in the extent of the risks posed to human health worldwide from these threats. For this year's report, cadmium has replaced arsenic in this listing because of its greater anthropogenic basis but the efforts to deal with arsenic problems from natural contamination show little real success. At the same time, the sources and pathways are better understood and, at the national level, the growing lists of sites are shared and discussed with national authorities as the basis for determining national priorities for action.

At the scientific level, the application of internationally recognised approaches for estimating health impacts has led to much greater credibility and acceptance of the scale of the impacts. Indeed, Pure Earth is now pushing forward the development of DALY methodologies for serious pollution pathways that have to date received little attention, such as some of the mercury aspects.

Further refinement of site numbers and health estimates continues but there is more than adequate data to justify much more efforts to address and reduce the pollution impacts on local communities. Unfortunately, while some progress is made at the level

(Left) Residents of Mailuu Suu have been afflicted with a variety of ailments relating to radionuclide exposure. High rates of birth defects, miscarriages and stillbirths continue to place an enormous burden on the region's population.

Photo by Noriko Hayashi

TOXIC SITES IDENTIFICATION PROGRAM

of individual sites and localities, there is little change to be seen in the overall overwhelming scale of the pollution challenge.

Low- and middle-income countries continue to grapple with the health consequences of exposure to these pollutants. Pure Earth continues to bring awareness to these pollution issues, conducting intervention and outreach programs and finding low cost solutions to perform site remediation. Each of the pollutants described affect the health and lives of millions globally, often an end product of the livelihoods that sustain them. Efforts also include shifting industrial processes to safer, more sustainable methods that may ensure the livelihoods of millions and reduce the health impacts and suffering of both workers and families.

Lead

Population at risk: 26 million people
Estimated DALYs: 9 million

Lead (Pb) is a heavy metal that occurs naturally in the environment and has been mined for use in a variety of products, including paint, dyes, ceramic glazes, pesticides, ammunition, pipes, weights, cable covers, car batteries and sheets used for protection from radiation. Lead is often combined with other metals to form alloys and until recently, was used worldwide as a gasoline additive to make engines more efficient by improving octane ratings.

Despite its beneficial use in the production of multiple items, exposure to lead can have deleterious effects on human health. Levels of lead in the environment have been increasing for hundreds of years, but it has only been in the past century that the health impacts from lead exposure have been noticed and examined, particularly in children. One of the most common sources of lead exposure in low- and middle-income countries (LMICs) is from used lead-acid battery (ULAB) recycling. Other common industries associated with releases of lead include mining, primary and secondary metal smelting, steel and iron production and pigment production.

Pure Earth estimates that approximately 26 million people are at risk for exposure to lead globally, with an estimated burden of disease of 9 million DALYs. As of 2015, the Toxic Sites Identification Program has identified nearly 800 sites around the world where exposure to lead threatens the health of the population. Pure Earth continues to develop methodologies for estimating the number of unscreened sites where pollution from lead and other toxic pollutants may threaten the health of the population. In doing so, a more accurate burden of disease caused by lead and other pollution may be understood.

Pathways & Route of Exposures

Lead can be released into the air during its Lead can be released into the air during its production, processing and recycling phases. After lead settles on soil through precipitation or as particulates, it adsorbs to soil particles that can be blown around and endanger nearby populations. Lead particles can also settle onto nearby surface water bodies and contaminate groundwater sources used for drinking. Contaminated soil and water sources may in turn contaminate food sources, as lead has been shown to accumulate in plants and animals that live and feed in contaminated areas.

Individuals are exposed to lead primarily through ingestion and inhalation of lead-contaminated materials. Lead has also been shown to transfer between an exposed mother and her child while pregnant (*in utero*) and through breastfeeding. Absorption through the skin is another possible route of exposure. However, this pathway does not often lead to high lead levels. Once lead has entered the body, it can transfer into soft tissues and organs and eventually be stored in bones and teeth for up to 30 years.[16] As a result, teeth have been used in some studies to determine levels of lead exposure from both chronic and acute exposure to high doses.[17] More commonly, the analysis of blood samples is used for assessing lead exposure, resulting in a blood lead level (BLL) value indicating blood lead content in micrograms per deciliter.

Health Effects

Lead exposure can have both acute and chronic health effects. Children who are exposed to lead are particularly at risk for adverse health effects due to their smaller mass and the inhibition of ongoing developmental processes resulting from exposure. As a result, exposures to very small amounts of lead have been associated with long-term neurological and cognitive defects in children. Fetuses are also very susceptible to adverse health effects from lead exposure, and may develop birth defects. As a result, the Centers for Disease Control (CDC) recently decreased the level of concern for children regarding lead exposure from a BLL of 10 µg/dL to 5 µg/dL.[18]

Some of the overall adverse health impacts from lead include neurological damage, intelligent quotient (IQ) decrement, anemia, muscle and joint pain, loss of memory, decreased concentration, nerve disorders, infertility, increased blood pressure and chronic headaches. At very high doses, lead exposure can also result in seizures and death.

Exposure to doses of lead over a long period of time can result in detrimental health effects. The danger of lead exposure was highlighted in Dakar, Senegal in November 2007 and March 2008 when 18 children died of acute lead poisoning. The children were exposed to lead dust and contaminated soil from the community's main economic activity, ULAB recycling. Blood analyses of the children from the area revealed the average blood lead level to be 129.6 µg/dL, significantly higher than what is recommended by the CDC.[19] Furthermore, a study conducted by Caravanos et al (2014) estimated the impact of lead exposure on IQ in rural and urban Mexico, where leaded glaze is commonly applied to pottery and cookware. Results from the study predicted that 15% of the total population would experience a decrement of 5 or more IQ points due to lead exposure.[20]

Used Lead-Acid Battery (ULAB) Recycling

Lead-acid batteries are the oldest form of rechargeable battery, composed of lead plates resting in a solution of sulfuric acid. This is contained within a polypropylene or polyethylene plastic casing. Lead-acid batteries are very common in devices with motors, and are frequently referred to as "car batteries". Although the batteries can be recharged, the lead plates in batteries will eventually wear over

time, corroding from chemical reactions that render them unable to properly store energy. Once the unit is no longer capable of storing energy, it often sent to a recycler.

These batteries are a substantial source of recycled lead worldwide and have become a significant source of income for many poor communities in LMICs. Of all used lead-acid batteries, 97% of them will eventually be recycled for lead retrieval. ULAB recycling will continue to be a major source of recycled lead as long as the global demand remains high. As of 2014, lead had one of the highest recycling rates in the world, even when compared to recycling rates for more conspicuously consumed products such as newspaper, glass, aluminum and copper.[21] Although this high rate of lead recycling reduces its rate of landfilling and the need to mine for lead, the dangers of unregulated lead recycling are substantial.

Global population and economic trends have also increased the risks posed by the ULAB recycling industry. As ULAB recycling has become a source of income for many people, old batteries are often shipped in bulk over long distances, often from high-income regions. Population densities have also increased in urban centers where ULAB recycling is often performed, thereby increasing the amount of individuals exposed to lead and other ULAB recycling contaminants. High unemployment rates and increased car ownership compound this issue. Taking these factors into consideration, it is no surprise that ULAB recycling occurs in almost every city in nearly every LMIC. Despite the size of the ULAB recycling industry, there are few environmental safety controls and exposed populations often have little understanding of the hazards involved.

Exposure

Occupational exposure is the most common type of lead exposure for populations associated with

(Far left) A worker smelts or to extract lead in Bihar, India. Smelting involves the application of heat to mineral-rich rock or scrap metal to extract valuable metals. Health effects from exposure to lead via inhalation or ingestion include neurological damage, IQ decrement, anemia, muscle and joint pain, loss of memory, decreased concentration, nerve disorders, infertility, increased blood pressure and chronic headaches.

Photo by Pure Earth

(Left) Workers of Perkampungan Industri Kecil (PIK) in Tegal Regency of Central Java, Indonesia sort used-lead acid battery waste and conduct smelting operations. Efforts by Pure Earth have encouraged zoning initiatives to relocate industrial operations away from residential villages. While relocating operations to an urban industrial center decreases hazardous exposure to villagers, workers continue to be exposed through inhalation of contaminated dust particles.

Photo by Lara Crampe

ULAB recycling. To obtain lead from these batteries, recyclers often break casings by hand or with an axe. The battery acid, containing high levels of lead, is then dumped onto the ground. Once the lead plates have been retrieved, they are often melted. The melting process will also result in releases of lead ash in to the air, which can be inhaled or ingested if the lead settles onto soil or water surfaces. One study in Pakistan found the children of lead recyclers to have the greatest exposure rate, likely resulting from the parents' clothing that is brought in from the workplace.[22]

Children may also come into contact with lead-contaminated material when playing with ULAB waste or when handling rocks or dirt contaminated with lead. As a result, ingestion is the most common route of exposure associated with contaminated soil. Nearby populations can also be exposed to lead through ingestion of contaminated water or inhalation of lead ash.

Initiatives & Strategies

In 2003, the Basel Convention on the Control of Transboundary Movement of Hazardous Wastes and their Disposal created a site of technical guidelines for environmentally sound ULAB recycling.[23] However, these measures are often not followed in LMICs for many reasons; many recyclers have not been formalized and remain unaware of the dangers and risks posed by ULAB recycling.

Pure Earth and others have implemented a number of interventions at targeted sites over the past several years. Each intervention is tailored to individual sites, but broadly follows a program of assessment, community education, home cleaning and surface capping to mitigate exposure. Excavation and other ex-situ options are often prohibitively costly, difficult to engineer and may increase the risk of exposure. Thus more realistic approaches adopted by Pure Earth and others typically involve capping solutions with good institutional controls and management.

Smelting & Metal Extraction

Introduction

Smelting involves the application of heat to a mineral-rich rock or scrap metal to extract valuable metals. The two main types of smelting are primary and secondary smelting. Whereas primary smelting involves the processing of mineral ore, secondary smelting involves the reprocessing of scrap metals. Mining extraction (primary smelting) often results in lead dust production, as lead is often present in rocks and soils that contain valuable metals including copper, nickel, zinc, silver and cobalt. However, both forms of smelting can result in environmental lead releases.

Smelting involves heat and the addition of a chemical reducing agent, typically a carbon source such as coke or charcoal. Heat and chemical agent application change the oxidation state of the metal through the removal of oxygen from ore, leaving behind the desired metal. However, many ores don't purely contain the desired mineral, so cleaning agents such as limestone can be added to remove impurities.

Smelting and metal extraction industries can release large amounts of pollution into the environment. Emissions from these industries contribute heavily to global lead emissions, as well as global arsenic, cadmium and chromium emissions.[24] Certain facilities can also emit large quantities of hydrogen fluoride, sulfur dioxide, nitrogen dioxide and fine particulates. Additionally, some heavy metals can be released into the air as fine particulates, either through smokestacks or indirectly during other stages. Lastly, results of secondary smelting, including organic vapors and sulfur oxides, have also been associated with production of smog, carbon monoxide and fine particulates.[25]

These industries also produce a large amount of contaminated effluents and solid waste. The additional rock removed from the ore, known as slag, can contain multiple contaminants including lead. Some processes used by particular facilities can also produce large amounts of sulfuric acid.[26] In multiple cases of lead smelting sites, slag piles and effluents contain and release numerous acids and contaminants into the environment including nearby bodies of water.

Exposure

Exposure to lead from smelting and metal extracting industries primarily occurs through inhalation and ingestion of lead-contaminated materials. Dust particles contaminated with lead can be inhaled, or ingested after they have settled and deposited onto agricultural fields and crops. Of particular importance are individual crops' ability to accumulate lead.[27] For example, a Chinese study was able to show that crops such as corn can accumulate heavy metals including cadmium and lead. An additional study found that 20 different vegetables grown near a zinc smelter exceeded safe dietary guidelines for mercury, lead, cadmium and zinc.[28] Lead may also accumulate in livestock and be ingested through drinking contaminated surface water and groundwater sources. Dermal exposure to lead has also been shown to result in lasting health effects, particularly in children.

Occupational workers are most directly exposed to lead from these industries by working at metal processing plants and smelters. However, some members of the community, particularly mothers and children, may go through slag piles in an effort to obtain pieces of lead that may have been discarded in haste. This was seen in the community of Morelos, Mexico, where soil samples greatly exceeded safe guidelines for lead levels due to environmental contamination wrought by the community's copper smelter. As a result, blood lead levels particularly in children were much higher than recommended by the CDC.[29]

Initiatives & Strategies

Lead processing and smelting facilities can be built efficiently and with proper emissions controls. However, construction and maintenance of these facilities can be very costly. As a result, a majority

CASE EXAMPLE

Mexico

Phasing Out Lead Glaze in Morelos, Mexico

Since 2008, Pure Earth has been working with local authorities in Mexico to address the issue of lead in pottery. Leaded glaze is used extensively throughout Mexico. Acid from spicy food may leach lead from the glaze into food consumed by individuals. As lead has been completely phased out of gasoline since 1997, leaded pottery is now the main source of lead exposure in the country.

In 2014, a peer review paper published in the Annals of Global Health by Pure Earth, the National Institute of Public Health in Mexico (INSP), The City University of New York and Columbia University concluded that although blood lead levels (BLLs) have decreased significantly in Mexico over the past 35 years, they remain significantly elevated. In urban areas, the post-leaded gasoline average BLL in Mexico is still more than 4.5 times higher than the average found in the United States (5.52 and 1.2 ug/dL, respectively). Researchers conducting the study estimated that this would result in 820,000 disability adjusted life years (DALYs), with an average lead-induced IQ decrement of 5 points in Mexican children aged 0 to 4 living in urban areas. In rural areas, where robust data was not available, the resulting health effects are expected to be much worse. These results indicate that nearly half of Mexican children have a BLL that is above the threshold where intelligence and behavior is affected. In comparison, only 2.5% of children in the United States hit this threshold.

