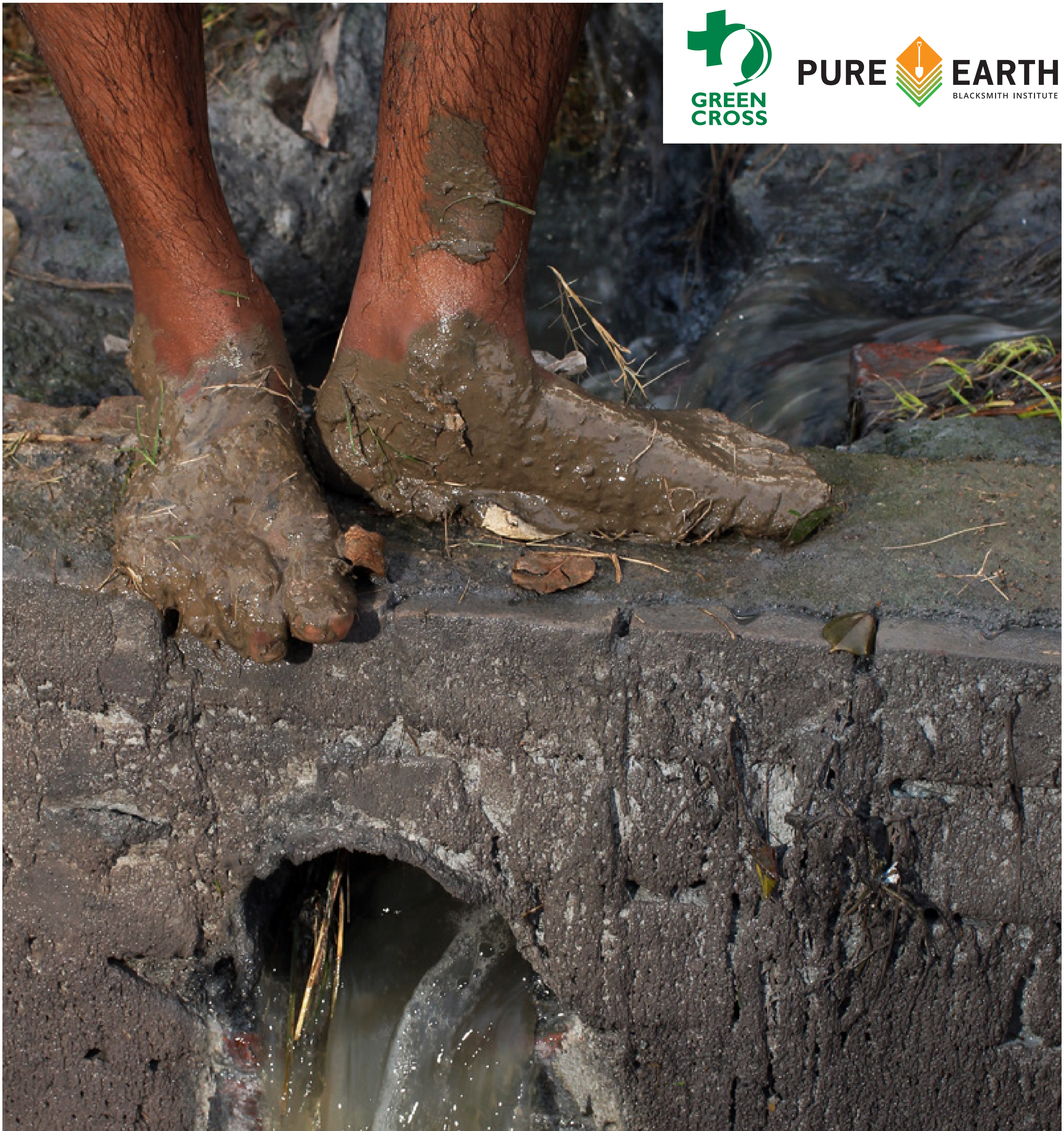

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2016 WORLD'S WORST POLLUTION PROBLEMS

The Toxics Beneath Our Feet

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 young man stands barefoot on land next to his farm in Sheikpura village on the outskirts of the city of Kanpur in India. Beneath his feet, contaminated water pours out sewerage pipes and enters his farm.

Photo by Sean Gallagher

Back cover photo:
In a Dhaka, Bangladesh tannery, a man works barefoot in a pool of toxic chromium-based chemicals used to process leather.

Photo by Larry C. Price

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Executive Summary

The 2016 World's Worst Pollution Problems report is the 11th in an annual series published by Green Cross Switzerland and Pure Earth. Over the past decade, this series has identified and drawn attention to the worst, and most dangerously polluted places on the planet, while documenting and quantifying the startling health and environmental impacts of this neglected problem. The "World's Worst" series of reports aim to raise global awareness about the extent and impacts of toxic pollution in low- and middle-income countries while also highlighting cost-effective solutions.

This year's report, *The World's Worst Pollution Problems 2016: The Toxics Beneath Our Feet* presents an update of the top ten polluting industries based on each source's global burden of disease. The top ten industries are identified as used lead acid battery (ULAB) recycling, mining and ore processing, tanneries, dumpsites, industrial estates, smelting, artisanal small-scale gold mining (ASGM), product manufacturing, chemical manufacturing, and the dye industry. These industries collectively put over 32 million people at risk and account for 7 million to 17 million Disability-Adjusted Life Years (DALYs) in low- and middle-income countries. Each industry sector is described in detail with its respective pollutants outlined.

Worst Polluting Industries Ranked by DALYS

RANK	INDUSTRIES	DALY
1	ULAB	2,000,000–4,800,000
2	Mining and Ore Processing	450,000–2,600,000
3	Lead Smelting	1,000,000–2,500,000
4	Tanneries	1,200,000–2,000,000
5	ASGM	600,000–1,600,000
6	Industrial Dumpsites	370,000–1,200,000
7	Industrial Estates	370,000–1,200,000
8	Chemical Manufacturing	300,000–750,000
9	Product Manufacturing	400,000–700,000
10	Dye Industry	220,000–430,000

(Left) A woman tends fires of burning coal at a village outside Djaria, India, the epicenter of the country's largest coal deposits. Villagers scavenge coal from the bottom of nearby open pit mines, burn the coal pieces to form charcoal, then sell bags of the processed coal in local markets.

Photo by Larry C. Price

(Above) A young boy walks through the Hazaribagh tannery district of Dhaka, Bangladesh, carrying a basket of freshly tanned hides. Hazaribagh is the most polluted area of Dhaka, where the effluent from more than 200 tanneries flow into the nearby Buriganga River.

Photo by Larry C. Price

Introduction

The Evidence Grows

Efforts to identify, document and assess the problems posed by toxic sites worldwide have been chronicled by the World's Worst Pollution Problems series since 2006. As the extent and number of the worst sites became better understood, it became important to generate figures for the health impacts of these sources. This year's report uses the growing body of scientific and medical research on toxic effects of different pollutants to revisit the World's Worst Pollution Problems listed in 2012 and to update both the knowledge of the scale of the problems and, more importantly, the health impacts.

In the four years since that report was published, Pure Earth and Green Cross Switzerland have investigated and analyzed hundreds of additional contaminated sites globally and refined our burden of disease calculations. This information has produced significantly more accurate estimates of the global burden of disease of toxic pollution.

The 2016 World's Worst Pollution Problems Report seeks to quantify the human health impacts of toxic pollution with a particular focus on chemical exposures in low- and middle-income countries (LMICs). The report evaluates the leading pollution-causing industries globally and associated contaminants that can be harmful to both human health and the environment.

Data for the report is largely the result of toxic site identification efforts by Pure Earth, formerly Blacksmith Institute, and Green Cross Switzerland. The report is compiled using analysis of Pure Earth's toxic site database and a thorough evaluation of peer-reviewed literature.

The goal of this year's report is to present a much improved understanding of the main polluting industries, their contribution to global toxic pollution and significance in terms of human health.

Scale of the Problem

The number of toxic sites identified and recorded by Pure Earth, Green Cross and local collaborators has continued to increase and an extrapolation from this suggests that there are perhaps 150,000 sites in the approximately 50 countries where investigations are underway. As the numbers increase, the average population at risk of the sites tends to decrease, since the largest and most obvious sites are usually the first to be recorded. The current estimate of the population at risk in low- and middle-income countries is about 200 million, which is double earlier expectations of 100 million people.

Large as these numbers are, they are almost certainly underestimates. As researchers and communities continue to identify and expose toxic hot spots and their surrounding populations, the numbers will likely increase. Similarly, though it is now accepted that pollution can lead to a broad range of acute effects as well as longer-term consequences, scientists are still trying to understand the true depth and mechanisms of these connections. In its most current figures, the World Health Organization reports that an estimated 23 percent of all deaths in 2012 (representing 12.6 million people) and 26 percent of deaths in children under age five were attributable to environmental risk factors, including pollution.[1] Approximately one-fifth of the global cancer incidence is associated with environmental exposures.[2] This number is disproportionately higher in developing countries.[3]

MAIN FINDINGS FROM 2012 REPORT

The 2012 report extrapolated from Pure Earth's then-current database of contaminated sites to create a top ten list of industrial sources, which ranked industries using estimates of their contribution of toxic pollutants to the global burden of disease. The report developed the first-ever figures for health impacts, estimated in Disability Adjusted Life Years (DALYs), a standard health sector comparator.

The top ten list of industrial sources were identified as: battery recycling, lead smelting, mining and ore processing tannery operations, industrial/municipal dumpsites, industrial estates, artisanal gold mining, product manufacturing, chemical manufacturing and the dye industry. The global health impact of these industrial sources totaled more than 17 million DALYs, with lead-acid battery recycling listed as the top-contributing source with almost 4.8 million DALYs. The report also concluded that the public health impacts of these industrial sources were equal to or greater than that of some of the most deadly infectious diseases, which are highly funded and receive global attention.