Fortunately, there is a solution. A lead-free glaze, developed in Mexico with governmental support, works with boron as a substitute. The process is similar in function and creates a similar aesthetic compared to traditional leaded glazes. Boron burns in traditional low temperature kilns and has a lower cost than traditional lead glaze.

Unfortunately, not many potters have switched to the lead free glazes, due to fast-held beliefs that customers are too discerning to accept pottery made with the new glaze. To increase demand, Pure Earth has implemented a pilot project in the State of Morelos in association with the INSP, the Morelos Health Secretary and the Mexican Institute of Social Security (IMSS). The project aims to increase demand for lead free pottery by working with restaurants and hotels and creating awareness of the problem in an effort to promote their transition to safe pottery. The project has also screened 304 newborns for lead poisoning; those children identified with high BLLs are now receiving the appropriate medical treatment. The results of the health screenings have been shared with the government and will be published shortly. Pure Earth expects to expand this work to other regions and support governments in the implementation of a national strategy to address this issue.

of the lead smelters and processing plants in LMICs are old or abandoned. Old smelters often have very little or no emissions controls, leading to releases of lead and other pollutants into the air and onto soil and water surfaces. As a result, many old and abandoned smelters have left behind a legacy of pollution on nearby soil surfaces and in river sediments from throughout their lifetimes. Dust from the lead smelting process can also travel over far distances and contaminate large swaths of land. Therefore, remediation is often focused on removing or limiting the source of the pollution and contaminated material to prevent further contamination and reduce exposure.

Radionuclides

Population at risk: 22 million people*
Estimated DALYs: N/A

*Estimate includes 800k to 1 million at risk based on point source exposure to radionuclides derived from 91 identified sites in the Toxic Sites Identification Program.

Radionuclides are so called as they undergo a process known as radioactive decay. Some of them occur naturally in soil and rocks, while man has artificially created others. Radionuclides are atoms with an unstable nucleus. Radioactive decay occurs as a result of the unstable nucleus's desire to become a stable nucleus. This process primarily occurs through disintegration and releases of excess energy in the form of radioactive particles and radiation. These radioactive elements will decay at a fixed rate, known as a half-life. A half-life is the length of time it will take for half of the unstable material to degrade into a more stable form. The length of the half-life depends upon the element and isotope, which can range from fractions of a second to millions of years.

The type of radiation emitted from this process also varies with the main categories of radiation that can be emitted including alpha, beta, gamma and neutron radiation. Under normal circumstances, the only way to reduce the radioactivity of a radioactive material and its associated harmfulness is through the natural decay process. As a result, it can take long spans of time for exposure levels to certain radioactive materials to be considered safe, necessitating proper storage and handling precautions during this time.

Radioactive materials are classified into two classes: high-level and low-level.[30] High-level materials are primarily the result of fuel used by a reactor to produce electricity or weapons materials, while low-level materials are those with a short half-life or have been contaminated with nuclear materials. Similarly, radionuclides can be divided into the two-categories of "heavy" or "light". Heavy radionuclides, also known as unstable nuclides, are elements having over 83 protons in their nuclei. Conversely, light nuclides include elements that have fewer than 83 protons in their nuclei.[31]

Some types of radioactive materials include clothing used in the nuclear industry, medical materials and equipment from inside reactors. The more common, large-volume sources of radioactive wastes, however, are from uranium mining and use of nuclear reactors. Uranium-238, the most common isotope of uranium found in nature, will also naturally decay to radium-225, which has a half-life of 1,600 years.[32] The latter will decay to radon gas, which poses an exposure risk in some areas of the world even in well-insulated homes. Other common (artificial and natural) radionuclides are cesium-137, strontium-90, cobalt-60, plutonium, technetium-99 and thorium.[33]

Radionuclides have been beneficially used in a range of medical and scientific applications. For example, they have been used to diagnose, treat and research diseases in the biomedical industry. Gamma emitting radionuclides have also been use as tracers to monitor organ functions while other radionuclides, such as radium and radon, have been used to treat certain cancers.[34] Other radionuclides have been used to label models and study certain biological processes, such as DNA replication. However, the main application of radionuclides today is for their use in energy production and weapons industry.

Pure Earth estimates that between 800,000 and 1 million people are at risk for exposure to radionuclides at 91 sites involving the mining and processing of uranium globally (identified through the Toxic Sites Identification Program (TSIP). As radionuclides are comprised of a heterogeneous set of materials, we do not present a burden of disease estimate. As of 2015, TSIP has confirmed these sites pose a threat to the health of the population exposed.

However, it must be noted that our estimate of the population affected by radionuclides only includes those that may have their physical health impacted at sites identified through the Toxic Sites Identification Program. A study conducted by Green Cross Switzerland, in conjunction with the University of Southern California Institute for Global Health with cooperation from local partners, estimates that the physical and psychological well-being of over 10 million people continues to be affected by repercussions stemming from the Chernobyl nuclear disaster.[35] This study systematically reviewed published research along with input from focus group findings to determine the extent of physical and psychological effects from this single incident.[36] Future studies hope to elucidate the number of individuals similarly affected by other nuclear incidents such as that which occurred at the Fukushima Daiichi Power Plant on March 11th, 2011. A similar literature review conducted by Green Cross Switzerland through the University of Southern California estimates that up to 385,000 individuals suffered psychological consequences from this incident. These incidents must be taken into account to fully understand the burden of disease resulting from the threat of radionuclide exposure.

Furthermore, there is an additional population at risk of exposure to radionuclides via low-dose background radiation, and those personnel in the nuclear industry. Beginning with the development of the nuclear industry since the 1950's, it is estimated that millions have been exposed to elevated levels of man-made radiation.[37] Studies have shown such background radiation to cause an increase in infant morality, cancer rates and low-birth weights.[38,39] Low radiation doses may also result in an increase frequency of mutations in chromosomes and genes in human somatic, bone marrow and muscle cells.[40,41,42] Globally, it is estimated that over 10 million nuclear personnel are exposed to additional anthropogenic ionizing radiation on a daily basis.[43]

Calculating the physical health risks and burden of disease associated with exposure to radionuclides is a complex undertaking that is both nuanced and difficult to model. For example, elemental mercury disability weights have not been established for radiation exposure. Additionally, exposure to radiation is dependent on both time and wavelength. Alpha particles cannot penetrate the skin but are very dangerous if ingested. Gamma particles are always dangerous, but levels can vary greatly based on relatively small spatial differences. Attempting to capture the myriad ways people are exposed to radiation at contaminated sites, and to further estimate the disease burden would be a significant undertaking.

"Radionuclides" is therefore very much a catchall category, capturing a heterogeneous set of materials. Thus, unlike elemental mercury and lead, we do not feel confident in generating a DALY value for radionuclides. Accordingly, we list radionuclides as a top threat, though do no provide a DALY value.

Pathways & Routes of Exposure

In general, exposure to these radioactive materials occurs from ingestion and inhalation or external radiation exposure. Wastes from uranium mining and processing can contaminate water bodies and nearby soils, particularly through leaks

and industrial failures. Both uranium and radon exposures have been associated with inhalation, while radium exposure has been seen to occur as a result of food contamination.[44] Exposure can also occur from excessive use of radiation during medical treatments.

Health Effects

In general, there is no safe level of radiation exposure. Acute health effects from a single large dose include nausea, vomiting and headaches. Increased exposure to radiation can result in radiation poisoning. The health effects from radiation poisoning include fatigue, weakness, fever, hair loss, dizziness, disorientation, diarrhea, blood in stool, low blood pressure and death. However, some health effects have been noted to be associated with particular radionuclides. It should be noted that some radioactive materials have also a chemical toxicity, (e.g. uranium) and are heavy metals. For example, uranium exposure has been associated with kidney damage (related to heavy metals) and DNA damage (related to radionuclides).

Ionizing radiation exposure causes damage primarily to the cells. If enough cells are hit by radiation, cancer development may result. In fact, radon is classified as a human lung carcinogen with studies have indicating that inhalation of radon can lead to an elevated risk for leukemia and has been noted as the second leading cause of lung cancer death in uranium miners.[45,46] Chronic exposure to radon has also been associated with a decrease in white blood cells, which are important for the maintenance of a functional immune system.

Children are particularly susceptible to radiation exposure. As they grow, their cell counts increase, thereby providing more opportunities for the radiation to interfere with critical development processes. Radiation exposure in children can result in a series of adverse health effects, particularly on

(Far left) A tailings dump at Mailuu Suu contains radiocnuclides such as uranium, strontium and cesium mixed with the groundwater supply. Food and water sources may become contaminated from uranium-contaminated water and dust generated from past mining activities.

(Left) Temiraly Sarbashov, a local of Mailuu Suu, Kyrgzystan, stands at the entrance of dump filled with waste resulting from uranium processing. Between 1946 and 1968, Mailuu Suu produced and processed more than 10,000 metric tons of uranium ore. Workers are paid the equivalent of $400 U.S. dollars for two weeks for relocating and managing tailings dumps.

Photos by Noriko Hayashi

fetal development. Exposure to radiation while in the womb has been shown to result in smaller head or brain size, poorly formed eyes, abnormal growth patterns or mental retardation.[47]

The psychological impacts resulting from exposure to radionuclides have been thoroughly studied at the site of the Chernobyl nuclear disaster that took place on April 26th, 1986. Psychological effects of such nuclear disasters include that deriving from displacement and stigmatization. These psychological effects may manifest themselves as on-going psychological stress, post-traumatic stress disorder (PTSD), diminished well being and may contribute to depression, anxiety and suicidal ideations.

Anxiety and PTSD may stem from health concerns, loss of a family member, destruction of the community and discrimination in both marriage and employment.[48] Rescue and emergency workers are particularly susceptible to such stresses relating to blame for post-disaster mismanagement, a large additional burden for those likely having been exposed to radionuclides during the recovery work. Stigmatization largely affects young women, who worry they are viewed negatively based on assumptions about the effects of radiation on pregnancy.[49]

Additional studies have shown exposure or the perceived threat of exposure to radionuclides has significant psychological consequences in children, which may present themselves as hyperactivity disorders, emotional problems, as well as conduct and peer problems.[50] These psychological impacts will continue to weigh on both current and future generations.

CASE EXAMPLE

Tajikistan

Digmay Mine Tailing Site Intervention

In 2015, Pure Earth, Green Cross Switzerland and the Youth Group on Protection of the Environment (Sughd Region) set out to remediate three of the largest mine tailing sites in northern Tajikistan. These tailing sites posed a significant risk to the nearby population as they had not been properly sealed and leached pollutants into the nearby environment.

Intervention included analysis of local soil and drinking water, identifying the risk of exposure for nearby residents, disseminating information to residents regarding health risks caused by exposure to radiation and the remediation of contaminated soils.

Training sessions were held for residents informing them of the source and pathways of exposure to radiation. To limit radionuclide-containing dust in the home, trainees were asked to conduct periodic indoor cleanings and to limit the dust's mobility by watering the earth around their homes.

Trainees were briefed on how best to navigate areas of high radiation risk and encouraged to use informal personal protective equipment in the event they did not have access to a respirator. Additionally, trainees were provided with information on how to best store food and drink in areas at high risk of contamination. Further training involved food preparation methods for those growing fruits and vegetables on plots at risk for radionuclide and heavy metal contamination.

Seven hotspots contaminated by radionuclide were identified near a former tailings pipeline running adjacent to the residential area and contaminated soil was removed by truck and replaced by clean soil where necessary. Follow-up evaluations and radiation monitoring were conducted. Radiation levels were successfully lowered to within range of expected background levels for the region in five of the seven identified hotspots.

Uranium Mining & Radioactive Waste Disposal

Overview

Uranium mining is the process of extracting uranium from uranium-rich ore. It is a very volume-intensive process, as uranium ores typically have low concentrations of the element, which can be as low as 0.1% to 0.2%.[51] Due to limitations from the mining process and limited locations of uranium deposits, uranium extraction occurs in select countries.

Open-pit mining and in-situ leaching are the two most common mechanisms by which uranium is obtained. In open-pit mining, uranium ore is removed through blasting and drilling uranium-rich deposits. Water is often used during these steps to limit and prevent inhalation of uranium dust. Once the ore has been obtained, it will be crushed and leached in a uranium mill. During the leaching process, chemical agents, such as sulfuric acid and alkaline solutions, are used to extract the pure uranium from the ore. The final product will be pure uranium, known as "yellow cake" and sold as uranium-238. In-situ leaching, also known as solution mining, transfers this leaching process directly to the uranium ore deposits. The leaching solution is dumped into wells in the deposits and then pumped to the surface as a uranium-rich liquid. This process is more commonly applied due to the low production costs and decreased damage to extraction surfaces. Both of these processes—particularly open-pit mining—will result in exposed uranium and hazardous tailings materials that may contaminate the surrounding area and pose risks to workers and nearby populations.

As uranium ore typically only contains small traces of uranium, nearly 99% of the ore is not used and is discarded. As a result, waste from uranium mining will contain a toxic combination of heavy metals, chemical agents from the leaching process and other contaminants such as arsenic. The discarded ore will also likely contain 85% of the radioactivity of the original ore due to the common presence of other long-lived radionuclides such as thorium-230 and radium-226.

Radioactive waste, a resulting by-product of nuclear reactors, is another means by which populations can be exposed to uranium. However, radioactive waste can also come from fuel processing plants, power generation facilities, military exploits, hospitals and medical research facilities. Radioactive wastes from mining have comparably lower radiation levels than reactor wastes, which are most often highly hazardous. Long-term storage of the latter poses a challenge that remains unresolved to the present day.

Exposure

Due to the longevity of the remaining radionuclides and potency of mining wastes and tailings, long-term stability, security and proper management are necessary to protect the nearby population. Unfortunately, uranium mining in LMICs is poorly regulated, particularly so when compared to the oversight usually performed in high-income countries. This is compounded by the priority of production over safety. In addition to the radiation hazard, the mines pose an additional heavy metal hazard as many of the mined materials also have a chemical toxicity.

Although mine tailings will often have low levels of radioactivity, they can pose particular harms when the waste is concentrated or stockpiled in a small area. Furthermore, water used in the mining process will often become contaminated and contaminate local water surfaces. As a result, food and water sources can become contaminated from uranium-contaminated water and from dust generated during uranium mining processes, particularly from open-pit mining. Studies have shown that certain crops, such as lettuce, can absorb uranium from contaminated soils.[52] Close proximity to radioactive waste and the infrastructure built to contain it has also been noted to increase the risk of exposure to gamma particles and neutron radiation.

Initiatives & Strategies

Some countries have management plans for radioactive waste and protocols for radionuclide-associated industries. In addition, many international and national plans exist for management of high-level waste. However, many LMICs often do not implement international standards or have national regulations. In many of these locations, there are few industry or governmental resources available to address the issues associated with radioactive waste disposal, contamination and resulting exposure.

In general, the approach for addressing uranium waste sites is similar to strategies used for containing mining wastes from other industries. Due to the particular hazards of radionuclide waste, additional efforts should be implemented to ensure that the waste does not come into contact with water sources or soils used for food production.

Unfortunately, treatment options for these sites are often limited as many uranium mining processing and extraction facilities are located in rural areas. However, a wide range of approaches has been used in LMICs to ensure populations near uranium-contaminated sites are less exposed to the contaminated material. For example, safer and more secure warehouses for the waste can be built and uranium waste ditches can be covered with clean and safe soil. Most importantly, improvement of community awareness on the risks of uranium exposure should be a large component of any site remediation associated with uranium contamination.

Mercury

Population at risk: 19 million people
Estimated DALYs: 1.5 million

Introduction

Mercury (Hg) is a heavy metal that occurs in several forms including elemental mercury, inorganic mercury and organic mercury. Each of these forms has a different toxicity and is associated with a different exposure pathway. Elemental mercury, also known as metallic mercury, is naturally occurring in the environment and is often extracted from cinnabar ore. This form of mercury may be refined into the liquid state after being heated to 1,000 degrees Fahrenheit. It is then used in products such as thermometers, electricity switches and dentals fillings, as well as for the production of caustic soda and chlorine gas. However, one of the most common uses of mercury in LMICs is for the extraction of gold from gold-containing ores.[53]

Inorganic mercury includes a series of mercury compounds such as mercuric chloride, mercuric acetate and mercuric sulfide.[54] However, exposure to harmful levels of inorganic mercury is usually uncommon. Organic mercury is produced when elemental mercury is combined with carbon and is most commonly found in the environment as methylmercury, a compound that forms when microorganisms in water bodies metabolize elemental mercury.[55] Due to the structure of the compound, this form of organic mercury accumulates in the fatty tissues of many organisms, including those consumed by humans.

Mercury can enter the environment naturally and from industrial sources resulting from industrial mining, chemical manufacturing, fertilizer manufacturing, solid waste disposal and metal smelting. However, the largest anthropogenic source of mercury release into the environment in LMICs results from artisanal small-scale gold mining (ASGM).[56]

Pure Earth estimates that 19 million people are at risk for exposure to mercury globally, with an estimated burden of disease of 1.5 million DALYs. As of 2015, the Toxic Sites Identification Program has identified over 450 sites around the world where exposure to mercury threatens the health of the population.

CASE EXAMPLE

Indonesia

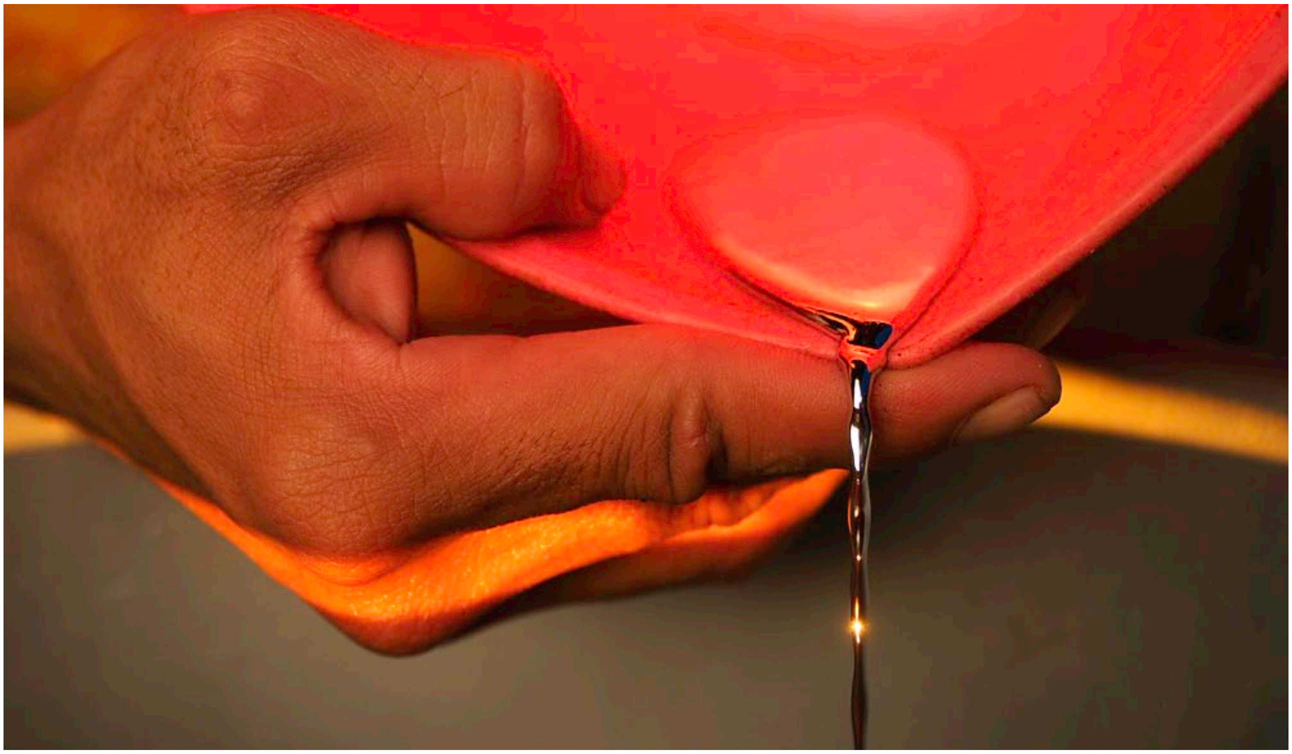
Teaching safer mining practices in Central Kalimantan, Indonesia

Yayasan Tambuhak Sinta (YTS) is a leader in artisanal gold mining safe practices and advocacy. Founded in 1997 by a mineral exploration company, YTS provides expertise in gold extraction, mining technologies and health campaigning. Since 2009, YTS and Pure Earth have been working together to address harmful gold mining practices in Central Kalimantan, Indonesia through education and hands-on training. Miners in Indonesia are encouraged to take these lessons in safer mining practices and share them with local communities.

YTS promotes mercury reducing and mercury-free gold extraction methods using South-South technology transfer. A pilot project conducted between 2013-2014 trialed a popular and effective method from the Philippines, as well as an Indonesian method (Manado method). Both are based on improved gravimetric separation and the application of the non-toxic chemical borax, at the end stage. The project analyzed ore samples from over 50 locations in Indonesia to identify areas where the technology could apply. The trials showed that the Manado method and direct cyanidation (*gelondong tumpah*) were the most effective mercury-free techniques in the Indonesian context.

In communities where mercury-free technology was not suitable, YTS distributed retorts (mercury recapturing machines). Retorts allow miners to lower costs from purchasing mercury, and reduce the element's exposure to the atmosphere. YTS also implemented health and education campaigns in communities where these techniques were introduced.

Safe mercury recapture demonstrations and changes in the behaviors of both miners and gold shop owners are testaments to YTS' success. In 2015, YTS is working with Pure Earth advisors to draft a National Action Plan on mercury-phase out with the Ministry of Environment and Forestry. An inception workshop in August shows support and promise toward a mercury-free Indonesia.



It is estimated that the livelihoods of at least 10 million people are dependent on artisanal small scale gold mining (ASGM), nearly all of whom use quicksilver (elemental mercury) to extract gold from ore. Many of these miners and their families are exposed to dangerously high levels of elemental mercury: in the workplace, in the home and in their communities. However a Disability Weight, necessary for the calculation of DALYs, has not been established for this type of exposure and therefore it is not possible to calculate DALYs from elemental mercury exposure for inclusion in the report. Pure Earth is currently in the process of setting up a research programme with German specialists to make progress in this area and it is hoped that it will be possible to include DALY estimates for mercury in future reports.

Because the scale of exposure is so significant and some estimates are needed, the approach used has been to capture this DALY burden through a surrogate value. In rough terms, the typical DALY value for a moderately contaminated lead site is taken as equivalent to that of a heavily contaminated mercury site. This is reasonable because both metals have similar adverse impacts on the developing brain of children. Because this neurological outcome (and in particular, IQ decrement) comprises the largest share of DALYs from lead, this is seen as the best analog for which data is presently available. It must be noted that this approach has not been subject to formal peer review and therefore can at best be considered indicative.

Pathways & Exposure Routes

Processes such as ASGM involve the heating of elemental mercury, resulting in the release of mercury vapors into the environment. These mercuric vapors can then settle as dust onto

(Far left) At the Rau Rau mining camp in Southeast Sulawesi, Indonesia, a miner pour mercury from a pan to be used in one of the thousands of ball mills that are used to process gold ore. The process results in a thick slurry that is further processed to extract gold particles in the suspended liquid. Much of the mercury used in this process is spilled or atomized, finding its way directly into the environment. Waste piles with elemental mercury may lead to further contamination if they are not properly protected from natural forces such as wind and rainfall, and the mine waste leachates can persist in rivers, lakes and streams for years, posing serious health risks.

(Left) At the Padang Bilah mining community in Southeast Sulawesi, Indonesida, 30-year-old miner Rizki adds mercury to a pan of gold ore. At his right is his eight year old daughter, Ismawati. Pure Earth's ASGM intervention projects all have the same objective: to introduce affordable techniques to artisanal mining communities to eliminate or reduce mercury emissions. A number of cleaner alternatives to mercury amalgamation currently exist for gold extraction. However, many artisanal communities have been using the traditional practice of mercury amalgamation for decades and are unaware of alternatives.

Photos by Larry C. Price

soil surfaces or surface water bodies through precipitation.[57] Waste piles with elemental mercury may lead to further contamination if they are not properly protected from natural forces such as wind and rainfall, and the mine waste leachates can persist in rivers, lakes and streams for years, posing serious health risks.[58]

Individuals may be exposed to mercury via inhalation, ingestion and dermal contact. The most direct pathway for mercury exposure is through inhalation of mercury vapors, which may reach the brain and cause permanent damage to the body. Exposure to methylmercury, a potent neurotoxin, often results from the consumption of contaminated food sources, such as fish and shellfish. Studies have also shown that livestock can develop high levels of mercury from grazing in contaminated areas, providing yet another possible route of mercury exposure for humans.[59] Other common routes of exposure to mercury in LMICs may include absorption through skin and the consumption of breast milk from exposed women.[1]

Associated Health Effects

Those exposed occupationally are most at risk from mercury poisoning due to their repeated direct contact with mercury. One study found that over half of ASGM workers in Indonesia experience chronic mercury intoxication, while those less exposed, such as mineral processors and nearby populations, also had high levels of mercury exposure.[60] In general, infants are most at risk for developmental problems from mercury exposure, which may occur through breast-feeding.[61]

Health effects most commonly reported among ASGM workers and community members are neurological in nature and may include tremor, ataxia, memory problems and vision disorders.

CASE EXAMPLE

Mongolia

Artisanal Small-scale Gold Mining (ASGM)

The Artisanal small-scale gold mining sector (ASGM) is an important livelihood activity in Mongolia. It provides much needed income to an estimated 100,000 miners, most of whom are from socially and economically marginalised communities that turn to mining to escape extreme poverty, unemployment and landlessness. Due to its profitability, ASGM has high potential to alleviate poverty. However, current practices are unsustainable, and inefficient. Practices such as whole ore amalgamation and overgrinding typically result in significant losses of both gold and mercury. Miners, generally working in small cooperatives (MSMEs), often informally, combine large amounts of mercury with gold-bearing crushed ore to form an amalgam, which is heated to evaporate the mercury, leaving gold behind. According to the UN Environment Program (UNEP), nearly 100% of all mercury used in ASGM is released into the environment, accounting for more than 1400 tons of mercury per year and 30% of total annual anthropogenic emissions.
The devastating impacts of mercury on community and environmental health are largely unknown to miners. Exposures to mercury can cause neurological, brain and kidney damage, miscarriages, respiratory failure, psychotic reactions, cardiovascular disease and death. Children (who play in gold processing areas), pregnant women and foetuses are especially vulnerable. Mining and processing often take place in populated residential areas, contaminating homes, workplaces and shops. As a result, miners, their families and communities directly inhale significant amounts of mercury vapour. The rest of the vapour enters the local environment or remains in the atmosphere, where it can travel intercontinental distances. In aquatic environments, bacteria convert elemental mercury into methylmercury, a far more toxic form which can bioaccumulate up the food chain, poisoning river systems, fish and crops, negatively impacting biodiversity and humans. This type of mercury is particularly acute and devastating, as was evidenced by the disaster in Minamata, Japan. These health impacts have negative implications for poverty and economic growth. They restrict miners' ability to earn income and inhibit community productivity.