The report clarified that these numbers were by no means conclusive, but could be taken as indicative of the potential scale of the problem. Devoting large amounts of time and resources to address the burden of HIV/AIDS, tuberculosis and malaria are necessary and noble pursuits. However, it is a striking fact that international and national government action on these disease burdens greatly outpaces the attention and resources given to toxic sites, even though they contribute greatly to the global burden of disease.

AN INTRODUCTION TO GBD AND TSIP

A major step forward in putting toxic pollution on the global public health agenda has been incorporating the associated health effects of chemical exposures in the Global Burden of Disease estimates. These figures (known as GBD data) are maintained by WHO and by the Institute for Health Metrics and Evaluation (IHME). The original GBD study in 1990 used the DALY metric to assess the burden of disease consistently across diseases, risk factors and regions. Subsequent iterations (about every five years) have expanded the emphasis on risk factors. The 2010 report included as risk factors ambient and indoor air pollution, a number of occupational health risks, and contaminant-specific information on lead and radon. The 2015 report, which is expected in late 2016 and will be released as a series of scientific papers, continues this refinement of risk factors.

Data and analysis from the Toxic Sites Identification Program is being provided as an input to the GBD process to allow toxic pollution to be included as a risk factor in future iterations.

As this knowledge grows, it is expected that deaths and disabilities that were previously linked to other risk factors will be more accurately attributed to pollution. However, much of the needed research is still in its nascent stages. There is only limited data on many of the complex biological and biochemical mechanisms behind the health impacts of toxic pollutants and this gap prevents researchers from truly grasping the scope of the health effects of pollution.

In the same broad context, a Commission on Pollution and Health has been convened by *The Lancet* medical journal, the Global Alliance on Health and Pollution and Mount Sinai Medical Center (New York). Its aim is to present critical data to key decision makers about pollution's severe and under recognized contribution to the global burden of disease and its staggering economic costs. Significantly, until recently the lack of detailed information across a sufficient range of sites and conditions has precluded robust economic analysis of the costs of pollution. Developing and presenting key health and economic facts can help to motivate governments that have been slow to prioritize pollution control measures. The Commission is scheduled to present its report in early 2017.

Pollution and the diseases that it causes have become a massive and extremely costly global problem. But at the same time as our understanding grows, so too has our capacity to develop and implement effective changes. That is one of the positive and encouraging trends of the past decades. Low- and middle-income countries are often limited in their resources to adequately address the health impacts from toxic pollution, which further marginalizes those most in need. A goal of this report and the collaboration between Pure Earth and Green Cross Switzerland is to increase understanding and funding in this area of public health.

Vulnerability of Children

The discussion surrounding pollution often fails to emphasize pollution's disproportionate health impact on children, infants and fetuses, and consequently how it impedes societal and educational advancement of a community-at-large. Children and infants are uniquely vulnerable to environmental toxicants compared to adults due to four major differences: disproportionate exposure to toxicants, immature metabolic pathways, sensitive developmental growth period and greater disease manifestation period.[4]

Children can have heightened exposure to pollutants from environmental and biological factors. Increased pollutant-exposure in children can result from their increased diet, hand-to-mouth behavior and their common close activity

(Above) A 12-year-old boy pauses after working at the bottom of a 40-foot-deep open pit gold mine in western Burkina Faso.
Photo by Larry C. Price

to the ground.[5] If children are living in a particularly toxic area, this can greatly increase their risk for disease. Biological differences between adults and children, specifically metabolic and toxicological processes that affect their ability to effectively excrete pollutants from the body, can also increase their susceptibility for developing disease.[6] In fetuses and infants, the blood-brain barrier is not fully developed. The accumulation of pollutants in the body and the inability to dispose of these toxicants can lead to central nervous system complications and general impaired growth and development.[7] Lastly, many of the diseases associated with pollution, including cancer and neurodegenerative disease, require many years to evolve from initiation to manifestation. Because of early life exposure, children are more susceptible to developing these diseases and often earlier in life.[8]

Children face even more severe potential outcomes from toxic exposure due to their smaller size and increased cellular surface area to volume ratio. Exposure to toxic pollution *in utero* can range from premature birth and low birth weight to vision and cognitive impairment.[9] These biological factors leave children highly vulnerable to the effects of toxic pollution.

(Left) A worker stands ankle-deep in toxic chemicals used to tan skins at a leather factory in Dhaka, Bangladesh.
Photo by Larry C. Price

The diseases associated with many of the pollutants and industry sources identified by this report have severe and lasting impacts on children that continue to disable LMICs and individual communities' advancement. Some measurable outcomes that are analyzed through this report are mortalities, DALYs and populations at risk. Through this report, Pure Earth and Green Cross Switzerland emphasize the top pollutants and their industrial sources as a means to protect one of the world's most vulnerable populations—its children.

What Can Be Done

A paramount objective of Green Cross Switzerland and Pure Earth is to find and implement practical solutions to global toxic pollution problems. This requires initiation of effective approaches. In the most urgent cases, these approaches may only be the start of a long-term cleanup.

One of the most important areas of progress since the initial *World's Worst* report is the gradual emergence of a broad coalition of international organizations, public and private, who have recognized the scale and importance of the toxics agenda and who are cooperating to address it. The challenge of pollution is recognized in the Sustainable Development Goals (SDGs), specifically under SDG 3 on Good Health and Well-Being.

Current efforts include the implementation of on-the-ground projects and related activities to address priority sites and pollution issues. Technical and financial support is also provided to communities, governments and industry groups in order to build their capacities, and to put in place better systems and cleaner processes.

The toxics agenda is becoming even more relevant to achieving international goals in areas such as maternal and child health, since the impacts may be significant at levels well below those at which clinical symptoms are seen. Unfortunately, even the high health impacts estimated in previous reports may still be an underestimate of the damage caused by polluted places.

This report outlines the most important polluting industries and contaminants associated with toxic pollution and chemical exposures. Furthermore, it provides a better understanding of the increasingly significant burden of disease from industrial pollution, representing the most accurate BoD estimates to date.

In total, the 2,600 sites screened by Pure Earth and Green Cross Switzerland put close to 47 million people at risk for a wide range of health impacts. From this research we estimate that close to 200 million people are at risk from industrial pollution worldwide. The total global DALYs attributable to pollution from industrial sources are estimated to be 17 million. This is comparable to disease burdens from other well-documented widespread diseases such as tuberculosis and malaria. By highlighting and quantifying the vast health impacts of toxic pollution through this report, Pure Earth and Green Cross Switzerland intend to bring attention to these issues and foster remediation efforts between communities, governments, and industries.

FOOTNOTES

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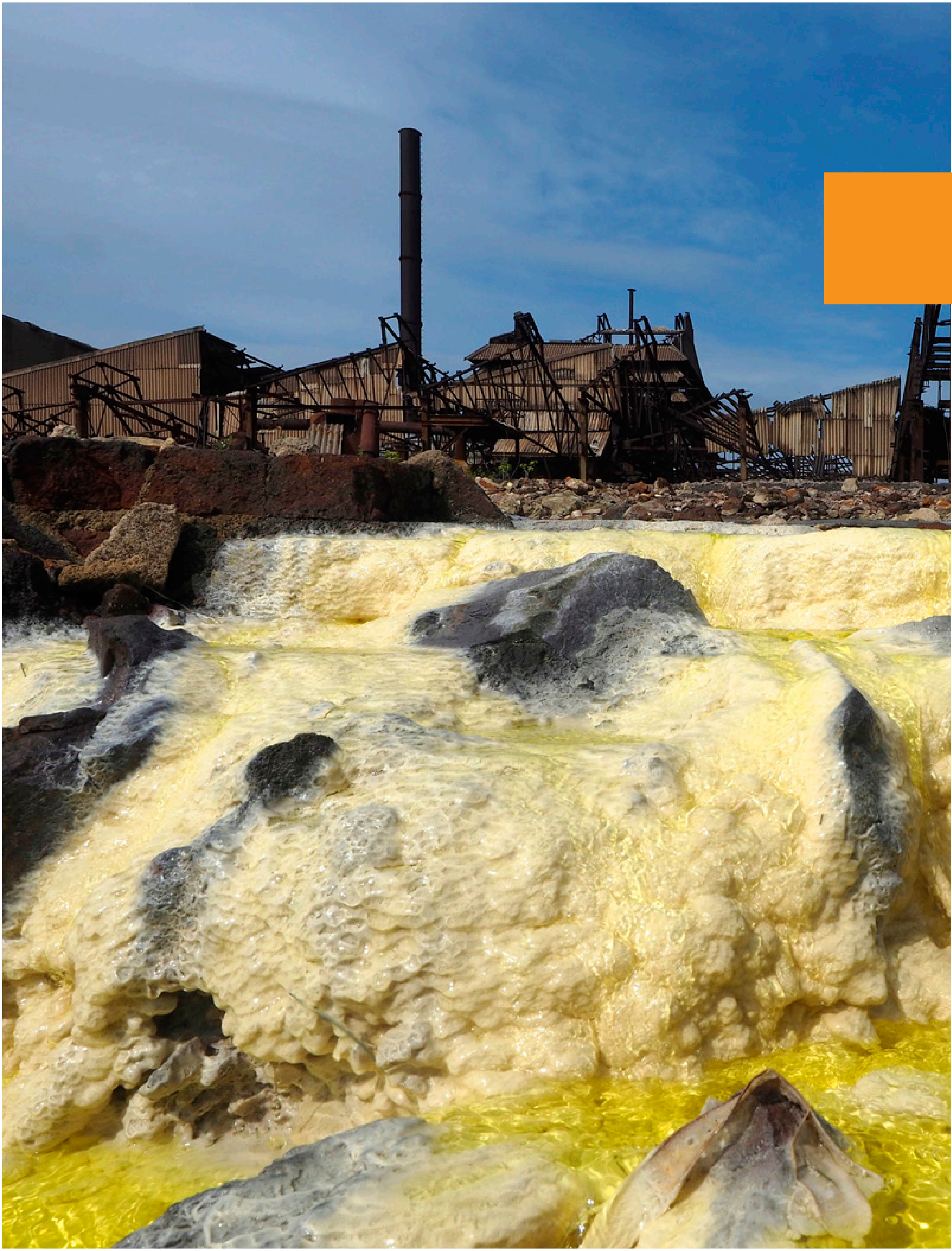

Refining the Global Burden of Disease Estimates

Global Health Burden of Toxic Pollution

The global burden of disease from pollution is a relatively new field of analysis. Key data observatories such as the World Health Organization (WHO) and the Institute for Health Metrics and Evaluation (IHME) are beginning the process of quantifying the health impacts of pollution. To date, the analysis and results presented have been mainly related to the risks of ambient and household air pollution. While chemical exposures and toxic pollution are increasingly important contributors to global morbidity and mortality, very little research has been published on the subject, although a number of peer-reviewed papers have been generated from the TSIP data. At the same time, the extent of chemical and soil pollution from urbanization, industrial development and informal industry seems to be greater, particularly in low- and middle-income countries.