Although ASGM is relatively new livelihood activity in Mongolia, it continues to rise as an increasingly important economic activity in Mongolia. Despite the overall slow in economic growth in 2014, mining was one of the few economic sectors that grew. There are currently an estimated 100.000 miners working in about 18 provinces throughout the country, almost 50% of whom are women. The attractiveness of ASGM continues to rise as gold prices remain high and the viability of traditional livelihoods such as agriculture and livestock raising continues to decline due to severe weather events and economic crisis. An estimated 20% of the rural workforce is engaged

in ASGM, and about 400,000 people depend on it indirectly for their livelihoods. The Government of Mongolia has been proactive in its efforts to reduce mercury emissions from ASGM. In 2008, it banned the use of mercury in ASGM. In 2010, it issued the Regulation on Extraction Operation of Minerals from Small Scale Mines under Government Resolution No. 308 and made related amendments to the Law on Mineral Resources and Law on Land to further reform the mining sector. The regulations require the MEGD, the State Specialized Inspection Agency and local government agencies (LGAs) to ensure full and strict enforcement of the various mining and environmental laws, and places responsibility for training and capacity building for small-scale mining cooperatives/associations with the MEGD and the LGAs.

In 2013, Blacksmith Initiative and the Environment and Security Center of Mongolia (ESCM) implemented a two-year project to improve the economic and environmental sustainability of ASGM, and reduce poverty in ASGM areas in Mongolia.

A year after the project start more than 700 small-scale gold miners (42.5% are women and 3.1% are pensioners) were trained in Tov, Selenge and Bayankhongor provinces in mercury-free, more efficient ASGM techniques. Most of these trainees live below government set poverty level. 35 local miners were trained as teachers by Philippino experts to teach the mercury-free Philippino method to other miners. This led to an increase in efficiency of ore processing and reduced environmental impacts. The introduced methods were not only applicable to Mongolian ore, but were also well received by miners. Miner feedback indicated it was an attractive method because it did not require buying expensive equipment, and was easy to implement.

The project team also visited a variety of ASGM sites to measure heavy metal contamination levels in soil and air. 38% of the samples taken exceeded the maximum accepted levels of heavy metals in soil, with high levels of arsenic, lead, cobalt, molybdenum, and selenium. In some place, a concentration of highly toxic carcinogenic arsenic exceeding 110 times the national standard. High levels of mercury vapour were also recorded. The results indicate that stricter regulation enforcement and public awareness efforts are necessary to prevent miners, their family members, and general public from health impacts of heavy metals. Weak control and monitoring capacity of local as well as national governments coupled with high turnover among professional and trained governmental staff exacerbate the problem. Expansion of local capacity building, especially the ability of government agencies to monitor environmental contamination and to train miners in mercury-free processing techniques is necessary in order to protect human health and the environment.

Additional symptoms reported by ASGM workers include headache, mood swings, muscle weakness, trouble sleeping, dizziness, irritation of the mouth, fatigue, difficulty walking, persistent cough, thoracic pain and rhinitis.[62,63] A higher incidence of kidney and autoimmune dysfunction may also be found in such communities, resulting from the inhalation of elemental mercury vapour or the consumption of methyl mercury contaminated fish. Pregnant women consuming contaminated fish may also contribute to neurodevelopmental problems in developing fetuses, with symptoms including mental retardation, delayed development, language disorders, seizures and a loss of memory. Acrodynia, characterized by redness and severe discomfort in the extremities, may result in children chronically exposed to mercury.[64]

Exposure to methylmercury, a potent neurotoxin, causes unique harmful effects on the body. Its introduction into the body may influence enzymes, as well as cell membrane and neuron functioning.[65] The impacts of methylmercury became well known in the 1950s, after it was realized that 30 years of mercury-laden industrial wastewater dumped from the Minamata Plant in Minamata, Japan was the cause of over a thousand cases of mercury poisoning.[66] While few symptoms were seen in mothers, children suffered from paralysis and intelligence disorders. Sensory disturbance, mental retardation, cerebellar ataxia, dysarthria, numbness, deformed or shaking limbs, visual problems, and auditory disorders are all symptoms common of what is now known as Minamata disease. Methylmercury exposure may also result in arthritis, miscarriage, respiratory failure, neurological damage and death.[67]

Artisanal Small-Scale Gold Mining (ASGM)

Overview

Artisanal small-scale mining (ASGM) refers to small-scale informal operations focused on extraction and processing of metals. ASGM is one of the largest sources of mercury contamination in LMICs such as Mozambique, where it accounts for up to 90% of the nation's gold production.[68] Many sites in these countries will use mercury for gold extraction, with little to no safety or environmental controls. Mercury, which can bind to gold, is often mixed with gold-containing crushed ore to form a hardened amalgam of the two elements.[69] The remaining material that is not mercury or gold will be washed away while the amalgam is heated with a blowtorch to evaporate mercury and leave pure gold behind. In addition to mercury remnants, the discarded material will also often contain other harmful heavy metals that can contaminate nearby areas. The burning of the amalgam regularly takes place within homes, directly exposing workers and their families to mercury vapors.[70]

Many artisanal miners are from socially and economically marginalized populations.[71] In many of these communities, the cycle of poverty often forces individuals to work in hazardous working conditions, with little awareness about the harms posed by informal participation in the ASGM industry. Despite the dangers, ASGM operations continue to operate and expand as the demand for heavy metals continues to grow and as other livelihoods, such as farming, become less attractive and less economically viable.[72]

Exposure

Artisanal miners are often directly exposed to mercury vapors through the amalgam burning process. In many cases, the burning process occurs in homes, exposing the worker as well as any other occupants that reside in the building. One study in Tanzania found that ASGM miners involved in the amalgam burning process had the highest levels of mercury in their blood, hair and urine compared to other workers involved in the ASGM industry.[73] Studies have also indicated that the majority of female gold miners participate in the amalgam burning process, where they are the most susceptible to mercury exposure.[74]

The silt that is often washed away from the amalgam as waste will also contain small amounts of mercury, which may then contaminate the nearby environment. It is estimated that one to two grams of mercury are released into the environment for every gram of gold retrieved by ASGM.[75] ASGM wastes and releases of mercury can contaminate water sources and soil surfaces, posing a danger if ingested. Mercury can also bioaccumulate in plants located in contaminated soils, as noted by a Chinese study of an ASGM community in China, where consumed vegetables and wheats had total mercury levels significantly higher than deemed safe by local safety standards.[76] Dumped elemental mercury can also result in high methylmercury levels in native fish and shellfish populations. Ingestion of these contaminated food sources poses yet another possible route of exposure to mercury.

Initiatives & Strategies

International awareness of the health impacts from mercury exposure has increased with the creation of the Minamata Convention on Mercury. Agreed at the fifth session of the Intergovernmental Negotiating Committee in January 2013, the global treaty aims to implement a series of programs to regulate trade and supply of mercury, control production of mercury-added products and manage processes where mercury or mercury compounds are used, such as in ASGM.[77] As of May 2015, 128 countries have signed the Convention, of which more than 80 signatures are from LMICs.[78]

Pure Earth, along with a range of partners active in addressing ASGM, all have the same objective: to introduce affordable techniques to artisanal mining communities to eliminate or reduce mercury emissions. A number of cleaner alternatives to mercury amalgamation currently exist for gold extraction. However, many artisanal communities have been using the traditional practice of mercury amalgamation for decades and are unaware of alternatives. For example, a type of technology called a retort can be used to capture and recycle mercury released during the burning process. Shown to recycle up to 95% of the mercury used, this technology dramatically reduces the amount of mercury released into the environment and thus, the amount artisanal workers are exposed to.[79] However, the largest barrier to uptake of mercury-free technologies is a lack of awareness and understanding. Increasing awareness on the risks posed from mercury use and promotion of cleaner technologies will continue to be a critical component for the elimination and reduction of mercury use in gold extraction activities in LMICs.

Chromium

Population at risk: 16 million people
Estimated DALYs: 3 million

Chromium (Cr) is a naturally occurring heavy metal found in the earth's crust. Although it can be released into the environment through natural processes, it is also released from industrial sources. Chromium is typically found in two forms: chromium III and chromium VI, which are respectively known as trivalent chromium and hexavalent chromium. Trivalent chromium is the most stable of the forms and occurs naturally. In contrast, hexavalent chromium does not occur naturally, and is often the end product of anthropogenic activities.

Industries associated with chromium use include leather tanning operations, metal processing, stainless steel welding, chromate production and chrome pigment production. Chrome uses in tanning is a particular problem, both with the chrome processing plants that supply chrome salts to the tanneries and at tannery complexes that do not have adequate wastewater control and treatment. Due to the relatively inexpensive cost of labor and materials, almost half of the world's tanning and leather industries are located in low- and middle-income countries (LMICs).[80]

Pure Earth estimates that 16 million people are at risk for exposure to chromium globally, with an estimated burden of disease of 3 million DALYs. As

of 2015, the Toxic Sites Identification Program has identified over 300 sites around the world where exposure to chromium threatens the health of the population.

Pathways & Exposure Routes

Industrial processes and improper management of waste products can result in chromium-contaminated air, water, soil and food. The most common routes of exposure to chromium through these media are ingestion, inhalation and dermal contact with soil, water, or particulates in the air contaminated with chromium. The most common route of exposure in occupational settings is inhalation, which has been linked with a variety of health problems.

Associated Health Effects

Development of adverse health effects resulting from chromium exposure is dependent on the route of exposure and the type of chromium affecting a population.

Of the two forms, hexavalent chromium poses greater health risks due to its higher toxicity and the associated cellular uptake pathways. General health effects from exposure to hexavalent chromium include damage to the gastrointestinal, respiratory and immunological systems, as well as reproductive and developmental problems. Furthermore, hexavalent chromium is a known human carcinogen. Depending on the route of exposure, exposure to hexavalent chromium can increase the rate of various types of cancers. Observations documenting higher lung cancer rates in workers occupationally exposed to chromium date back as far as the 1930s.[81] Additionally, the inhalation of chromium may lead to nasal perforation, leaving affected individuals more susceptible to attacks on the respiratory system. Gastrointestinal effects

(Far left) A young worker pulls discarded leather trimmings from local tanneries. Tannery operation regions, such as in Dhaka, Bangladesh, can produce from 600 to 1,000 kilograms of solid waste for each ton of processed hide.

(Left) Saida, a tannery worker suffers from a serious skin condition resulting from contact with toxic effluent from the workplace.

Photos by Sean Gallagher

have been associated with ingestion of chromium-contaminated material, with recent studies showing hexavalent chromium to be stomach carcinogen in humans.[82]

It is important to note that although trivalent chromium has a lower toxicity compared to its hexavalent counterpart, negative health effects can result from trivalent chromium exposure. Studies have shown that chronic exposure to trivalent chromium, particularly in occupational settings, can cause significant damages to lymphocyte DNA.[83] Studies of both chromium compounds have also indicated that chromium accumulation in the human body may have adverse effects on iron metabolism, a critical process for the maintenance of normal bodily functions and an essential component of red blood cells.[84] As most of the human body's iron is contained in red blood cells, iron deficiency anemia may result if the body cannot absorb enough of the metal.

Tannery Operations

The leather industry is one of the largest industrial sources of chromium contamination in LMICs. Between 1970 and 1995, LMICs contributed to 56% of the global production of light and heavy leather materials.[85] The leather industry is comprised of three different sectors including animal husbandry and slaughter, tanning and product manufacturing. Of these stages, chromium is used most often during the tanning process.

During this process, raw leather is treated and made more durable allowing leather to be formed and crafted into various products later on. The tanning stage is composed of three phases including the pre-treatment of the animal hides, application of a tanning agent and material finishing comprising of drying and shining stages. However, it is important to note that these three stages are not static as the tanning process can include sizing of hides, weaving, bleaching, carbonizing, dyeing and finishing.[86] Processing of light and heavy leather materials also occurs during the tanning process. Light leather materials can eventually be manufactured into the tops of shoes and other various leather product, while heavy leather materials are often used in belts, straps, leather used in machinery, and for the soles of shoes.

The types and concentrations of chemicals can also vary between the pre-treatment, tanning and finishing stages of leather manufacturing. Chromium is most widely used in these processes as leather tanned with chromium is likely to be more soft, pliable, stable in water, and take less time to produce when compared to the use of other tanning agents.[87]

These facilities produce large amounts of toxic waste from tanning processes. In some locations, tanneries will not only discharge wastewater into nearby water sources, but also dump large amounts of chromium-contaminated solid waste (e.g. skins, hides, and fats) onto riverbanks and nearby fields. Tannery operation regions, such as in Dhaka, Bangladesh, can produce about six hundred to one thousand kilograms of solid waste for each ton of processed hide.[88] Lack of environmental safety controls and environmental monitoring can result in contamination of water sources and soil surfaces with cadmium, iron, magnesium, chromium, calcium, nickel, lead and zinc from additional tanning agents, as well as potassium, sodium, magnesium and copper from other treatment processes.[89] Although pipelines and canals may exist for the purpose of transporting waste away from tanning facilities, they often run through nearby villages. As a result, pipeline leaks pose great hazards as they may lead to the contamination of agricultural soils, drinking water sources and residential spaces.

A particular issue related to chrome use in tanneries is waste from the processing of chromium ores to the chromium salts use by the tanners. The process is relatively simple and was often carried out in unsophisticated plants that have little control over emissions and waste. A major waste stream is Chromium Ore Processing Residue (COPR) that contains high levels of toxic hexavalent chrome. Unfortunately, the COPR is a coarse sandy material, which has often been taken from processing sites and used for construction purposes including filling wetlands; as a foundation for industrial or domestic buildings; or a base for local roads. Through this process, the highly dangerous hexavalent has been spread throughout the community in several unfortunate locations. An added problem is the leaching of hexavalent chromium from the waste materials and into local streams and groundwater, generating an additional set of exposures and risks, which are often difficult to manage.

Exposure

Populations living near tannery operations are most often exposed to chromium through contact with chromium-contaminated water from activities such as irrigation, swimming, bathing and washing of dishes and clothing. Effluents from chromium industries can contain high concentrations of dissolved and suspended organic and inorganic solids, toxic metal salts, heavy metals, chrome and harmful electrolytes. Toxic effluents released from chromium plants often contaminate surface and groundwater sources and pose serious hazards to nearby communities. For example, more than 200 tanneries in the region of Hazaribagh, Bangladesh generate 7.7 million liters of liquid waste and 88 tons of solid waste every day. Direct discharges of this waste substantially contaminated surface and ground water sources in the region with dangerously high levels of chromium, cadmium, arsenic and lead.[90] Contamination of rivers can also lead to accumulation of chromium in local food sources, including fish and shellfish species.