Most contaminated sites tend to be relatively small, but the aggregate number of people impacted by many thousands of these sites globally is large. Leaching of chemicals from contaminated soil can result in contamination of groundwater used for drinking, washing or bathing. Furthermore, many toxicants can enter rivers or become airborne via contaminated dust or particles, greatly increasing the potential population at risk. The contaminants at polluted sites that pose the greatest threats to human health are environmentally persistent substances such as heavy metals, persistent organic pollutants (POPs), including persistent and obsolete pesticides, and radionuclides. Metals of greatest concern include mercury from mining activities, lead from battery recycling and smelting, chromium used in leather tanning and cadmium. Development of DALY estimates for different types of sites allows some comparisons to be made of the health impacts and therefore also of the potential benefits of interventions.

(Left) Toxic chromium compounds from an abandoned chemical factory in Ranipet, India, leach into the watershed. The factory produced chromium-based chemicals used in the leather tanning industry. This chromium waste accumulated in massive mounds on the factory grounds, where it remains today, more than 20 years after the plant closed 1995.

Photo by Larry C. Price

A LOOK AT AVAILABLE PEER-REVIEWED LITERATURE

Pure Earth and Green Cross Switzerland have been actively conducting research to investigate the impacts of toxic pollution in communities across the world. Their contribution to the existing literature has resulted in over 25 recent publications that have aided in filling the research gaps surrounding pollution, health, and development. Most of the research topics have highlighted the environmental health impacts of chemical exposures, toxic pollutants, and their respective industries, which often generate health burdens comparable with other widely, recognized public health challenges.

In a recent publication, Pure Earth discussed the health burden from lead exposure at toxic waste sites in Argentina, Mexico and Uruguay. The results showed an estimated 316,703 persons within the three countries were at risk of exposure to the pollutant at 129 unique sites identified through the Toxic Sites Identification Program. Exposure to lead was estimated to result in between 51,432 and 115,042 DALYs, depending on the weighting factor used. This was comparable to DALYs from Parkinson's Disease and Acute Hepatitis B and C in those countries.

Calculating DALYs—*Disability Adjusted Life Years (DALYs)*

To develop estimates of the burden of disease associated with contaminated sites this report relies mainly on information from the Pure Earth Toxic Sites Identification Program (TSIP) and on the method for estimating disease burden at these sites described by Ericson et al.[10] Site characteristic information and necessary data on health exposures and outcomes are often not available for low- and middle-income countries and therefore information on health impacts attributable to pollution at contaminated sites has not previously been estimated. Now that these estimates are beginning to be developed systematically, it is expected that these issues can be addressed more fully in international estimates of the global burden of disease.

There are three notable advances in the field that have improved our burden of disease estimates. First, the several hundred additional sites assessed by Pure Earth and Green Cross Switzerland continue to improve our knowledge of both the type and quantity of polluted sites in low- and middle-income countries. Additionally, we have fine-tuned our "Initial Site Screening" methodology to obtain more accurate and complete data collection at each site, allowing us to better characterize contaminated sites and their associated population at risk. Second, we now have a "disability weight" for elemental mercury exposure that allows us to calculated Disability-Adjusted Life Years (DALYs) for mercury exposure with a level of certainty that we previously did not have. This value is forthcoming in the peer-reviewed literature but has been shared with us by the researchers for the purpose of calculating our results here. Finally, Pure Earth has engaged in several extrapolation exercises since 2012, culminating in published peer-reviewed scientific research. These exercises have validated many of our current extrapolations and helped us better understand the connections between toxic exposures and population health.

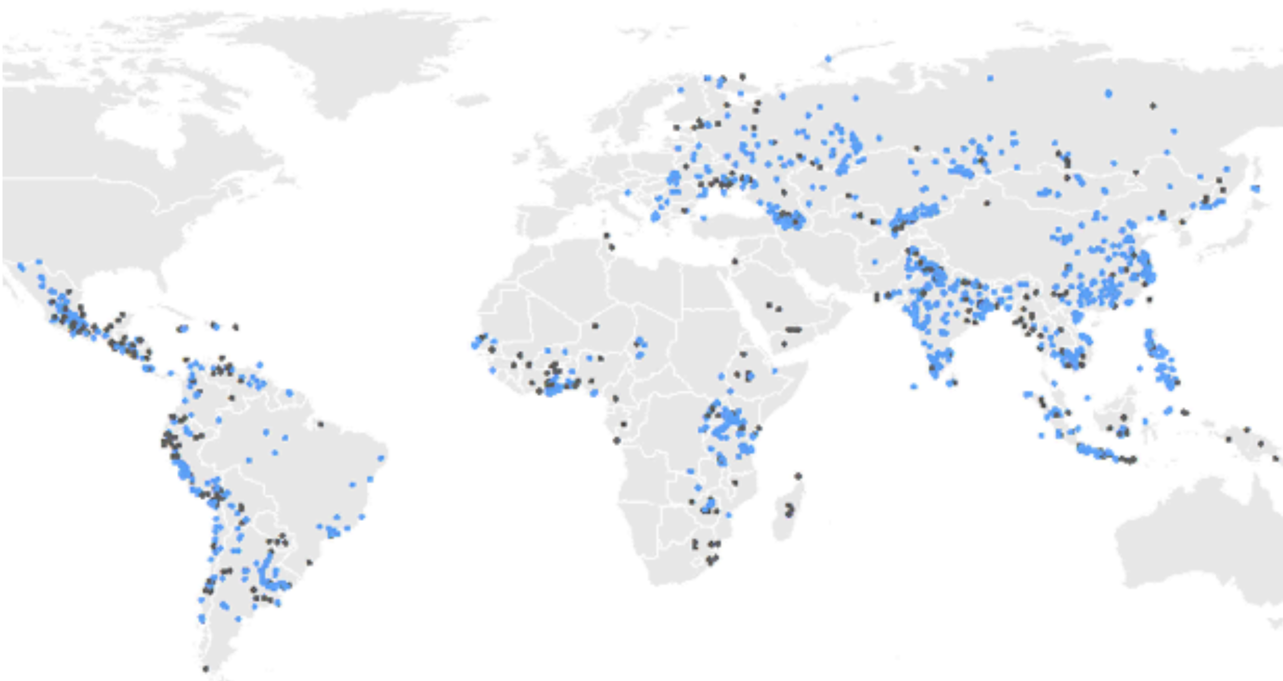
Source: Pure Earth's Toxic Sites Identification Program, 2016

Figure 1: Identified and Screened Contaminated Sites—Pure Earth's Toxic Sites Identification Program

DALYs are intended to indicate the sum total of morbidly and mortality in a given population and have become a standard public health metric for understanding the relative impact of health outcomes and risk factors. In the case of soil-based pollution, remarkably little has been done in estimating the attributable health risk globally. Accordingly, there are few validated models for the calculation of DALYs that may result. Chatham-Stephens et al. presented one such approach in their 2013 paper finding nearly a million DALYs attributable to pollution in India, Indonesia and the Philippines—comparable in scale to malaria.[11] Even the underlying principles for the calculation of DALYs continue to be modified, with the Institute for Health Metrics Evaluation overhauling their approach in 2010 and the World Health Organization making similar changes in 2013. Due in part to these challenges, the estimations we present here are intended to be indicative rather than definitive quantifications of the attributable disease burden.

We feel confident in presenting ranges for three pollutants only—lead, mercury and chromium. We encourage other researchers to further explore this area and validate or critique our calculations.

Applying DALYs Globally

Extrapolated data from Pure Earth's TSIP database results in an estimate that there are at least 150,000 contaminated sites in the 50 countries surveyed to date and that 200 million people globally are exposed to contaminated soil at those sites. These figures are based on data for a limited number of pollutants and are a serious underestimation of the probable real global impact. The health exposure and impact data for many of the pollutants is still very unclear and therefore the suspected effects have not been included in the figures reported here. The contributions from each of the top ten polluting

industries are discussed in detail below.
Looking specifically at lead, which is one of the most significant pollutants—IHME has made estimates for worldwide impacts largely related to exposures from lead deposited in past years from leaded gasoline or from leaded paint. These IHME estimates, presented in the GBD, suggest that lead was the key risk factor for 16.8 million DALYs globally in 2013. This is an order of magnitude greater than the impacts so far identified for the sources discussed in this report. Current research in the USA suggests that the global health impacts of lead are considerably higher than previously understood but this work is not yet published. It is likely that the impacts of other widespread metals in the environment are also much greater than yet reported but much more data and scientific research will be required to demonstrate this.

The Burden Associated with the Top Ten Sources

The global burden from toxic pollution is extensive, affecting entire communities, families, and the general livelihood of all persons at risk. Within the focus of these top ten industrial sources, the burden is extensive. The top ten polluting industries have been identified to affect 32 million people and its legacy pollutants have far reaches within affected communities.

Within each of the industry sectors, the top pollutants identified and evaluated to date are lead, mercury and chromium. The results showcase that although there has been much improvement to toxic pollution in LMICs, more still needs to be done. The burden of disease associated with the top ten pollution sources listed within this report merits the ongoing work of Pure Earth and Green Cross Switzerland. Pure Earth continues to build on data collection, research, and analytical bases for expanding the scientific justification for the health impact figures.

(Right) A woman in Indonesia breaks up lead slag left over from the recycling of used lead-acid batteries.

Photo by Pure Earth

FOOTNOTES

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The Top Ten List Revisted

The top ten list presents the most significant industries leading to estimated global health impacts in LMICs. All of the identified industries utilize pollutants that have been detailed in the below section.

The construction of the list is based on calculation of the health impact from pollutants found at sites investigated by Pure Earth and Green Cross Switzerland. These calculations were done using the DALY calculation as described in the Global Burden of Disease and DALYs section. The ranking for the 2016 report draws heavily on data from Pure Earth and Green Cross Switzerland's ongoing efforts to identify and evaluate pollution hotspots, which allows for more thorough analysis of pollutants, pathways and affected populations. These estimates are extrapolations based on estimated at risk populations, limited health information and assumptions previously mentioned. As noted earlier, these estimates are deliberately conservative and are believed to significantly under-count the real health impacts.

Lead-Acid Battery Recycling

Lead-acid batteries are rechargeable batteries that are most commonly used as automotive batteries in vehicles for starting, lighting and ignition. They consist of a plastic case containing lead plates covered with a lead paste submersed in dilute sulfuric acid. Lead-acid batteries are rechargeable, but eventually the lead plate material and paste breaks down and the battery can no longer hold an electrical charge. Such used lead-acid batteries (ULAB) are classified as hazardous waste under the Basel Convention and their disposal is regulated in all OECD countries. When used lead-acid batteries are recycled properly the battery, the plastic and the metallic components are separated. The plastics are recycled and usually used to manufacture more battery cases. The used lead plates and paste material are smelted to remove any impurities and cast into lead ingots.[12] Lead ingots are used in the manufacture of new lead-acid batteries, thereby making a continuous closed loop system.

(Left) A small boy carries a pan of gold ore along the denuded landscape of a small-scale gold mining area in western Burkina Faso.

Photo by Larry C. Price

(Above) A man in Tegal, Indonesia, uses a hammer to break up old batteries by hand in order to extract the valuable lead within. The improper recycling of used lead-acid batteries takes place in almost every low- and middle-income country, sometimes in backyards and kitchens. Toxic lead is spilled everywhere in the process.

Photo by Larry C. Price

In LMICs, recycling of these batteries is a large industry as the lead in the batteries can be reused in various product-manufacturing processes. Countries with limited lead ore sources are eager to collect and recycle lead-acid batteries to supplement their lead resources. The rising demand for automobiles in low and middle-income countries is driving the upsurge in demand for lead.[13]

Battery recycling contributes to more than 150 sites in the Pure Earth database, potentially putting almost 1 million people at risk. Geographically, the largest numbers of polluted sites are in Southeast Asia, with Africa, Central and South America also contributing a substantial amount. In addition, it is known that battery recycling is also a significant industry in South Asia and China as well.

Key Pollutants

The amount of lead and the highly toxic nature of the element clearly make it the top pollutant at polluted battery recycling sites. Other pollutants include arsenic and cadmium. Lead causes a host of health problems and disproportionately affects children, causing developmental and neurological problems. Reference the health impacts of lead earlier in the report for more information.

(Above) A group of miners in Indonesia
Photo by Larry C. Price

Pure Earth found that lead exposure was the single largest risk contributing to DALYs in the countries assessed. Even with the severe underestimate of the scale of the issue, the estimated DALYs from the lead-acid battery recycling range from 2 million to 4.8 million, with almost 1.9 million people at risk.

Exposure Pathways

In informal recycling processes, used lead-acid batteries are broken up using hand axes or hammers; smelting of the metallic components occurs out in the open or inside domestic homes; and the toxic waste products are disposed of into the surrounding environment untreated. In addition, some used lead-acid batteries are reconditioned by cutting them open, throwing away any defective plates and sometimes the toxic sludge that settles on the bottom of the battery, and then resealing the cases. This type of recycling also leads to the dispersion of lead into the environment.

Emissions and fugitive dusts released from the small scale melting and casting of molten lead and from waste are the main exposure pathways. When lead is melted—often in a domestic setting—the fumes condense as particulates, which can settle into the immediate surroundings and fall onto soil and waterways. Fugitive dust emissions also are deposited in the local area. Waste collected from these processes is often dumped into uncovered piles or directly into nearby waterways, and contaminants then leach into ground water and waterways used by local communities. The largest pathways of exposure in the Pure Earth's database are ingestion of contaminated soil, particularly by children who often play in the dirt, or the ingestion of lead dust that has settled on food or inhalation of dust or emissions.

Industrial Mining and Ore Processing

Mining and ore processing are essential industries that supply the majority of minerals, metal and gems needed to produce a wide variety of products and materials. The raw materials are ore deposits that contain valuable metallic and nonmetallic resources. These resources are mined through surface excavation or underground mining. Both surface and underground mining techniques have their own benefits and drawbacks, but surface mining continues to be the dominant method due to lower typical costs and technology development.[14] Both processes tend to produce large quantities of waste rock, which need to be removed to provide access to the valuable deposits but are not worth processing.

Ores, once mined, are often "concentrated" at the mine to increase the percentage of valuable material and reduce transportation costs. This concentrate is then further processed to recover the valuable material. For metal ores, the processes include smelting, refining and finishing. The concentration step typically generates large quantities of wet, very fine materials often containing various residues of processing chemicals. These "tailings" are difficult to manage because of the volumes and physical characteristics and have been involved in a number of significant pollution incidents. Tailings are often a major challenge at abandoned mines because they are frequently unstable.

The technology for smelting and refining processes has improved considerably in recent years, particularly in relation to control of dust emissions and corrosive fumes, but older facilities often lack the proper equipment and technology to prevent the release of toxic chemicals into the environment.

It is estimated that the health of nearly 7 million people is at risk from mining and ore processing locations in the countries in which Pure Earth has done investigations. These exposures result in 450,000 to 2.6 million DALYs, depending on the disability weights. Limitations in the existing methodology and gaps in underlying science mean that the analysis relies almost entirely on health outcomes associated with lead and chromium. Therefore, other substances, particularly metals such as mercury and cadmium, are not included in the current figures and the real DALY impact of this industry is likely much larger.

Key Pollutants

The most hazardous pollutants reported at Pure Earth mining and ore processing sites are lead, chromium, arsenic, cadmium and mercury. The key pollutants are identified as lead and chromium based on their respective DALYs impact while mercury is the top exposure risk in the population. Other pollutants that may be present at the mining sites include radionuclides, cyanide and other heavy metals.

Exposure Pathways

The source of exposure for the population from mining and ore processing is primarily from waste products in both active and legacy pollution sites. These waste products include wastewater, waste rock (containing metal and ore), tailings, process solutions and processed ore. At abandoned or poorly closed mining sites, tailings and improperly stored waste can pollute ground and surface water, as well drastically affect agricultural activities. In poorly managed mining and processing plants, untreated waste water, slag and solid waste are often directly dumped into surface waters or may accumulate near the mines. Further environmental issues can arise as metals may be washed along with soil leading to heavy erosion and runoff contamination. The contaminated soil

Case Study

(Above) A boy stands on a mountain of hides.
Photo by Larry C. Price

Leather Tanning in Hazaribagh, Bangladesh

In 2009, Pure Earth conducted a detailed site assessment of the Hazaribagh tannery zone in Dhaka, Bangladesh. Chromium is a key pollutant at under-regulated tannery sites, as the chemical is widely used to make leather goods more durable. Hazaribagh is densely populated and heavily contaminated, housing up to 95 percent of all tanneries in Bangladesh. Most tanneries in Hazaribagh do not have proper systems for treating high-volume chromium waste. About 85,000 tons of rawhides are processed for leather production in Bangladesh annually. Processing one metric ton of rawhide generates 200 kg of leather (containing 3 kg Cr), 250 kg of non-tanned solid waste, 200 kg of tanned waste (containing 3 kg Cr), and 50,000 kg of wastewater (containing 5 kg Cr). More than 60 percent of the chromium used can be found in the resulting waste.

Pure Earth measured water samples with chromium levels above the recommended maximum contaminant level (100 µg/L). However, the leather industry maintains high demand and employment; the Export Promotion Bureau (EPB) reported that Bangladesh earned US $1.29 billion in the 2013–2014 fiscal year from its leather industry. Over 8,000 workers in Hazaribag tanneries suffer from gastrointestinal, dermatological and other diseases.

(Above) Children scavenge coal from the bottom of nearby open pit mines outside Djaria, India, the epicenter of the country's largest coal deposits. The coal is burned to turn it into charcoal, then bagged and sold in local markets.

Photo by Larry C. Price

and water may adversely impact agricultural, food and drinking water systems.

Lead Smelting

Lead smelting is the industrial process of extracting lead metal from ores or mixed scrap, usually by heating, with added materials. In primary smelting, lead is separated from collected ore materials in a series of steps that separate lead from other metals and then purify the metal. Secondary lead smelting begins with scrap from worn-out, damaged or obsolete lead products, most often from used-lead acid batteries. During both primary and secondary processes, particulate matter, sulfur dioxide and other volatile compounds are emitted into the air. Waste in the forms of toxic wastewater and solid waste are also released.

According to the Pure Earth TSIP database, there are an estimated 1.1 million people at risk from lead smelting industries at more than 70 polluted sites around the world. This has resulted in a range of 1 million to 2.5 million DALYs where lead was identified as the primary pollutant.

Key Pollutants

Lead is the largest contributing contaminant from lead smelting industries, but mercury and cadmium have also been identified as major pollutants of concern. Cadmium, although not

(Above) In Kebasen, Indonesia, three new battery smelters process thousands of batteries a day. The workers each sit on a battery casing on the floor and swing small axes to split open the batteries and remove the lead cells. Other workers shovel the cells into the furnaces. After the lead melts, they pour it into trays to make ingots. The lead is bought by a company that makes fishing weights and air gun pellets.