Effluents from chromium industries may

contaminate soils with heavy metals, such as copper, cadmium, nickel and lead. Contamination of agricultural soils with chromium can also result from releases of tannery waste or use of commercially available fertilizers containing tannery waste, posing hazards to nearby populations who inhale or ingest contaminated soil particles and individuals consuming crops from these regions.[91] Studies have shown that ingestion of chromium-contaminated soil can result in chromium accumulation in the bodies of humans and livestock. In some cases, such as in the Hazaribagh region in Dhaka, Bangladesh, chromium-laden solid tannery waste is used as a principal component for poultry feed and fish feed. One study recently analyzed a series of poultry samples from this region, including poultry feed and eggs, concluding that 25% of the chicken liver samples contained levels of hexavalent chromium from poultry feed.[92]

Initiatives & Strategies

A variety of methods exist for the remediation of chromium-contaminated sites. Groundwater contaminated with hexavalent chromium can be treated in-situ with electron donor additions, which help to convert hexavalent chromium to trivalent, the much less toxic form. However, large-scale groundwater treatment is complex and expensive. Certain salt-tolerant bacteria also have been used as agents to reduce chromium from tannery-waste contaminated soils while bone charcoal has also been applied at some sites to remove chromium from contaminated water bodies.[93,94] Vermiculture, the application of worms to concentrate and absorb heavy metals, is another approach that can be used for the treatment of chromium-contaminated soils. Yet another approach involves injection of molasses into hexavalent chromium contaminated soils.[95] Bacteria feeding on the molasses transform hexavalent chromium to the less harmful trivalent chromium, which is then likely to bind with available rock substrates.

Pesticides

Population at risk: 7 million people
Estimated DALYs: 1 million

Pesticides have been used extensively throughout the world to increase agricultural output and protect crops from pests and diseases. They are also used for controlling disease vectors like mosquitoes in malaria areas. Often chemical in form (though heavy metals have also been used), they are used to repel or eliminate species that have an adverse effect on agricultural or horticultural production. Pesticides may be classified according to the organism being targeted, its chemical structure or the potential health hazard it may pose.[96] These compounds work by interfering with biological mechanisms, particularly those used for the function of ion channels in the nervous system.[97]

Pesticides were first used on a large scale starting in the 15th century. Farmers would often use arsenic and lead compounds to eliminate insect species, but it was not until the 17th to 19th centuries that a wider range of pesticides, including nicotine sulfate, pyrethrum, and rotenone were applied to fields. Many of these compounds were extracted from natural products.[98] During the Green Revolution, a movement lasting from the 1940s to 1970s, which focused on the promotion of technology development initiatives for agriculture, there was a global promotion and application of synthetic (and was later on understood harmful) agrochemicals. Primarily occurring in India, the programs worked to expand industrial irrigation infrastructure, develop new hybrid seed varieties and foster use of synthetic fertilizers and potentially toxic pesticides. Pesticides have also been used to protect human populations from vector-borne tropical diseases, such as malaria since the 1950s.[99]

Many pesticides can cause detrimental health effects, including both organophosphate and

organochlorine pesticides. These compounds work by disrupting enzymes that regulate specific neurotransmitters. Organochlorines are classified as Persistent Organic Pollutants (POPs), as they may remain the environment for extended periods of time and have global mobility. When introduced into the food chain, they may bioaccumulate with the highest concentrations being found in humans, fish-eating birds and marine mammals. A number of organochlorines, including DDT, chlordane and lindane, have since been largely banned for use in multiple countries as it became clear that their persistence and ability to transport over long distances resulted in severe consequences for wildlife and the environment.[100]

While not as persistent as organochlorines, organophosphates are considered to be more toxic, and as a result, have had the use restricted or banned. Organophosphate chemicals include chlorpyrifos, methyl parathion, azinphos methyl, and malathion. Other pesticides known or suspected to cause detrimental health effects include glyphosphate, methyl bromide, metadof, duron and novaquat.

A handful of these compounds are so dangerous that some organophosphates were further developed before and during World War II into chemical warfare agents.[101] One such compound, Agent Orange, was an equal combination of two herbicides and was used as a defoliant during operations conducted in the Vietnam War era. As manufacture of the herbicides took place at an accelerated pace, it is believed that dioxins were introduced into the defoliant which was then spread onto environments in Vietnam, Laos and Cambodia.[102] Obsolete pesticides such as this have

(Far left) An agricultural worker sprays pesticides on a field in the Punjab region of northwest India. The World Health Organization estimates that nearly 3 million agricultural workers primarily from LMICs suffer from acute pesticide poisoning.

(Left) Vegetables are commonly washed alongside drainage channels where pesticide runoff may collect. This is one of many ways that persistent organic pollutants may enter the food chain and bioaccumulate in the humans and animals that consume them.

Photos by Sean Gallagher

been stockpiled around the world, often in poor containment structures that corrode and leak.

The economic costs of acute effects from pesticide exposure are substantial. One study in Nepal found that the average treatment cost from pesticide exposure was around 114 Nepalese Rupees per person, nearly a third of a Nepalese resident's total health expenditure. Overall, the study found that the health costs for people in Nepal suffering from pesticide-related illnesses were almost eight times higher than for those not directly exposed to pesticides.[103]

Pure Earth estimates that 7 million people are at risk for exposure to pesticides globally, with an estimated burden of disease of 1 million DALYs. As of 2015, the Toxic Sites Identification Program has identified over 200 sites around the world where exposure to pesticides threatens the health of the population. In view of the global, long-term use of pesticides, this number will very likely increase in the future.

Pathway & Exposure Routes

After application, pesticides are often washed away by rain into bodies of water. Over a million tons of pesticides will experience this fate annually, generally a result of excessive application. Pesticides can also enter the environment through leaching of chemicals from pesticide storage facilities. A number of these compounds are classified as persistent organic pollutants (POPs), which are known to have long life spans and slow deterioration rates. These POPs can bioaccumulate in human and animal tissues and may also increase in concentration throughout the food chain through a process called biomagnification, as many POPs can accumulate in the fats of species and become absorbed by the species' predators.

Exposure to pesticides most commonly occurs through absorption, inhalation, ingestion and direct dermal contact.[104] Dermal exposure may occur during pesticide loading and mixing, application or clean up. Absorption of pesticides through the skin may vary based on the amount of chemical and duration of the exposure event, presence of other foreign substances on the skin, the ambient temperature and humidity, as well as the use of personal protective equipment.[105] Pesticides may also enter the body through inhalation during pesticide application or the ingestion of contaminated crops. Multiple cases of food poisoning around the world have also resulted from the ingestion of foodstuffs heavily contaminated with pesticides. For example, between 1993 and 1994, over 600 cases of food poisoning due to pesticides were reported in Vietnam.[106] Ingestion of POPs-contaminated foodstuff will also lead to biomagnification in the body fat with related long-term health effects.

Health Effects

Pesticides can be very toxic to the human body. However, some health effects are unique to certain pesticides, as pesticides vary in chemical structure and application. Generally, acute effects from pesticide exposure often include headaches, nausea, dizziness and convulsions. All of these symptoms were reported in a survey of 2,000 agricultural workers in Asia, Africa, and Latin America.[107] Unfortunately, acute pesticide poisoning is often underreported and based on inaccurate and inadequate information.[108] The World Health Organization (WHO) predicts that nearly 3 million agricultural workers primarily from LMICs suffer from acute pesticide poisoning. Furthermore, they estimate that an additional 20,000 unintentional deaths and 735,000 cases of chronic illness occur as a result of pesticide exposure.[109]

Multiple studies have indicated that chronic exposure to pesticides may result in neurological, reproductive and dermatological health impacts.[110] A variety of health effects have been noted, including chronic head and stomach pains, vision loss, birth defects, damage to the central nervous system, immune system deficiencies, pulmonary diseases, respiratory issues, deformities, DNA damage, hormone system disruption and death. Exposure to pesticides has also been determined to be a risk factor for cancer development. Multiple pesticides have been associated with cancers of the prostate, pancreas, liver and other organs.[111] For example, lindane has been associated with breast cancer and fertility problems. Contact with organophosphate residues on fruit and vegetables has also been shown to double a child's risk for development of attention-deficit/hyperactivity disorder (ADHD) development.[112]

Exposure to dioxins deriving from such obsolete herbicides such as Agent Orange may result in a number of additional health effects. As dioxin belongs to the class of persistent organic pollutants, it may remain in the environment over long periods of time, contaminating fine soil particle and finding its way into fish, molluscs and fowl. Exposure to dioxin may cause disruption in bodily functioning and reproductive processes. It may additionally affect the skin, as well as the reproductive, immune, cardiovascular, endocrine, gastrointestinal and nervous systems. Pre-natal exposure to dioxin may result in disrupting development of the nervous, reproductive and immune systems.[113]

Agricultural Use

Overview

Agriculture is one of the most important sectors in low- and middle-income economies. Studies have indicated that GDP growth from agriculture can benefit the income of a country's population by two to four times compared to that from GDP growth from other industries.[114] As a result, pesticides have been used and promoted for decades to improve agricultural output, enhance crop growth and protect crops from harmful pests. However, many of these pesticides pose harmful health risks to both the environment and to human health and difficulty in striking a balance between the need to have high agricultural output and local food security versus the desire to protect the health of populations and of the environment.[115] This balance has undergone further pressure, as the gradual movement of people from rural to urban areas has led to fewer people responsible for food production. This trend, along with the fact that many LMICs are food exporters to higher-income countries, has led to increased reliance on pesticide use.[116] The long-term use of agrochemicals is also lowering soil productivity, which is often countered by even higher use of agrochemicals.

Many harmful pesticides are often cheap to produce and very effective. As a result, many of them are still used throughout LMICs for agricultural and horticultural practices or are waste-mined form landfills and sold on black markets. Surveys conducted by the Pesticide Action Network in Asia found that seven out of the ten most commonly used pesticides are classified as highly hazardous. In addition to application of these pesticides, the surveys noted that there was poor storage and containment infrastructure to prevent leaks and releases of pesticides. The surveys also indicated that there was poor awareness of the effects of pesticide exposure and a lack of safety training programs.

In an attempt to regulate pesticide use around the world, an International Code of Conduct on the Distribution and Use of Pesticides was adopted in 1985. This code was later amended in 1989 and reviewed further in 2002. These directions were created to guide national standards for pesticide use and exposure. However, as many harmful pesticides are cheap and effective, many are still used in LMICs.

Exposure

The majority of the world's poor are involved in the agriculture, particularly rural populations in LMICs. As regulations, control mechanisms and awareness are often lacking, many people in these countries are at risk for exposure to hazardous pesticides. Excessive application, which has become a common trend, further increases the risk for pesticide exposure. Some studies have estimated that more than 90% of sprayed insecticides and herbicides will affect and contaminate sources other than the intended target organism.[117]

Farmers are often burdened and suffer greatly from pesticide use as they often come into direct contact with the pesticides. In many cases, farmers are exposed dermally, as protective equipment and cost-efficient pesticide practices are not often used. For example, a survey conducted by the Pesticide Action Network found that, of 2,000 agricultural workers in Asia, Africa, and Latin America, 47% to 59% of them suffered from headaches and dizziness from pesticide application. Many of these workers also reported that they did not use protective gear.[118] Lack of protective equipment, however, is more often than not due to lack of access to finances for such gear. Much of the burden also falls on women, children and infants.[119] Farmers and nearby populations can also be exposed via inhalation from pesticide spraying and via ingestion from contaminated water bodies and soils.

Initiatives & Strategies

Eradication and decreased application of toxic pesticides, particularly in LMICs, are focuses of many international initiatives and programs. The Stockholm Convention on Persistent Organic Pollutants, created by the United Nations Environment Programme (UNEP), forbids the production and use of POP chemicals (which includes many of the traditional pesticides) and works to increase awareness about pesticides and phase out hazardous pesticide and

POP application.[120] The Food and Agricultural Organization (FAO) of the United Nations has a similar objective. Specifically, goals of the FAO are to promote agricultural practices that involve limited or no pesticide application, to more effectively respond to pest outbreaks, and to reduce creation of new stockpiles of hazardous pesticides. WHO is working to reduce the use of pesticides for disease vector control and promotes, where feasible, the use of non-chemical alternatives.

However, the importance of community-based educational programs focused on teaching agricultural workers about the risks of exposure to hazardous pesticides cannot be understated. Local NGOs have focused on providing education on pesticides, such as the Bolivian organization, "Plagbol" (Plagucidas Bolivanas), which offers telephone advice and training programs on appropriate pesticide use.[121] Community-based programs have been created in many LMICs, often with the help and aid of international organizations, such as those previously discussed.

Production and Storage

Overview

Despite international efforts, pesticides that have been labelled as highly hazardous or for restricted use continue to be produced, used and stored or are waste-mined and sold on local black markets. Many of these pesticides are included in the following categories: persistent organic pollutants, organochlorines, organophosphates and carbamates. Specific examples include heptachlor, chlordane, DDT, dieldrin, aldrin, endosulfan and profenofos.

Even though some hazardous pesticides may no longer be applied in certain regions, there are many uncontrolled sites that contain such compounds. A majority of old stockpiles of hazardous pesticides reside in LMICs. For example, the FAO estimated in 1996 that there were 15,000 to 20,000 tons of obsolete pesticide stocks in African countries.[122] An additional several hundred thousand tons are suspected in countries of the former Soviet Union. Many of these structures were built as a result of the Green Revolution to meet agricultural demands. However, many of these are now abandoned. Due to a lack of maintenance and oversight, these containment facilities can deteriorate over time, leak or crack, and contaminate the nearby environment with pesticides. In many cases, drums of harmful pesticides have been stored in the open, deteriorated or leaked. These sites are also targets of small businessmen waste-mining pesticides, repackaging them into small bags and selling them in local markets.