Photo by Larry C. Price

identified as a top pollutant within this report, was identified as one of the top six toxic threats of 2015. Of the million people at risk from lead smelting industries, 96 percent are related directly to lead, mercury or cadmium pollutants.

Smelting is a common industrial process for recovering metals from ores, and is used worldwide for copper and related metals and for zinc ores. All of these operations have the potential for emitting large quantities of toxic pollutants and are being included in TSIP surveys. However, there is not enough information to evaluate the full range of possible pollutants.

Exposure Pathways

Toxic chemicals from lead smelting processes can be emitted into the air, soil and water to directly affect human health and agricultural systems. During the smelting process, fumes and dust particles containing arsenic, antimony, cadmium, copper, mercury and lead can be emitted. These particles can settle in soil, to accumulate and possible impact surface and groundwater. Improperly disposed wastewater can also leach into drinking water and agricultural systems to impact food sources and negatively affect human health.

(Left) In the Vellore district of Tamil Nadu, women arrive at the tanneries early in the morning wearing jewelry and brightly colored saris, as though they were going to a shop or restaurant, certainly not to a place where they are constantly splattered with rotting animal flesh. They wrap themselves in plastic to protect their clothes, some pull on gloves, and then they go to work. Some stand or sit for hours, plucking hair by hand from softened hides stretched over frames. Others stir sheets of leather floating in vats of chemicals.

Photo by Larry C. Price

Tannery Operations

Leather tanning is the process of converting raw animal hides or skins into leather for consumer products. Tannery processes treat raw hides to remove animal hair, flesh and oil glands using tannic acid and other chemical substances that prevent decay, make them resistant to wetting, and keep them durable.[16] Tanning uses tannins, chromium, alum or other chemical agents, some of which can be hazardous to human health and the environment, if not carefully controlled. Of particular concern is the use of chromate salts, commonly used in the stabilization process.[17] Uncontrolled chromium wastes and chromium-contaminated wastewater can be released into the environment at high amounts.[18] Most tanning operations are regulated, but there are still many small tanneries operating with few controls.

Key Pollutants

Chromium is the most pervasive and hazardous pollutant found in the tannery processes. Trivalent chromium is used as part of the tanning process and is washed off from leathers and can be present in tannery wastewater in significant amounts. Trivalent chromium is not highly toxic, but in its use in various processes can oxidize into the more harmful hexavalent chromium.[19] Hexavalent chromium is a carcinogen that can be potentially harmful to lung and stomach cancer.

There are more than 100 sites identified by the Pure Earth Toxic Sites Identification Program polluted by tannery operations, putting almost 1.5 million people at risk. These sites consist of contaminated legacy tannery sites or small poorly run facilities. Pure Earth estimates that exposure to hexavalent chromium and lead specifically from tanneries contributes to about 15 percent of the some 1.2 to 2 million DALYs in the area of the 100 identified sites.

Exposure Pathways

Harmful chemicals, primarily hexavalent chromium, can be discharged as wastewater or in solid waste and sludge. Chromium can be present in wastewater at level up to 100-400mg/L.[20] Untreated wastewater can also contain acids and alkalis water, pesticides and insecticides, and other harmful chemicals. Solid waste products can include chromium-contaminated waste and animal flesh that can contribute pathogens. The waste is often released through direct dumping or improper disposal in unprotected dump sites. Pollutants may be absorbed by the soil and leach into groundwater sources. The main pathways for human exposure to pollutants from tanneries are ingestion of contaminated food and water.

Artisanal Small-Scale Gold Mining

Artisanal gold mining refers to small-scale low-tech, informal activities focused on mining and processing ore to recover gold. Although AGM sites are individually small scale, collectively the sector comprises 20 percent of the world's gold production.[21] Additionally it releases more mercury into the environment than any other sector worldwide. The technologies and methods are exceedingly primitive and the ore is usually processed with rudimentary methods that have little to no pollution controls.

The majority of artisanal gold mining sites in the database are in Africa and Southeast Asia, although there is a high concentration of artisanal miners in Latin America as well. It is estimated that artisanal gold mining occurs in as many as 55 countries employing between 10 and 15 million miners.[22] Artisanal gold mining is a subsistence industry engaged in at the individual level, and is most likely to be prevalent in countries or regions with limited government oversight or regulation of small-scale industrial activities. Small gold mining operations can be started with very little investment or infrastructure and producers can often make 70 percent or more of the price of international gold, a rare economic advantage in small-scale or informal industries.[23] Gold is an easily traded commodity and prices are generally stable or growing, making it a very attractive subsistence industry for marginalized members of society.

Artisanal gold mining is a small-scale industry, but contributes a large number of polluted sites to the Pure Earth's database. There are over 200 sites that potentially expose more than 4.2 million people to the risk of toxic pollutants, particularly mercury. There is limited scientific data available to allow calculation of DALYs from mercury exposure at identified sites, although it is the key pollutant in artisanal gold mining. Meanwhile, lead and chromium from artisanal gold mining sites contribute roughly 600,000 to 1.6 million DALYs to the total burden of disease in the 50 countries assessed.

Key Pollutants

Mercury is the top pollutant in artisanal gold mining operations. In Pure Earth's database close to 3.4 million people are at risk for exposure from artisanal gold mining. Mercury is a bio-accumulative toxin that is absorbed by fish, birds and other wildlife, contaminating local food chains. It is known to cause neurological damage, especially in fetuses and children. As prevalent and hazardous as mercury is in small-scale mining, other pollutants are also released. Within the database, lead has been found at more than 20 sites, putting close to 250,000 people at risk. Lead is often released in the air when the lead-containing ore is crushed. Lead also causes neurological and developmental damage in children.

Exposure Pathways

The US EPA estimates that approximately 400 metric tons of mercury is released into the air each year from the processing of gold in artisanal gold mining.[24] Mercury is released during the heating of amalgam, when mercury is evaporated. The mercury vapor is inhaled directly by workers and is absorbed into surrounding surfaces, where it is re-emitted into the air over time. The mercury vapor is also and settles on plants, soil and in waterways nearby. Gold processing is often undertaken in residential areas and done in the open around children and other family members, directly exposing the community to the mercury vapor. Those not directly exposed to the fumes are at risk of ingesting mercury that has been absorbed by waterways, soil or fish. The largest majority of exposures in the Pure Earth's database are through inhalation of contaminated dust or vapors and ingestion of contaminated water.

(Right) A gold miner in Indonesia pours out mercury from a small bottle while a child sits next to him. Toxic mercury is used widely in artisanal and small-scale gold mining.
Photo by Larry C. Price

Industrial/Municipal Dumpsites

Municipal solid waste (MSW), often termed "garbage" or "trash," is an inevitable byproduct of human activity. Unfortunately, in many LMICs improper industrial and municipal waste management have given rise to unmanaged dumpsites. These industrial/municipal dumpsites have the ability to pose a threat to health and also may have a long-term effect on the environment.

There are almost 150 industrial or municipal dumpsites in Pure Earth's database that are polluting local communities, potentially putting almost 3.5 million people at risk. The largest number of these recorded dumpsites are in African, Eastern European and Northern Asian countries. Combined, these regions make up more than half of the total at risk population in Pure Earth's investigations of dumpsites. However, industrial and municipal dumpsites are prevalent throughout the developing world including in South and Central America and South and Southeast Asia, and the total numbers of dumpsites and people at risk are undoubtedly much higher.

Key Pollutants

Each dumpsite varies in pollutants depending on the source of the waste, but the most common pollutants identified and reported within Pure Earth's sites are lead and chromium. Combined, lead and chromium are found in almost a third of the identified industrial and municipal dumpsites, potentially affecting more than 3.5 million people around the world and resulting in an estimated 370,000 to 1.2 million DALYs. The health impacts of these pollutants have been detailed under the top four pollutants categories and include lung cancer, neurological problems and cardiovascular diseases. Other common pollutants found in dumpsites include cadmium, pesticides, arsenic and other volatile organic compounds. Broader health risks include fires, collapses and slides, infectious diseases, cuts and fractures, and so on.

Exposure Pathways

The main sources of pollutants from dumpsites are either leachate (contaminated liquids soaking into the groundwater), dust from poorly covered or controlled landfills and landfill gas that is not captured.[25] Leachate can contain heavy metals, VOCs or hazardous organic compounds. These pollutants are carried into aquifers or surface waters. Dust from dumpsites may contain metals and human pathogens that come into contact with this pollution through contaminated groundwater and soil, or direct contact with the waste site.[26] Children are seen playing in and around dumpsites, introducing direct exposure with hazardous waste through dermal contact, inhalation of dust or accidental ingestion. Informal neighborhoods are often built on top of previous dumpsites where the soil, groundwater and nearby surface waters are contaminated, indirectly exposing the local population to leached pollutants. A notable issue with dumpsites in the developing world is the presence of scavengers - workers and their families at dumpsites who make their living by recovering economically valuable materials in the waste. In such situations, people come into direct contact with the contaminants at the waste site.

(Above) Man collecting water sample from pipe.
Photo by Pure Earth

Industrial Estates

Industrial estates are specific areas zoned for industrial activity in which infrastructure such as roads, power, and other utility services are provided to facilitate the growth of industries and to minimize impacts on the environment. Industrial estates are often located outside of major populated areas but poorly managed air emissions and wastewater discharges still have the ability to impact the environment and health of surrounding populations. The industrial uses and processes within estates vary widely, and thus the pollutants in each will vary as well. Like most pollution issues, a lack of strict enforcement has led to threatening environmental and health impacts in communities, primarily in LMICs.

Industrial estates are located all over the world and the sites are highly variable across many different countries. Currently, the Pure Earth database records that a majority of identified sites polluted by industrial estates are located in South Asia, mainly in India and Pakistan, although such estates are known to exist in many developing countries seeking to increase their manufacturing sector.