Exposure

For populations living near or working by old or abandoned pesticide production and storage facilities, the main route of exposure to pesticides is through ingestion, inhalation and dermal contact. Pesticides can be inhaled or ingested from leaks that have contaminated nearby water bodies and soils. Pesticides can also be inhaled if contaminated soils are disturbed and result in the release of dust particles into the air.

POP-based pesticides, such as DDT or lindane, can contaminate sources for long periods of time. The properties and dangers of this pesticide became globally known through Rachel Carson's famous investigative work *Silent Spring*. DDT can persist in the environment, meaning that it does not easily degrade by biological, chemical or physical processes. DDT can also travel long distances and accumulate in the fats of organisms throughout the food chain. As a result, DDT can accumulate in the fat of human bodies from any pathway, including ingestion of contaminated animal food sources. DDT exposure and accumulation has been known to cause a variety of adverse health effects, including stomach issues, intestinal problems, damages to the liver, kidney, nervous system, and reproductive systems, as well as developmental defects and cancer.

Initiatives & Strategies

In late 2014, Pure Earth was awarded a small contract from the Food and Agricultural Organization of the United Nations (FAO) to investigate an obsolete pesticide dump in the Ahava Valley of Somaliland. In recent years, the Desert Locus Control Organization of East Africa had used the Ahava Valley to store obsolete organochlorine pesticides such as DDT, aldrin, dieldrin and lindane. In addition to these compounds, the organophosphate malathion was found at the site. Pure Earth worked to pack 55-gallon drums of the discarded obsolete pesticides into overpack drums and topped them off with contaminated rubble. Once sealed and ready for export, these drums were delivered to a qualified facility capable of incinerating the contaminated waste. Follow-up remediation efforts included adding soil amendments to the contaminated area in an effort to neutralize any remaining organochlorines.[123]

There are many international initiatives and programs with the objective to reduce the amount of harmful pesticide stockpiles in LMICs. For example, the Africa Stockpiles program has concentrated efforts to reduce stockpiles in Ethiopia, Mali, Morocco and Nigeria. Green Cross Switzerland in a joint effort with FAO, UNEP, WHO, national governments, NGOs and technical experts is managing several large projects to introduce the Stockholm Convention in West Africa. Additional projects include repackaging several hundred tons of DDT and related wastes in Georgia, Kyrgyzstan and Tajikistan.

Cadmium

Population at risk: 5 million people
Estimated DALYs: 250,000

Cadmium is a bluish-white metal, rarely found in the earth's crust. However, industrial activities such as mining, smelting and refining release large amounts of cadmium that is often found in lead and copper ores. It is mainly used in the production of nickel-cadmium batteries, fertilizers, coatings and plastic stabilizers.[124] Worldwide use and disposal of electronic waste including televisions, computers and smart phones, greatly contributes to cadmium's release into the environment. Its presence is of greatest concern in LMICs, where industrial activities continue to release cadmium into the environment.[125]

Ore mining and refining activities are the largest anthropogenic release of cadmium into the environment, caused by both emissions and the leakage of contaminated water.[126] Combustion of fossil fuels and the incineration of waste, as well as the use of mineral fertilizers and sewage sludge as fertilizer also contribute greatly to anthropogenic cadmium sources.

Public awareness surrounding cadmium's effects on health was first brought to attention during an exposure event in Fuchu Toyama Prefecture, Japan. Women living in regions with cadmium-polluted waters began to suffer from advanced renal and bone disease, now known collectively as Itai-Itai (Ouch-Ouch) disease, one of the Four Big Pollution Diseases of Japan. Regular mining for gold, silver, lead, copper and zinc beginning as early as the 1500s contributed to cadmium's release into the environment. Mining production continued to increase during the Russo-Japanese War, as well as the World Wars that followed. As cadmium began to accumulate in nearby rivers and riverbeds, it found its way into rice fields as contaminated water was used for irrigation. Although it became clearer that the symptoms of Itai-Itai disease were not simply a regional anomaly deriving from natural sources, it was not until 1955 that scientists began to target cadmium as the potential cause of illness. Release of the cadmium into the environment had lessened by this time, but no formal public announcement

was made regarding cadmium's connection to the disease until the late 1960s.

In early 2012, Jinhe mining company released a large quantity of cadmium into the Guangxi Longiang River in the Guangxi Zhuang Autonomous Region of China. The cadmium spill caused massive fish deaths and threatened the water supply of the water of the greater area. While remediation efforts still continue, environmental releases of cadmium such as that seen in Guangxi continue to place a large burden on the public.

Pure Earth estimates that 5 million people are at risk for exposure to cadmium globally, with an estimated burden of disease of 250,000 DALYs. As of 2015, the Toxic Sites Identification Program has identified over 150 sites around the world where exposure to cadmium threatens the health of the population.

Pathways & Route of Exposures

Cadmium has been shown to have a marked route dependency, with only 5% of an oral dose being absorbed by the gastrointestinal tract. However, cadmium absorption through the lungs is markedly high, with up to 90% of a given dose being absorbed. Cadmium has a unique toxicological profile, with extremely low concentrations capable of causing significant toxicity. As the metal may not undergo metabolic degradation, the human body is ill equipped to rid itself of cadmium.[127]

The contamination of farmland with cadmium via industrial processes is thought to be the main source of exposure for the non-smoking population. The main contributors to dietary cadmium exposure include bread, potatoes, cereal grains and vegetables. Leafy vegetables and other agricultural products may bioconcentrate cadmium from the

(Far left) A rice paddy field near the Guixi smelter in the Jianxi province of China is readied for remediation. The Guixi smelter is the largest copper factory in China, and began smelting operations in the 1980's. The contamination of farmland via industrial processes is thought to be the main source of cadmium exposure for the non-smoking population. Leafy vegetables and other agricultural products may bioconcentrate cadmium from the soil and serve as an exposure pathway through the diet.

(Left) A worker applies lime and soil amendments consisting of wheat milling byproduct to adjust soil pH in an agricultural field. By adjust soil pH, cadmium may be fixed in soil preventing it from leaching into groundwater and entering crops. Cadmium may enter the body through the diet and due to its unique toxicological profile, extremely low concentrations are capable of causing significant toxicity.

Photos by Xuebing Sun

soil, and serve as an exposure pathway through the diet, finding its way into the body through both the digestive and respiratory tracts.

Air-borne cadmium particles produced during industrial activities may serve as another exposure pathway through the inhalation of contaminated dust. Electroplating workers, particularly in the aircraft industry, are often at risk of cadmium exposure through the inhalation of airborne cadmium, and this body burden may be further exacerbated in those workers who smoke tobacco.[128]

Health Effects

Detrimental health effects resulting from exposure to cadmium first came to light in the mid 19th century, as studies acknowledged respiratory and gastrointestinal symptoms resulting from the use of a cadmium containing polishing agent. Symptoms of acute cadmium exposure via inhalation include dizziness, nausea, vomiting, choking, headache and pulmonary irritation. Exposure through inhalation may also result in chronic bronchitis, with heavier exposures causing fibrosis and emphysema. Severe intoxication via inhalation may also result in respiratory distress syndrome due to acute pneumonitis and pulmonary edema, or cardiopulmonary obstructive disease. Following acute cadmium ingestion, health effects include hepatotoxicity with additional symptoms including vomiting, diarrhea and abdominal pain. In cases of severe intoxication via ingestion, death may result due to fluid loss, renal failure, cardiopulmonary depression or liver damage.

The most common observed health effect from chronic cadmium exposure in both the general population and in occupationally exposed individuals is kidney and renal damage. Tubular and glomerular damage resulting from cadmium's affinity toward epithelial cells may result in nephritis and nephrosis. Additionally, cadmium exposure is also a risk factor for type II diabetes and diabetic complication.[129]

Cadmium is a known carcinogen, having been designated as such by the World Health Organization's International Agency for Research on Cancer (IARC). Research studies have repeatedly found an association of cadmium exposure with pulmonary cancers, as well as cancers of the prostate and kidney, while others have found an association with cancer of the liver, hematopoietic system, urinary bladder, breast and stomach. Aside from cadmium's known association with lung cancer, inhalation may also result in inflammation and fibrosis. Evidence continues to build for an association between exposure and pancreatic cancer.

Cadmium is also a known cardiovascular risk factor and has been shown to contribute to the onset of atherosclerosis, which may contribute to hypertension, stroke, cardiac arrest and heart failure.[130] A correlation exists between osteoporosis and cadmium burden in some populations, namely for post-menopausal women, as exposure decreases bone mineral density and increases the chance for fracture. Such decreases in bone density are likely related to kidney malfunction and reduced reabsorption rates in the nephron.

Itai-Itai disease, resulting from cadmium poisoning, includes a number of health effects including the weakening and deformation of bones, gait abnormalities, bone pain, anemia, coughing, kidney failure and death. Recent research has also shown cadmium to have epigenetic effects; altering DNA that is passed from mother to offspring and leading to malignant transformations.[131] Additional teratogenic effects due to cadmium ingestion include fetal malformation and restriction of growth.[132]

Initiatives & Strategies

Pure Earth's Efforts to remediate cadmium pollution hotspots have included supporting local efforts in the Jianxi province of China, where the largest copper factory in China began smelting operations in the 1980's. Strategies being investigated include fixing cadmium into the rice paddy soil to stop migration into groundwater, thereby limiting its uptake by rice and other crops. Past projects have included the use of lime and soil amendments consisting of wheat milling by-product. In doing so, soil pH may be adjusted and cadmium may be fixed in the soil, preventing it from leaching into groundwater and entering rice crops.

Other remediation methods include the use of alternate rice strains that accumulate cadmium more readily than the varieties consumed. This rice is then harvested and used in metal recycling processes, as well as the production of energy through the use of biomass.

Conclusions

The patterns of pollution and harm from these top pollutants and others across the world are becoming clearer and the need for interventions is more widely accepted. Pilot and small-scale projects and programs are demonstrating that improvements can be made on the ground, and there is an urgent need for commitment to address the problems. Larger amounts of financing will be required over a period of years, but actions can begin with relatively modest funds.

Despite all of the efforts and some local success, the three years since the 2012 report have shown no measureable reduction in the overall burden from toxic pollution, while the numbers of sites identified or suspected continue to rise.

FOOTNOTES

16. U.S. Department of Health and Human Services Agency for Toxic Substances and Disease Registry. Toxicological profile for lead. Agency for Toxic Substances and Disease Portal Web site. http://www.atsdr.cdc.gov/toxprofiles/tp13.pdf. Published August 2007. Updated 2007. Accessed October 1, 2015
17. Hodgson S, Manmee C, Dirks W, Shepherd T, Pless-Mulloli T. Determinants of childhood lead exposure in the postleaded petrol era: The tooth fairy cohort from newcastle upon tyne. J*ournal of Exposure Science and Environmental Epidemiology*. 2014
18. Centers for Disease Control and Prevention (CDC). Blood lead levels in children. CDC's Childhood Lead Poisoning Prevention Program Web site. http://www.cdc.gov/nceh/lead/acclpp/lead_levels_in_children_fact_sheet.pdf. Published 2012. Updated 2014. Accessed October 1, 2015
19. Haefliger P, Mathieu-Nolf M, Lociciro S, et al. Mass lead intoxication from informal used lead-acid battery recycling in Dakar, Senegal. *Environ Health Perspect*. 2009;117(10):1535-1540
20. Caravanos J, Dowling R, Téllez-Rojo MM, et al. Blood lead levels in Mexico and pediatric burden of disease implications. *Annals of Global Health*. 2014;80(4):269-277
21. International Lead Association. Environmental and social responsibility for the 21st century. International Lead Association Web site. http://www.ila-lead.org/UserFiles/File/ILA9927%20FS_Recycling_V06.pdf. Published 2014. Updated 2014. Accessed October 1, 2015
22. Khan DA, Qayyum S, Saleem S, Ansari WM, Khan FA. Lead exposure and its adverse health effects among occupational worker's children. *Toxicol Ind Health*. 2010;26(8):497-504
23. Secretariat of the Basel Covention. Technical guidelines for the environmentally sound management of waste lead-acid batteries. Basel Convention on the Control of Transboundary Movement of Hazardous Wastes and Their Disposal Web site. http://archive.basel.int/pub/techguid/tech-wasteacid.pdf. Published 2003. Updated 2003. Accessed October 1, 2015
24. Dudka S, Adriano DC. Environmental impacts of metal ore mining and processing: A review. *J Environ Qual*. 1997;26(3):590-602
25. International Finance Coporation. Environmental, health and safety guidelines base metal smelting and refining. International Finance Corporation Web site. http://www.ifc.org/wps/wcm/connect/4365de0048855b9e8984db6a6515bb18/Final+-+Smelting+and+Refining.pdf?MOD=AJPERES. Published 2007. Updated 2007. Accessed October 1, 2015
26. Carn S, Krueger A, Krotkov N, Yang K, Levelt P. Sulfur dioxide emissions from peruvian copper smelters detected by the ozone monitoring instrument. *Geophys Res Lett*. 2007;34(9)
27. Bi X, Feng X, Yang Y, et al. Allocation and source attribution of lead and cadmium in maize (zea mays L.) impacted by smelting emissions. *Environmental Pollution*. 2009;157(3):834-839
28. Zheng N, Wang Q, Zheng D. Health risk of hg, pb, cd, zn, and cu to the inhabitants around huludao zinc plant in china via consumption of vegetables. *Sci Total Environ*. 2007;383(1):81-89
29. Carrizales L, Razo I, Tellez-Hernandez JI, et al. Exposure to arsenic and lead of children living near a copper-smelter in San Luis Potosí, Mexico: Importance of soil contamination for exposure of children. *Environ Res*. 2006;101(1):1-10
30. United States Nuclear Regulatory Commission. "Background on Radioactive Waste." Available at http://www.nrc.gov/reading-rm/doc-collections/fact-sheets/, April 12, 2007.
31. U.S. Environmental Protection Agency. "Commonly Encountered Radionuclides." Available at http://www.epa.gov/rpdweboo/radionuclides/index.html, October 1, 2010.
32. Agency for Toxic Substances and Disease Registry "Case Studies in Environmental Medicine. Radon Toxicity." Public Health Service, U.S. Department of Health and Human Services, 1992.
33. U.S. Environmental Protection Agency. "Commonly Encountered Radionuclides." Available at http://www.epa.gov/rpdweboo/radionuclides/index.html, October 1, 2010.
34. U.S. Environmental Protection Agency. "Radionuclides (Including Radon, Radium and Uranium)." Available at http://www.epa.gov/ttn/atw/hlthef/radionuc.html, November 6, 2007.
35. Samet J, Patel S. Selected health consequences of the Chernobyl disaster: A further systematic literature review. *Focus Group Findings, and Future Directions*. 2013
36. Samet JM, Director U, Chanson D. Fukushima Daiichi power plant disaster.
37. Yablokov A. A review and critical analysis of the