Industrial estates are linked with more than 100 of the contaminated sites in the Pure Earth's database and pollutants from them potentially affect an estimated 5.8 million people near these sites. Industrial estates are estimated to contribute an estimated 390,000 to 1.06 million DALYs to the total disease burden in the 49 countries assessed. It should be noted that industrial estates release multiple and varied pollutants and this calculation of the burden of disease only examined known pollutants based on the Pure Earth's database information. The largest contributor reported is lead but there is likely a much higher impact from the cumulative impact of combined pollutants not yet defined in our site investigations. As a result, this DALY calculation is very likely an underestimate.

Key Pollutants

Like many industrial sites, the primary contaminants of concern recorded are lead and chromium. The population at risk from lead and chromium in the industrial estates sources is estimated to be 1.2 million people. It is about 21 percent of the total number of 5.8 million people at risk from the industrial estates sector.

Exposure Pathways

Pollution at industrial estates is generally caused by a lack of appropriate waste processing infrastructure or pollution controls. Air pollution emissions, contamination of surface waters or aquifers that communities rely on for water, and improper disposal of hazardous wastes are prevalent at poorly managed and controlled estates. Industrial estates are sometimes located close to population centers but, alternatively, population centers often including squatter settlements grow near the estates due to availability of jobs. The World Bank Group recommends that industrial estates require systems for vapor recovery, sulfur recovery, recovery of waste, recycling of wastewaters, spill prevention and hazardous chemical and waste storage. These controls would reduce VOC emissions, sulfur emissions and the release of many toxic pollutants.[27]

Because of the high variability of activity at industrial estates, there are many ways in which pollutants can enter the environment. Industrial estates contain the types of industries that are covered elsewhere in this report, including lead smelting and processing, battery manufacturing and recycling, and chemical and product manufacturing. However, there are many additional types of industry processing that happens at industrial estates, complicating the identification, assessment and clean up. At polluted sites, general pathways for pollutants include wastewater, direct exposure to improperly disposed waste or sludge, and dust or emissions. Pathways for human exposure include inhalation of dust, dermal contact, food ingestion and water ingestion.

Chemical Manufacturing

The U.S. Bureau of Labor Statistics categorizes the following as chemical manufacturing: basic chemicals including pigments, dyes, gases and petrochemicals; synthetic materials like plastics; paint products, cleaning products; and other chemicals including film, ink and explosives. Pharmaceutical manufacturing is also considered under the umbrella of chemical manufacturing. These products and their related chemicals are essential to society and are needed to facilitate our daily life. They treat medical problems, improve standards of living and are relied upon for a vast range of activities. However, during the production of these chemicals and products, dangerous by-products and waste are often generated. A common feature in much of the organic chemical industry is the use of VOCs (Volatile Organic Compounds) as solvents and raw materials, while manufacture of solvents is also a major part of the industry. Dye and pesticide industries are major contributors to the pollution problems of chemical manufacturing. They are addressed separately in this report.

Chemical manufacturing is a large source of pollution worldwide and represents close to 200 of the polluted sites in the Pure Earth's database, potentially putting approximately 3 million people

(Above) Spraying an agricultural field outside Kolkata, India.
Photo by Larry C. Price

at risk of exposure. The majority of sites recorded are in China, Eastern Europe and South Asia. The chemical manufacturing industry is truly a global industry with 16 different countries contributing to the trading and selling of chemicals, and there are contaminated chemical manufacturing sites all over the world .

Part of the reason for the expansive reach of chemical manufacturing is the diverse and varied types of sectors and activities that are included in it. New chemicals are introduced and old chemicals are withdrawn constantly, changing the chemical manufacturing market frequently, making it difficult to monitor and evaluate. The sheer size of the industry makes it difficult to monitor as well; it accounts for approximately 7 percent of global income and 9 percent of international trade.[29]

Chemical manufacturing contributes an estimated 300,000 to 750,000 DALYs. A key limitation of our approach was our inability to calculate DALYs from VOCs and pesticides. Insufficient dose-response and disability weight information resulted in the complete exclusion of VOCs and pesticides from the calculations at present. The estimate is therefore a considerable under-calculation as it only takes into account the health impacts of lead and chromium.

Associated Pollutants

The pollutants found in the largest quantities at chemical manufacturing sites investigated by Pure Earth include pesticides and volatile organic compounds. However, other pollutants found include arsenic, cadmium, cyanide, mercury, chromium and lead.

It is important to note that although DALY calculations could not be made for volatile organic compounds, exposure to VOCs released from chemical manufacturing sites potentially puts more than 1.5 million people at risk at the sites investigated by Pure Earth. VOCs are low molecular weight chemicals which convert to vapor easily, and VOC vapors are emitted from many products and processes. While many VOCs are relatively non-hazardous (aside from their flammability), thousands of VOCs are toxic, including benzene, formaldehyde, toluene, vinyl chloride and chloroform.

Exposure Pathways

Chemicals can be released through emissions from heating and processing, accidental release of dust or other particulates, accidental spills and improper disposal of solid waste and wastewater. Once in the environment exposure media include air, water, soil and food. In the TSIP database, which focuses on chemical dumps and abandoned sites, the exposure pathways are evenly split between inhalation of contaminated dust and soil, ingestion of contaminated water and food and inhalation of contaminated gases or vapor. The chemical manufacturing industry is the largest single consumer of water by sector in all OECD countries.[30] The large amount of process water used also provides many opportunities for pollutants to be released through wastewater.

Product Manufacturing

As countries gain economic growth and individuals gain spending power, more consumer products are being developed to satisfy this need, creating demand for product manufacturing, the general term for industries that produce consumer goods. Product manufacturing is a major contributor to individual country GDP and the global economy. The World Economic Forum reports that 70 percent of country GDP variations can be explained by differences in the amount of manufactured products exported.[31] Reduction of trade barriers, improved geopolitical relationships, and the improvement of infrastructure and technologies have all enabled this expansion and the global spread of product manufacturing.[32] Due to globalization and efforts to incentivize manufacturing, some countries have been slow to apply regulations and/or have not been vigorous in ensuring that companies comply with environmental standards. The result, in some places, has been widespread pollution problems associated with product manufacturing.

Product manufacturing pollution is an issue at more than 100 sites in the Pure Earth's database, and potentially exposes almost 2.3 million people to toxic pollutants. More than half of the sites are located in South Asia and Southeast Asia where regulations on product manufacturing are not always strongly enforced. Other regions represented include several African countries and China. China is second in the world in manufacturing and produces 15 percent of the worlds manufactured products.[33]

Product manufacturing at the 100 sites in the database potentially exposes almost 2.3 million people to toxic pollutants and is estimated to result in approximately 400,000 to 700,000 DALYs. The contribution to these DALYs is nearly evenly split between lead and (hexavalent) chromium exposure. Like industrial estates, product-manufacturing sites release a diverse mix of pollutants. Lead and chromium are the top pollutants identified in the Pure Earth's database information. There could potentially be a much higher impact from the cumulative impact of combined pollutants, including possible pollutants not yet identified and measured in our site investigations. As a result, this DALY calculation is very likely an underestimate.

(Above) Waste water and sludge collect near an industrial estate in India.

Photo by Pure Earth

Key Pollutants

Although pollutants vary based on each manufacturing site, Pure Earth surveys have identified the principal pollutants to be lead, mercury and chromium, which are identified as top pollutants in this report. Other pollutants are cadmium, arsenic, cyanide, dioxins, sulfur dioxide and VOCs. Combined health effects from these pollutants include neurological, gastrointestinal, cardiovascular and renal system problems and lung cancer.

Exposure Pathways

Pathways for pollutants vary widely across types of product manufacturing; in general they include emissions from energy sources used to power production, emissions from incineration of waste products or heating during processes, and improper disposal of solid waste and wastewater. Some product industries use massive amounts of water, while other types of plants emit large amounts of emissions into the air. The majority of pollutant exposures in Pure Earth's database derive from inhalation of contaminated dust, soil or gases and ingestion of contaminated water. Other pathways include burning of solid waste. The chromium pollution at these sites is through both groundwater and air emissions.

(Above) Outside Kolkata, India, a worker carries leather scraps toward the top of a 12-foot boiling cauldron of hides. Eventually the hides are rendered into glue, a byproduct of the many nearby tanneries.

Photo by Larry C. Price

Dye Industry

Dyes are primarily used in the production of consumer products and are commonly found in paints, textiles, printing inks, paper, and plastics—adding to the color and patterns of materials. Natural dyes have increasingly been replaced by chemical dyes that provide and retain richer color throughout wash and exposure.[34]

There are a vast number of chemical dyes, each with its own individual process. In the textile industry alone, there are more than 3,600 types of dyes. In acid dyes, the dyes are used to color animal fibers, while basic (alkaline) dyes are used for paper products. Direct dyes are used on cotton-wool or cotton-silk, and pigment dyes are used in paint and inks.[35] Many of these specific dyes have their own production process, but sulfuric acid, chromium, copper and other metals are commonly found throughout the entire dye industry, where dyes are mixed, synthesized, filtered, dried and blended. Along the way, many other additives, solvents and chemicals are added as a catalyst for reactions.[36] The number and variety of chemicals used corresponds with the intricacy of the desired patterns and designs in the clothing and textile industry. As a result, the wastewater effluents of dye factories can pose a complex threat to the health and environment of the surrounding population.

The textile industry is one of the largest sectors globally and produces 60 billion kg of fabric annually. The wastewater load from the use of dyes is a key component of pollution and puts approximately 1 million people at risk. Pure Earth has identified more than 50 sites where dye use poses a serious issue to health, although specifics of the risks remain to be clarified. The dye industry is currently the lowest contributor to DALYs on the top ten list, contributing an estimated 220,000 to 430,000 DALYs to the total burden of disease in the sites assessed. These DALYs are all a result of the health impacts from chromium and lead.

Key Pollutants

The top pollutants by population at risk reported in Pure Earth's database are chromium, lead and mercury. Other harmful pollutants include cadmium sulfur, nitrates, chlorine compounds, arsenic, nickel and cobalt.

Exposure Pathways

Wastewater is a key pathway for exposure. In many pollution sites wastewater from the dye industry is directly dumped into surface waters without treatment. Wastewater carries a host of different chemicals from the processing of dyes and the World Bank estimates that textile dyeing and treatment contribute 17 to 20 percent of total industrial water pollution. The majority of pollution exposure in the Pure Earth's database comes from ingestion of contaminated water and ingestion of food, which has been irrigated with contaminated water.

(Right) Workers sort goat skins that have been tanned using chromium compounds. The chemicals are referred to as "chromium blue."

Photo by Larry C. Price

FOOTNOTES

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The Pollutants

As noted, three contaminants have been recorded at the majority of sites assessed through the Toxic Sites Identification Program: lead, mercury and chromium. These pollutants are not only associated with the top ten industries outlined in this report, but also provide the basis for calculating DALYs, making them integral in the industry ranking process. Below is more detailed information about these top three pollutants, providing a background description and basic epidemiology of each. Major health effects associated with each pollutant and an example conceptual site model are also provided. Information is also provided on one additional pollutant that is responsible for significant pollution and adverse health outcomes throughout many low- and middle-income countries: radionuclides. While it has not been possible to factor this pollutant into the DALY calculations, it is nevertheless a noteworthy pollutant with important public health implications.

Lead

Background and Epidemiology

Lead is a naturally occurring element found in all our parts of our environment. Because of its corrosion-resistant properties, it is commonly used in industrial manufacturing processes and can be found in everyday products that include paints, ammunition, pesticides, batteries and protective material from radiation. Additionally, lead was until recently a component in gasoline, used as an additive to improve engine efficiency. Despite its instrumental use in many industries, lead exposure can have serious impacts on human health. With increasing evidence of lead's harmful impacts, many nations have adopted regulations that limit exposure and lessen the impacts to the harmful chemical. Unfortunately, LMICs have been slow to adopt and apply similar regulations and its populations suffer from the burden of lead exposure.

(Left) Bottles of mercury are sold freely in many artisanal and small-scale gold mining communities, such as this one in Indonesia at a mining area near Wonogiri In Central Java.

Photo by Larry C. Price

Figure 2: Lead Exposure Model

As of 2016, the Pure Earth Toxic Sites Identification Program has identified more than 700 high-priority sites around the world where exposure to lead threatens the health of the population. Approximately 13 million people are at risk for exposure to lead globally with the majority of these populations living in LMICs, with an estimated burden of 1 million DALYs.

Health Effects

Lead can adversely impact health, primarily through ingestion and inhalation routes, and dermal contact in occupational settings with inadequate protective equipment. Health effects associated with lead exposure include neurotoxicity, developmental delays, hypertension, impaired hearing acuity, impaired hemoglobin synthesis and male reproductive impairment.[37] Importantly, many of lead's health effects may occur without clear signs of toxicity, which can allow chronic conditions to develop. Children are most vulnerable to lead effects. Children under six years old have a high risk of exposure due to hand-to-mouth behavior and young infants can be exposed in-utero through breastfeeding from a mother with lead poisoning.[38] The US Center for Disease Control (CDC) has set a BLL of 5ug/dL as the level of concern for lead exposure in children.[39]

Chromium

Background and Epidemiology

Chromium is a naturally occurring heavy metal found in the earth's crust. Its stability at high temperatures makes it desirable for industrial use.[40] Chromium is typically found in two forms: chromium III and chromium VI, respectively known as trivalent chromium and hexavalent chromium. Trivalent chromium is the most stable of the forms and occurs naturally. In contrast, the much more toxic hexavalent chromium 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 use

Figure 3: Chromium Exposure Model

in tanning is a particular problem, both with the chrome processing plants that manufacture chrome salts for the tanneries and at tannery complexes that do not have adequate waste and wastewater control and treatment. Due to the relatively low cost of labor and materials, almost half of the world's tanning and leather industries are located in LMICs.[41]

It is estimated that approximately 5 million people are at risk for exposure to chromium globally, with an estimated burden of disease of more than 1.4 million DALYs. As of 2016, the Toxic Sites Identification Program has identified more than 300 sites around the world where exposure to chromium threatens the health of the population.

Health Effects

Workers that are exposed to chromium are the group most at risk of developing adverse health effects. The most common route of exposure in occupational settings is inhalation, but ingestion and dermal routes also occur with chromium in soil, water or air.

Hexavalent chromium poses greater health risks due to its cellular uptake pathways and associated higher toxicity. 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,

Figure 4: Mercury Exposure Model

exposure to hexavalent chromium can increase the rate of various types of cancers.

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.

Mercury

Background

This heavy metal exists in several forms that include elemental, inorganic and organic. Some natural sources of mercury include volcanic eruptions and emissions from the ocean. Anthropogenic emissions include mercury released from fuels, raw materials or other products used in industrial processes. Although both forms of mercury exist, anthropogenic emissions significantly add to the abundance around the world and lead to a greater burden of mercury related diseases.

Of the three listed forms of mercury (elemental, inorganic, and organic), each has its own toxicity and exposure pathway. Elemental mercury in its solid form as metallic mercury (quicksilver) poses limited direct threat to human health, but when heated to become a vapor can be toxic. Inorganic mercury is highly toxic but typically only occurs in intermediate compounds like mercuric chloride,

In 2013, a report by the Environmental Company of the State of Sao Paulo (CETESB) showed an empty location next to the municipal school Jose Jorge Pereira was contaminated with a variety of chemicals. These pollutants included lead, arsenic, cadmium, vinyl chloride and trichloroethane amongst others. The school, which was constructed in 2005, is supposedly built over the same contaminated grounds. It was first investigated due to 600 school children reporting cases of dizziness, headaches and vomiting. The school has been closed, but no remediation efforts have been conducted.

Source: TSIP Database

mercuric acetate and mercuric sulfide.[42] Organic mercury is produced when elemental mercury is combined with carbon and most commonly exists as methyl mercury,[43] which can accumulate in the tissues of many organisms. In LMICs, one of the most widespread exposures of mercury is in the artisanal and small-scale gold mining (ASGM) industry, where mercury is used in the extraction of gold form gold-containing ores.[44]

Pure Earth estimates are that more than 8 million people are at risk for exposure to mercury globally. As of 2016, the Toxic Sites Identification Program has identified more than 400 sites around the world where exposure to mercury threatens the health of the population. It is estimated that the livelihoods of at least 100 million people are dependent on ASGM, nearly all of whom use quicksilver to extract gold from ore.[45] 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.

Health Effects

High levels of mercury can impact human health by harming the brain, heart, kidneys, lungs and immune systems. It can be introduced through inhalation, ingestion and dermal contact, but the most severe pathway of mercury exposure is through mercury vapors that may reach the brain and respiratory system to cause permanent damage. Inhalation of mercury vapor can produce higher incidences of kidney and autoimmune dysfunction within ASGM communities. ASGM workers have reported tremor, vision disorder

Figure 5: Radiation Exposure Model

and muscle weakness as just some of the many symptoms experienced as a result of their work.[46,47]

Exposure to mercury, even in small amounts, may causer serious health problems and is a threat to the development of a child in utero and early in life.[48] Expecting mothers can transmit mercury through consumption of mercury contaminated foods. This can lead to neurodevelopmental problems in developing fetuses. This presents a severe and generational issue for populations living in mercury-contaminated areas like ASGM and other industrial communities where mercury is not effectively managed.

Radionuclides

Background and Epidemiology

Radionuclide is a broad term to describe forms of elements where the atoms have an unstable nucleus and are therefore "radioactive." Some occur naturally in the environment, while others are man-made, either deliberately or as byproducts of nuclear reactions.[49] The US EPA has identified radionuclides of concern encountered in medical, commercial, or military activities and includes Americium-241, Cesium-137, Cobalt-60, Iodine, Plutonium, Strontium-90, Technetium-99, Thorium, Tritium, Uranium, Radon, and Radium. In the context of this report, uranium, radon and radium can be used as examples of the effects of radionuclides in general. Uranium is most commonly used in nuclear power plants and nuclear weapons, although very small amounts are used in photography and in leather and wood industries for stains and dyes. Radium is used as a radiation source for treating neoplastic diseases, in radiography as a radon source and as a neutron source for research. Radon is used in the medical field for treating malignant tumors and for experimental studies. In developed nations, most of the exposure to these radionuclides occurs in occupational settings ,and workers are therefore subjected to strict health and safety standards. In LMICs and informal sectors where protective measures are not enforced, radionuclides have the ability to cause serious human health impacts. Exposure to radionuclides can induce cancer, impaired immune defenses and abnormal developmental effects.

Approximately 3 million people are at risk for exposure to radionuclides at more than 80 sites involving the mining and processing of uranium identified through the Toxic Sites Identification Program. As radionuclides are comprised of a heterogeneous set of materials for which the health impacts vary considerably, it is not yet possible to present a burden of disease estimate but these sites pose a threat to the health of the population exposed.

Health Effects

Many radionuclides are naturally present throughout the environment in the air, soil and water. Uranium, which is commonly found in rocks and soil, can decay to form non-harmful radium-226 and eventually to form radon-222 gas.[33] High levels of radon can be found in indoor settings, where radon gas infiltrates from the ground and can collect in basement and confined settings. Occupational settings that process uranium or produce phosphate fertilizers, or living near uranium mines can make individuals more exposed to high levels of uranium, radium and radon than the general population.[33] Acute Radiation Syndrome (ARS), or radiation sickness, occurs when an individual is exposed to high levels of radiation, usually over a short time period. Chronic radiation poisoning includes fatigue, weakness, fever, hair loss, dizziness, disorientation and diarrhea. More severe chronic cases can lead to cancer and non-cancer effects.

Radionuclides deliver different health impacts depending on the form and intensity of the radiation. Specific health impacts from uranium include various kidney diseases. Human health impacts related to radium include leukopenia, anemia, jaw necrosis, brain abscess and terminal bronchopneumonia.[50,51] Chronic radon exposure has resulted in respiratory effects that include lung disease, pneumonia, lung fibrosis and general decreased lung function. Overall, radium and radon are known as potent human carcinogens. Radium is known to cause lung, bone, head and nasal passage tumors. Radon exposure can lead to lung cancer. Occupational uranium exposure was found to cases of lung cancer and tumors of the lymphatic and hematopoietic tissues.