"Effective dose of radiation" concept. *Journal of Health and Pollution*. 2013;3(5):13-28
38. Gould JM. The enemy within: *The high cost of living near nuclear reactors: Breast cancer, AIDS, low birthweights, and other radiation-induced immune deficiency effects*. Four Walls Eight Windows; 1996
39. Petrushkina N, Koshurnikova N, Kabirova N, Kuropatenko E, Zyrianov A, Brokhman S. Child mortality in Snezhinsk and Ozersk cities from the 1974-1995: Children registry and death rates in young population of the cities of Ozyorsk and Snezhinsk. . 1998:21-24
40. Livingston Kea. Radiobiological evaluation of immigrants from the vicinity of Chernobyl. *Int J Radiat Biol*. 1997;72(6):703-713
41. Cristaldi M, Ieradi L, Mascanzoni D, Mattei T. Environmental impact of the Chernobyl accident: Mutagenesis in bank voles from Sweden. *Int J Radiat Biol*. 1991;59(1):31-40
42. Goncharova R. Remote consequences of the Chernobyl disaster: Assessment after 13 years. *Low doses of radiation: are they dangerous*. 2000:289-314
43. Yablokov A. A review and critical analysis of the "Effective dose of radiation" concept, part II-an approach to an objective assessment of human radiation risk. *Journal of Health Pollution*. 2014;4(7):62-74
44. U.S. Environmental Protection Agency. "Radionuclides (Including Radon, Radium and Uranium)." Available at http://www.epa.gov/ttn/atw/hlthef/radionuc.html, November 6, 2007.
45. M. Al-Zoughool and D. Krewski. "Health Effects of Radon: A Review of the Literature." *International Journal of Radiation Biology*. 85.1 (2009): 57-69.
46. B. Vacquier, et al. "Mortality Risk in the French Cohort of Uranium Miners: Extended Follow-up, 1946-1999." Occupational and Environmental Medicine. 65.9 (2008): 597-604.
47. U.S. Environmental Protection Agency. "Radiation Protection: Health Effects." Available at http://www.epa.gov/rpdweboo/understand/health_effects.html, August 28, 2008.
48. Kamiya K, Ozasa K, Akiba S, et al. Long-term effects of radiation exposure on health. *The Lancet*. 2015;386(9992):469-478
49. Glionna J. A year after tsunami, a cloud of distrust hangs over japan: The Fukushima nuclear disaster has left residents doubting their government, their source of energy, even the food they eat. *Los Angeles Times*. 2012;11
50. Hasegawa A, Tanigawa K, Ohtsuru A, et al. Health effects of radiation and other health problems in the aftermath of nuclear accidents, with an emphasis on fukushima. *The Lance*t. 2015;386(9992):479-488
51. Diehl, P. Uranium Mining and Milling Wastes: An Introduction. *WISE Uranium Project*. Available at http://www.wise-uranium.org/uwai.html, August 15, 2004.
52. O. Neves, M.M. Abreau, and E.M. Vincente. "Uptake of Uranium by Lettuce (*Lactuca sativa L.*) in Natural Uranium Contaminated Soils in Order to Assess Chemical Risk for Consumers." Water, Air & Soil Pollution. 195.1-4 (2008): 73-84.
53. Kampalath RA, Jay JA. Sources of mercury exposure to children in low-and middle-income countries. Journal of Health Pollution. 2015;5(8):33-51
54. U.S. EPA (U.S. Environmental Protection Agency). Mercury compounds. Air Toxics Web site. http://www3.epa.gov/airtoxics/hlthef/mercury.html. Published 2000. Updated 2015. Accessed September 5, 2015
55. Braune B, Chételat J, Amyot M, et al. Mercury in the marine environment of the Canadian arctic: Review of recent findings. *Sci Total Environ*. 2015;509:67-90
56. Pacyna EG, Pacyna J, Sundseth K, et al. Global emission of mercury to the atmosphere from anthropogenic sources in 2005 and projections to 2020. *Atmos Environ*. 2010;44(20):2487-2499
57. Zheng N, Wang Q, Zheng D. Health risk of hg, pb, cd, zn, and cu to the inhabitants around huludao zinc plant in china via consumption of vegetables. *Sci Total Environ*. 2007;383(1):81-89
58. Gray JE, Theodorakos PM, Fey DL, Krabbenhoft DP. Mercury concentrations and distribution in soil, water, mine waste leachates, and air in and around mercury mines in the big bend region, texas, USA. *Environ Geochem Health*. 2015;37(1):35-48
59. Chibunda R, Janssen C. Mercury residues in free-grazing cattle and domestic fowl form the artisanal gold mining area of Geita district, Tanzania. *Food Addit Contam*. 2009;26(11):1482-1487
60. Bose-O'Reilly S, Drasch G, Beinhoff C, et al. Health assessment of artisanal gold miners in Indonesia. Sci Total Environ. 2010;408(4):713-725
61. Bose-O'Reilly S, Lettmeier B, Roider G, Siebert U, Drasch G. Mercury in breast milk–A health hazard for

infants in gold mining areas? *Int J Hyg Environ Health*. 2008;211(5):615-623
62. Yard EE, Horton J, Schier JG, et al. Mercury exposure among artisanal gold miners in Madre de Dios, Peru: A cross-sectional study. *Journal of Medical Toxicology*. 2012;8(4):441-448
63. Tomicic C, Vernez D, Belem T, Berode M. Human mercury exposure associated with small-scale gold mining in Burkina Faso. *Int Arch Occup Environ Health*. 2011;84(5):539-546
64. Gibb H, O'Leary KG. Mercury exposure and health impacts among individuals in the artisanal and small-scale gold mining community: A comprehensive review. *Environ Health Perspect*. 2014;122(7):667-672
65. Hong Y, Kim Y, Lee K. Methylmercury exposure and health effects. *Journal of Preventive Medicine and Public Health*. 2012;45(6):353
66. Ministry of the Environment, Japan. Lessons from minamata disease and mercury management in japan. Ministry of the Environment, Japan Web site. http://www.env.go.jp/chemi/tmms/pr-m/mat01/en_full.pdf. Published 2013. Updated 2013. Accessed October 2, 2015
67. Rice KM, Walker Jr EM, Wu M, Gillette C, Blough ER. Environmental mercury and its toxic effects. Journal of Preventive Medicine and Public Health. 2014;47(2):74, Rice KM, Walker Jr EM, Wu M, Gillette C, Blough ER. Environmental mercury and its toxic effects. *Journal of Preventive Medicine and Public Health*. 2014;47(2):74
68. Shandro JA, Veiga MM, Chouinard R. Reducing mercury pollution from artisanal gold mining in Munhena, Mozambique. *J Clean Prod*. 2009;17(5):525-532
69. Davies GR. A toxic free future: Is there a role for alternatives to mercury in small-scale gold mining? *Futures*. 2014;62:113-119
70. Saleem M, Alfred S, Bahnisch RA, Coates P, Kearney DJ. Mercury poisoning from home gold amalgam extraction. *Med J Aust*. 2013;199:125-127
71. Labonne B. Who is afraid of artisanal and small-scale mining (ASM)? *The Extractive Industries and Society*. 2014;1(2):121-123
72. Hilson G, McQuilken J. Four decades of support for artisanal and small-scale mining in sub-Saharan Africa: A critical review. *The Extractive Industries and Society*. 2014;1(1):104-118
73. Bose-O'Reilly S, Drasch G, Beinhoff C, et al. Health assessment of artisanal gold miners in tanzania. *Sci Total Environ*. 2010;408(4):796-805
74. Hinton J, Veiga M, Beinhoff C. Women, mercury and artisanal gold mining: Risk communication and mitigation. 2003;107:617-620
75. Krisnayanti BD, Anderson CW, Utomo WH, et al. Assessment of environmental mercury discharge at a four-year-old artisanal gold mining area on lombok island, Indonesia. *Journal of Environmental Monitoring*. 2012;14(10):2598-2607
76. Feng X, Dai Q, Qiu G, Li G, He L, Wang D. Gold mining related mercury contamination in Tongguan, Shaanxi province, PR china. *Appl Geochem*. 2006;21(11):1955-1968
77. United Nations Environment Programme (UNEP). Minamata convention on mercury. UNEP: Minamata Convention on Mercury Web site. http://www.mercuryconvention.org/Portals/11/documents/Booklets/Minamata%20Convention%20on%20Mercury_booklet_English.pdf. Published 2013. Updated 2013. Accessed September 5, 2015
78. United Nations Environment Programme (UNEP). List of signatories. UNEP: Minimata Convention on Mercury Web site. http://www.mercuryconvention.org/Countries/tabid/3428/Default.aspx. Published 2013. Updated 2015. Accessed October 2, 2015
79. Jønsson JB, Charles E, Kalvig P. Toxic mercury versus appropriate technology: Artisanal gold miners' retort aversion. *Resour Policy*. 2013;38(1):60-67
80. Azom M, Mahmud K, Yahya S, Sontu A, Himon S. Environmental impact assessment of tanneries: A case study of Hazaribagh in Bangladesh. International *Journal of Environmental Science and Development*. 2012;3(2):152-156
81. Jacobson E. Chromium: A thoroughly modern metal. Dartmouth Toxic Metals Superfund Research Program Web site. http://www.dartmouth.edu/~toxmetal/toxic-metals/more-metals/chromium-history.html. Published 2010. Updated 2010. Accessed October 30, 2015
82. Welling R, Beaumont JJ, Petersen SJ, Alexeeff GV, Steinmaus C. Chromium VI and stomach cancer: A meta-analysis of the current epidemiological evidence. *Occup Environ Med*. 2015;72(2):151-159
83. Medeiros MG, Rodrigues AS, Batoreu MC, Laires A, Rueff J, Zhitkovich A. Elevated levels of DNA-protein crosslinks and micronuclei in peripheral lymphocytes of tannery workers exposed to trivalent chromium.

Mutagenesis. 2003;18(1):19-24
84. Kornhauser C, Wrobel K, Wrobel K, et al. Possible adverse effect of chromium in occupational exposure of tannery workers. *Ind Health.* 2002;40(2):207-213
85. Jenkins R, Barton J, Hesselberg J. 7. the global tanning industry: A commodity chain approach. *Environmental Regulation in the New Global Economy: the impact on industry and competitiveness: Edward Elgar Publishing*. 2004:157-172
86. Correia VM, Stephenson T, Judd SJ. Characterisation of textile wastewaters-a review. *Environ Technol*. 1994;15(10):917-929
87. U.S. EPA (U.S. Environmental Protection Agency). Leather tanning. U.S. EPA (U.S. Environmental Protection Agency) Web site. http://www3.epa.gov/ttnchie1/ap42/ch09/final/c9s15.pdf. Published 1997. Updated 1997. Accessed October 1, 2015
88. Sharif MI, Mainuddin K. Country case study on environmental requirements for leather and footwear export from Bangladesh. United Nations Conference on Trade and Development Web site. http://r0.unctad.org/trade_env/test1/meetings/bangkok5/b5Draft%20case%20study%20Bangladesh.pdf. Published 2003. Updated 2003. Accessed October 1, 2015
89. Tariq SR, Shah MH, Shaheen N, Khalique A, Manzoor S, Jaffar M. Multivariate analysis of selected metals in tannery effluents and related soil. *J Hazard Mater*. 2005;122(1):17-22
90. Bhuiyan MAH, Suruvi NI, Dampare SB, et al. Investigation of the possible sources of heavy metal contamination in lagoon and canal water in the tannery industrial area in dhaka, bangladesh. *Environ Monit Assess*. 2011;175(1-4):633-649
91. Grubinger VP, Gutenmann WH, Doss GJ, Rutzke M, Lisk DJ. Chromium in swiss chard grown on soil amended with tannery meal fertilizer. *Chemosphere*. 1994;28(4):717-720
92. Mazumder L, Hasan S, Rahman M. Hexavalent chromium in tannery solid waste based poultry feed in Bangladesh and its transfer to food chain. *IOSR J Environ Sci, Toxicol Food Technol*. 2013;3:44-51
93. Megharaj M, Avudainayagam S, Naidu R. Toxicity of hexavalent chromium and its reduction by bacteria isolated from soil contaminated with tannery waste. *Curr Microbiol*. 2003;47(1):0051-0054
94. Dahbi S, Azzi M, Saib N, De la Guardia M, Faure R, Durand R. Removal of trivalent chromium from tannery waste waters using bone charcoal. Analytical and Bioanalytical Chemistry. 2002;374(3):540-546
95. Jeyasingh J, Philip L. Bioremediation of chromium contaminated soil: Optimization of operating parameters under laboratory conditions. *J Hazard Mater*. 2005;118(1):113-120
96. Anderson SE, Meade BJ. Potential health effects associated with dermal exposure to occupational chemicals. *Environmental Health Insights*. 2014;8(Suppl 1):51
97. Mostafalou S, Abdollahi M. Pesticides and human chronic diseases: Evidences, mechanisms, and perspectives. *Toxicol Appl Pharmacol*. 2013;268(2):157-177
98. Miller G, Spoolman S. *Living in the environment: Principles, connections, and solutions*. Cengage Learning; 2011
99. van den Berg H, Yadav RS, Zaim M. Strengthening public health pesticide management in countries endemic with malaria or other major vector-borne diseases: An evaluation of three strategies. *Malar J*. 2014;13:368-2875-13-368
100. Van Dyk JS, Pletschke B. Review on the use of enzymes for the detection of organochlorine, organophosphate and carbamate pesticides in the environment. *Chemosphere*. 2011;82(3):291-307
101. U.S. EPA (U.S. Environmental Protection Agency). Types of pesticides. U.S. EPA Web site. http://www.epa.gov/pesticides/about/types.htm. Published 2014. Updated 2014. Accessed October 2, 2015
102. Bailey CR. Agent orange: History, science, and the politics of uncertainty. by Edwin A. Martini. *Pacific Affairs*. 2014;87(1):187-189
103. Atreya K. Health costs from short-term exposure to pesticides in Nepal. *Soc Sci Med*. 2008;67(4):511-519
104. Eddleston M, Bradberry SM, Thompson JP. Pesticides, herbicides, and rodenticides. *Oxford Desk Reference: Toxicology*. 2014:297
105. Dung NH, Thien TC, Hong N, et al. Impact of agro-chemical use on productivity and health in Vietnam. Economy and environment program for Southeast Asia (EEPSEA); 1999
106. Dung NH, Thien TC, Hong N, et al. Impact of agro-chemical use on productivity and health in Vietnam. Economy and environment program for Southeast Asia (EEPSEA); 1999

107. Pesticide Action Network (PAN) Asia. *Communities in Peril: Global report on health impacts of pesticide use in agriculture. Regional reports for PAN International Production Supervision*. 2010
108. Litchfield MH. Estimates of acute pesticide poisoning in agricultural workers in less developed countries. *Toxicological reviews*. 2005;24(4):271-278
109. World Health Organization. Public health impact of pesticides used in agriculture. 1990
110. Wesseling C, McConnell R, Partanen T, Hogstedt C. Agricultural pesticide use in developing countries: Health effects and research needs. *International Journal of Health Services*. 1997;27(2):273-308
111. Jaga K, Dharmani C. The epidemiology of pesticide exposure and cancer: A review. *Rev Environ Health*. 2005;20(1):15-38
112. Bouchard MF, Bellinger DC, Wright RO, Weisskopf MG. Attention-deficit/hyperactivity disorder and urinary metabolites of organophosphate pesticides. *Pediatrics*. 2010;125(6):e1270-7
113. White SS, Birnbaum LS. An overview of the effects of dioxins and dioxin-like compounds on vertebrates, as documented in human and ecological epidemiology. *Journal of Environmental Science and Health, Part* C. 2009;27(4):197-211
114. Asenso-Okyere K, Davis K, Aredo D. Advancing agriculture in developing countries through knowledge and innovation: Synopsis of an international conference. *Intl Food Policy Res Inst*; 2008
115. Kesavachandran CN, Fareed M, Pathak MK, Bihari V, Mathur N, Srivastava AK. Adverse health effects of pesticides in agrarian populations of developing countries. In: *Reviews of environmental contamination and toxicology* vol 200. Springer; 2009:33-52
116. Ponting C. *A new green history of the world: The environment and the collapse of great civilizations*. Random House; 2011
117. Miller G, Spoolman S. Living in the environment: Principles, connections, and solutions. 2011
118. Pesticide Action Network (PAN) Asia. Communities in peril: Global report on health impacts of pesticide use in agriculture. PAN Asia Pacific Web site. http://www.panap.net/sites/default/files/PAN-Global-Report.pdf. Published 2010. Updated 2010. Accessed October 1, 2015
119. Goldman L, World Health Organization. *Childhood pesticide poisoning: Information for advocacy for action*. Chemicals Programme of the United Nations Environment Programme; 2004
120. Secretariat of the Stockholm Convention. Stockholm Convention Web site. chm.pops.int. Published 2009. Updated 2009. Accessed October 1, 2015
121. Jørs E. Acute pesticide poisonings among small-scale farmers in La Paz county, Bolivia. Department of International Health, Institut of Public Health, Faculty of Health Sciences, University of Copenhagen. 2004
122. Wodageneh A, Van der Wulp H. Obsolete pesticides in developing countries. *Pesticides News* (United Kingdom). 1996
123. Fuller R, DiMarco D. *The Brown Agenda: My mission to clean up the world's most life-threatening pollution*. Solana Beach, CA: Santa Monica Press; 2015:282.
124. Tellez-Plaza M, Jones MR, Dominguez-Lucas A, Guallar E, Navas-Acien A. Cadmium exposure and clinical cardiovascular disease: A systematic review. *Curr Atheroscler Rep*. 2013;15(10):1-15
125. Anetor JI. Rising environmental cadmium levels in developing countries: Threat to genome stability and health. *Nigerian Journal of Physiological Sciences*. 2013;27(2):103-115
126. Sigel A, Sigel H, Sigel RK. *Cadmium: From toxicity to essentiality*. Springer; 2013
127. Waalkes MP. Cadmium carcinogenesis. *Mutation Research/Fundamental and Molecular Mechanisms of Mutagenesis*. 2003;533(1):107-120
128. Julin B, Wolk A, Johansson J, Andersson S, Andrén O, Åkesson A. Dietary cadmium exposure and prostate cancer incidence: A population-based prospective cohort study. *Br J Cancer*. 2012;107(5):895-900
129. Thévenod F, Lee W. Toxicology of cadmium and its damage to mammalian organs. In: *Cadmium: From toxicity to essentiality*. Springer; 2013:415-490
130. Messner B, Knoflach M, Seubert A, et al. Cadmium is a novel and independent risk factor for early atherosclerosis mechanisms and in vivo relevance. *Arterioscler Thromb Vasc Biol*. 2009;29(9):1392-1398
131. Thévenod F, Lee W. Toxicology of cadmium and its damage to mammalian organs. In: *Cadmium: From toxicity to essentiality*. Springer; 2013:415-490
132. Wang Z, Wang H, Xu ZM, et al. Cadmium-induced teratogenicity: Association with ROS-mediated endoplasmic reticulum stress in placenta. *Toxicol Appl Pharmacol*. 2012;259(2):236-247

4

Is the World Beginning to Pay Attention?

After a decade of presenting the worst pollution cases and building up the evidence to demonstrate the devastating impacts of toxic pollution, improvements on the ground have been sadly limited.

Last year a number of individual countries were commended for their efforts to come to grips with specific problems. This year, it is possible to point to some positive developments increasing global focus and investment in addressing pollution.

Minamata Convention

In the middle of the 20th century, the small city of Minamata, Komamoto, Japan was the site of one of the world's most infamous outbreaks of mercury poisoning. The Chisso chemical factory released vast amounts of methyl mercury into Minamata bay, from where area residents ate fish. Minamata disease, as it came to be known, resulted in insanity, muscle weakness and in extreme cases, death. The deformities that resulted shocked the world. Perhaps most eerily, the "index" cases (or first cases in public health vernacular) were cats driven insane by mercury ingestion inexplicably running in short, concentric circles.

Since then, mercury's reach has increased, albeit with typically less severe exposures. Small-scale artisanal gold mining (ASGM) is the largest

(Left) Naicila, a five year old, bathes under a pipe carrying runoff from a nearby mining site outside the Padang Bilah mining community in Southeast Sulawesi, Indonesia. It is estimated that one to two grams of mercury are released into the environment for every gram of gold retrieved by ASGM.

Photo by Larry C. Price

anthropogenic sources of mercury globally (recently surpassing coal fired power plants). The mercury is used to amalgamate gold contained ore and is later put to flame where the mercury is vaporized and the gold is left behind. Once in the atmosphere mercury can travel great distances. Indeed the Inuit in the Artic have some of the highest body burdens of mercury in the world, despite a verifiable absence of quick silver in the north.[133] Read more in the mercury section of this report.

In an important step toward dealing with the problem, the United Nations Environment Program (UNEP) has worked tirelessly over the past 15 years to assess the extent of mercury pollution and develop resolutions to deal with the problem. The result of that work is the aptly named Minamata Convention, the text of which was agreed upon in January 2013. The key features of the Minamata Convention are "a ban on new mercury mines, the phase-out of existing ones, control measures on air emissions, and the international regulation of the informal sector for artisanal and small-scale gold mining."[134]

In September of this year, UNEP held a key meeting to foster implementation of the convention. We believe the convention will make enormous strides in addressing this health threat. Importantly however, vast stockpiles of mercury are already in existence and are regularly traded illegally. It is therefore equally as important that attention stay focused on identifying and implementing replicable solutions in this area. The United Nations adopted the Minamata Convention on Mercury on 24 September 2015. The convention, which bans new mercury mines and encourages the phase out of existing ones among signatories, could have tremendous impacts on the illegal trade of quicksilver.

(Far left) The patterns of pollution and harm from these Top Six Toxic Threats and others across the world are becoming clearer and the need for interventions is more widely accepted. Pilot and small-scale projects and programs are demonstrating that improvements can be made on the ground, and there is an urgent need for commitment to address the problems.

(Left) In last year's report, a number of individual countries were commended for their efforts to come to grips with specific problems. This year, it is possible to point to some positive developments increasing global focus and investment in addressing pollution.

Sustainable Development Goals

After much effort and debate, the UN General Assembly recently approved Sustainable Development Goals (SDGs), including specific goal to reduce the health consequences of pollution. As the issue of chemicals, waste and toxic pollution is critical to many elements of sustainable development, including poverty, health, environment and green economic growth, the Global Alliance on Health and Pollution (GAHP) secured support from a variety of government agencies, NGOs, academia and donors, including 38 different agencies/organizations from 25 countries. In total, 19 government agencies from 19 countries sent verbal, email or physical letters of support to GAHP. As a result, the target related to air pollution under the Health SDG was broadened to include water and soil pollution/ contamination. GAHP is continuing to provide input to the current process of refining the indicators for the SDGs. This is a critical next step in the SDG process as it determines how nations measure progress towards the goals of reducing deaths from pollution.

Pollution Management and Environmental Health Fund at the World Bank

The World Bank has long been the leading institution in international development. Bank programs ideally respond to the needs and requests of borrowing nations to deal with pressing concerns. Thus, Bank programs can act as a weathervane for the concerns of low- and middle-income countries.

Thus when in April of this year, the World Bank announced the formation of the Pollution Management and Environmental Health program (PMEH), it represented a significant turning point on this issue. According to the Bank "[t]he PMEH program, backed by a new multi-donor trust fund, builds upon the knowledge of World Bank experts as well as internal and external stakeholders and partners to achieve three objectives:

- Support client countries to significantly reduce air, land and water pollution levels through pollution management planning and investment to improve health
- Generate new knowledge on pollution and its health impacts in urban, rural and marine areas
- Promote awareness on this issue among policymakers, stakeholders and the public[135]

Global Commission on Pollution, Health and Development

The Global Commission on Pollution, Health and Development is a partnership of the medical journal *The Lancet*, the Global Alliance on Health and Pollution and the Icahn School of Medicine at Mount Sinai, with coordination from the United Nations Environment Programme and the World Bank. The Commission comprises the world's most influential leaders, researchers and practitioners in the fields of pollution management, environmental health and sustainable development. The Commission aims not just to inform the public dialogue and increase awareness—these are means to an end—but to achieve the end in its self: reducing poverty, illness and death caused by toxic pollution, and building healthy, prosperous economies.

The Commission's goal is to lay the foundation for solving the global pollution problem by defining pollution's many effects on health, economics, and development, and then presenting these data to world leaders to raise the priority of pollution control in the international development agenda and thus increase the resources allocated to this pressing global health problem.

The Commission Report will reveal the true public health and economic impacts from pollution globally, and will provide actionable solutions to policymakers. It is designed not only to be studied by academics, but to reach those heads of state, ministers of finance and international leaders whose policy and budget decisions can mobilize real change on the ground, with tangible projects to prevent and clean up pollution that harms the most vulnerable populations. The Commission will bring pollution squarely into the international development agenda.

Philip Landrigan, MD, distinguished professor and physician, and the Dean for Global Health at the Icahn School of Medicine at Mount Sinai, and Richard Fuller, President of Pure Earth, co-chair the Commission.

On-going Country Efforts

These global steps forward demonstrate hopeful momentum by the international community to prioritize and take action on toxic pollution. International organizations can support local and national actions with technical and financial resources, but in the end, it is national and local governments that must take the substantive actions on the ground.

FOOTNOTES

133. Kirby A, Rucevska I, YemelinV CC, Simonett O. Mercury–Time to act. United Nations Environment Programme. 2013;23
134. United Nations Environment Programme (UNEP). Minamata convention on mercury. 2013;2015(September 5)
135. The World Bank. Pollution management and environmental health. http://www.worldbank.org/en/topic/environment/brief/pmeh Web site. Published 2015. Updated 2015. Accessed October 1, 2015

About Pure Earth (formerly Blacksmith Institute)

www.pureearth.org

Our mission is to identify and clean up the poorest communities throughout the developing world where high concentrations of toxins have devastating health effects. Pure Earth devises clean-up strategies, empowers local champions and secures support from national and international partnerships. Interventions to mitigate these toxic exposures while protecting livelihoods have proven to be manageable, cost-effective, and eminently do-able. By partnering with and empowering local champions we clean up chemical and waste legacy toxic hotspots, prevent re-contamination and guard against future pollution.

About Green Cross Switzerland

www.greencross.ch

Green Cross Switzerland facilitates overcoming consequential damages caused by industrial and military disasters and the cleanup of contaminated sites from the period of the Cold War. Central issues are the improvement of the living quality of people affected by chemical, radioactive and other types of contamination, as well as the promotion of a sustainable development in the spirit of cooperation instead of confrontation. This includes the involvement of all stakeholder groups affected by a problem.

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