Pregnant women, children and occupational workers are most vulnerable to radiation exposure. Children are particularly susceptible due to more opportunities for radiation to interfere with their critical development process. Pregnant women are at risk of radiation exposure that may affect fetal development during pregnancy.[52] Exposure to radiation while in the womb can lead to abnormal development related to the brain, eyes and head.

A poorly appreciated issue is the physical and psychological impacts of nuclear disasters. 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 more than 10 million people continues to be affected by repercussions stemming from the Chernobyl nuclear disaster.[53] 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.[54] Future studies hope to understand better the number of individuals similarly affected by other nuclear incidents such as that which occurred at the Fukushima Daiichi Power Plant on March 11, 2011. A 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.[54] These incidents must be taken into account to fully understand the burden of disease resulting from the threat of radionuclide exposure.

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 1950s, it is estimated that millions have been exposed to elevated levels of man-made radiation.[55] Studies have shown such background radiation to cause an increase in infant mortality, cancer rates and low-birth weights.[56,57] Low radiation doses may also result in an increase frequency of mutations in chromosomes and genes in human somatic, bone marrow and muscle cells.[58-60] Globally, it is estimated that more than 10 million nuclear personnel are exposed to additional anthropogenic ionizing radiation on a daily basis.[49]

(Right) Obsolete pesticides are often left in abandoned buildings and stored in crumbling barrels. At this location in the former Soviet Union, workers in hazmat suits are working to ensure that the toxic substances are safely managed.

Photo by Pure Earth

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Five Other Major Sources

Other industries have been identified by Pure Earth as major sources of contamination outside of the top ten pollution sources. Petrochemical processing, electronic waste recycling, heavy industry, pesticide manufacturing and uranium processing contribute to almost 5 million DALYs and put more than 6.7 million people at risk, globally.

Petrochemical Industry

It is impossible when talking about pollution to ignore the drastic impacts that the oil and fossil fuel industries have had on environment and health. One particular source of pollution is the petrochemical processing industry. Petrochemicals are chemical compounds primarily derived from oil, natural gas or coal and many chemicals mentioned earlier in the report fall within this broad category. Basic petrochemicals include propylene, ethylene, butadiene, benzene, xylene and toluene and are commonly found in adhesives, plastics, electronics, clothing and rubber materials.[62]

Pollution from oil and natural gas industries has been significant and is actively being addressed in many places. Pure Earth continues to work to clean up areas that have been damaged from toxic petrochemicals.

Pure Earth has identified more than 80 sites contaminated from petrochemical processing and production. These sites, commonly in Africa, South America, Eastern Europe and South Asia, have a potential 4 million people at risk from exposure from these industries. The petrochemical sites in the TSIP database are largely polluted by untreated wastewater and sludge. As for many industries, LMICs often lack effective regulations surrounding petrochemical industries to ensure the health and safety of local

(Left) Man taking air samples at the Agbogbloshie e-waste site in Ghana. Informal recyclers burn e-waste to extract valuable metals. The burning releases toxic fumes that contaminate the community.

Photo by Pure Earth

(Above) One of the local Pure Earth remediation crews that worked on the cleanup of lead contamination in the community of Chowa in Kabwe, Zambia. Almost every child in Chowa suffers from lead poisoning. The contamination comes from lead mines and smelters located just a short five-minute walk away from hundreds of homes.

Photo by Pure Earth

populations. Some of the major health impacts from chemicals associated with this industry include neurological damage, lung diseases, and a variety of cancer diseases.

Electronic Waste Recycling

Consumer demand for the latest technological advances has resulted in growing quantities of electronic waste, commonly referred to as e-waste. E-waste includes everything from discarded computers, printers, cell phones, televisions, and other tech-related consumer products. The constant stream of new products generated almost 2.37 million tons of obsolete products in the United States in 2009 alone . It is estimated that 41.8 million tons of e-waste were produced in 2014.[64] It is reported that almost 80 percent of obsolete electronics delivered to a recycler in the United States will end up in a container, shipped to LMICs like China, Nigeria, India, Vietnam and Pakistan.[65]

In these countries, some of the items are refurbished and resold, but much is broken down and stripped to recover the small quantities of valuable metals that they contain. Recycling operations observed in some sites in LMICs have involved open-air dismantling of waste,

(Above) Lead smelting in Indonesia.
Photo by Pure Earth

burning of cable to recover copper, breaking of cathode ray tubes containing high levels of lead and open dumping of the final waste products.[66] These processes, especially the burning, release large amounts of toxins into the air where they are inhaled by e-waste workers and settle on the surrounding environment. Major pollutants identified in the Pure Earth TSIP database include lead, chromium, cadmium and PCBs.

Heavy Industry

A large component of industrial development and growth is the manufacturing of large metal components for other large industrial processes. This heavy industry includes metal casting, stamping, or rolling production processes of various metal parts that used in a wide range of industrial manufacturing processes, including energy and automotive plants. It involves many process steps that feature many different chemical additives, heating and melting of metal compounds and large amounts of water. Chemical additives include, but are not limited to, benzene, formaldehyde, toluene, cyanide salts and hydrofluoric acid.[67]

Most LMICs have begun to implement stricter regulations on heavy industry plants, but legacy pollutants still pose a threat to the health of surrounding populations. There are 80 polluted

(Above) A man sprays pesticides on a field in the Punjab region of northwest India. Excessive pesticide use in the region over the past 30-40 years has led to the accumulation of dangerous levels of toxins such as uranium, lead and mercury, which are contributing to increased health problems in rural communities.

Photo by Sean Gallagher

heavy industry sites in the TSIP database, potentially putting almost 1 million people at risk. The majority of polluted heavy industry sites in the Pure Earth's database are abandoned sites or small-scale plants that are unlicensed, unregulated and do not have the capacity to invest in new and safer technologies. The sites are geographically widespread with China, Eastern Europe, South and Southeast Asia having a large percentage of pollution sites from heavy industry.

Pesticide Manufacturing and Storage

Pesticides have been used extensively throughout the world to increase agricultural output and protect crops from pests and diseases. Pesticides include natural and produced chemicals designed for a specific impact on the target pest. The broad term encompasses insecticides, herbicides and bactericides, which are widely used within the agricultural system since roughly one-third of agricultural crops are produced with pesticides.[68] In all processes of pesticide production, storage, and use, there are potential pathways for human exposure, which can lead to severe health impacts.

(Above) Man standing on a pile of used lead-acid batteries. Some experts believe that lead poisoning from the improper recycling of used lead-acid batteries is the #1 childhood environmental health threat globally.

Photo by Larry C. Price

Disused or abandoned pesticide manufacturing and storage sites are estimated to put 1.2 million people are at risk globally, with an estimated burden of disease of 133,000 DALYs. As of 2016, the Toxic Sites Identification Program has identified more than 60 such sites around the world where exposure to pesticides threatens the health of the population. Regions with high contamination based from the TSIP database include Eastern Europe, Central and South America and South Asia. In view of the global, long-term use of pesticides, this number will very likely increase in the future.

Decaying storage facilities, waste from manufacturing processes and agricultural applications cause the majority of pesticide pollution. More than 4.6 million tons of pesticides, made up of 500 different types, are sprayed on crops annually. When sprayed, only 1 percent of pesticides end up being effectively utilized, with much of the material being distributed into the air and water. Surrounding communities directly consume pesticides through inhaling of contaminated air, ingesting or bathing in contaminated waters and ingesting food unknowingly covered with pesticides. When crops are irrigated the water picks up pesticides and carries them to surrounding waterways via runoff.

The breadth and reach of dispersed pesticides is alarming: studies have detected levels of DDT, lindane and aldrin in tree bark at the equator, in Greenland ice sheets and in Antarctic animals.

Stronger regulations regarding the manufacturing, storage and application of toxic pesticides have been introduced and are the focus 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 persistent organic pollutants (POPs), many of which are pesticides still used in LMICs.[69] The Food and Agricultural Organization (FAO) of the UN 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.[70] WHO is working to reduce the use of pesticides for disease vector control and promotes the use of non-chemical alternatives, when feasible. However, the importance of community-based educational programs focused on teaching agricultural workers about the risks of exposure to hazardous pesticides cannot be understated.

Uranium Processing

Uranium processing for the purpose of creating fuel for energy generation is a complex, multistep process that includes mining, milling, refining, enrichment and fuel manufacturing. After mining, uranium ore is processed into uranium oxide concentrate, which is then refined and converted to uranium hexafluoride, a chemical form suitable for further enrichment. Uranium hexafluoride is enriched through either gaseous diffusion or gas centrifuges where it is ready to be used for nuclear fuel manufacturing.[71]

The TSIP database includes a small number of former uranium mining and concentration sites, which potentially put more than 300,000 people at risk for severe health impacts. The majority of the sites are in Eastern Europe or located in Russia or the FSU.

Radionuclides are the major pollutants at these sites. At the legacy pollution sites, radioactive waste or tailings were often dumped in poorly controlled heaps, which could impact directly surrounding waterways, with no treatment or processing. At other contaminated sites, unintended spills or accidents have released radioactive waste into the environment. Radionuclides are found in the water, soil and food chain of these contaminated areas and many serious health effects have been observed which are attributed to the pollution. In addition to fuel processing, mining of uranium in LMICs frequently contributes toxic pollutants to the environment, as discussed in the mining and ore processing section of this report.

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Conclusion

While the problem of toxic pollution remains prevalent in many low- and middle-income countries, cost-effective solutions to treat and prevent the problem already exist. Pure Earth and Green Cross Switzerland continue to identify and assess sites contaminated by toxic pollution in order to prioritize site contamination and to implement meaningful projects. Continuing research and analysis of these sites will further establish the expanding scope of this underfunded public health crisis. However, the scale of this issue is too large to be addressed by NGOs alone. Country governments are making important progress in dealing with the problem but further efforts are required to improve the quality of life for millions of people affected by toxic pollution. Continued and increased international support is essential.

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