Mapping Global Environmental Lead Poisoning in Children

Alison L Clune[1], MPH; Henry Falk[1], MD, MPH; Anne M Riederer[1], ScD

1 Department of Environmental Health, Rollins School of Public Health, Emory University, Atlanta, GA

Corresponding Author:
Anne M. Riederer
13604 Cherrydale Drive
Rockville, MD 20850 USA

T. (404) 805-4982
arieder@emory.edu

Background. Despite major reductions in environmental lead contamination and mean blood lead levels (BLLs) in children, hotspot lead exposure remains a concern for children globally. Recent mass lead intoxication events in Senegal (2008) and Nigeria (since 2010) illustrate the potential severity of such exposures in children.
Objectives. The authors created a global map of children's BLLs from the published literature and from sites where Blacksmith Institute has worked to remediate lead contamination. This project is intended to draw attention to the continued existence of lead hotspots in the developing world and to underline the need for investigation in regions where data is of poor quality or nonexistent.
Methods. The authors collected data from the published literature through a PubMed literature search, and unpublished data from Blacksmith cleanup sites. Eligible studies measured blood lead levels in children (age < 18) using a standard laboratory method or the LeadCare® instrument and test kit, and met minimum data quality standards. Mean and median BLLs were classified into three categories: 1) < 10 µg/dL, 2) 10-19 µg/dL, and 3) ≥ 20 µg/dL. Lead exposure hotspots, those with a mean or median BLL ≥ 10 µg/dL, were stratified by suspected lead source and mean or median BLL.
Results. The authors reviewed 1,011 studies and datasets, 120 of which met the inclusion criteria. Of 242 included populations, 57 (24%) were lead hotspots. Most of the included studies came from North America, Western Europe, the Caribbean, India, Bangladesh, South Korea, and China; few studies came from Africa, Eastern Europe, Central Asia, the Middle East, Southeast Asia, the Pacific Islands, or South America. The 57 hotspots represented more than 8,000 children, mostly in countries that have child and adult mortality rates ranging from low to high child and very high adult mortality, as defined by the World Health Organization (WHO).
Conclusions. This mapping exercise underscores the continued and urgent need for high-quality investigations of lead exposure hotspots in regions where health is poor, and where no data currently exist. Designing effective remediation efforts will involve continued training of public health and environmental professionals in these countries to protect children most at risk.
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Introduction

Despite global efforts to reduce children's environmental lead exposure over the past several decades, lead exposure in heavily contaminated areas, or hotspots, is still an urgent public health concern in many parts of the world.[1-2] The World Health Organization (WHO) Global Burden of Disease Study Lead Working Group estimated that lead-associated mild mental retardation and cardiovascular diseases account for 0.9% of the global burden of disease.[3] This estimate excludes hotspot exposures, however, because data from such sites is not available in all cases, and the number of children living in hotspots is unknown. Hotspots have higher environmental lead levels than the general environment and so have the potential to cause severe lead poisoning in young children, sometimes leading to mortality.

Recent lead poisoning outbreaks in Senegal and Nigeria illustrate the potential severity of hotspot exposures. According to WHO, 18 children died in Thiaroye sur Mer, Senegal, during November 2007-March 2008 from encephalopathy caused by severe lead intoxication as a result of environmental contamination from informal used lead acid battery (ULAB) recycling.[4] Blood lead levels (BLLs) of 50 children (three months-19 years-old) included in the WHO investigation ranged from 39.8-613.9 µg/dL, with a mean (±SD) of 129.5 (±92.4) µg/dL.[4] In Zamfara State, Nigeria, 200 children have reportedly died from lead intoxication since March 2010[5] and an estimated 18,000 children and adults have been affected by widespread lead contamination resulting from the informal extraction of gold from lead-bearing ore.[6] Children's BLLs in two acutely affected Zamfara villages averaged 119 µg/dL (range 33.3-445 µg/dL), with 118 of the 463 resident children dying during May 2009-May 2010. Parents reported that 82% of the children who died experienced convulsions before death, a sign of severe lead poisoning.[5,7] As of July 2010, approximately 100 children from these villages were receiving chelation therapy while another 2,000 in five other villages were identified as needing it. Hospital records indicate that more villages may be affected, and lead poisoning may be more widespread than seen initially.[5]

In order to help draw attention to known lead-exposure hotspots, the authors created a global map of children's BLL reported in the published literature and from sites where Blacksmith Institute has worked to reduce lead contamination. The fact that BLL data is not available for many potential hotspots also warrants further examination.

Abbreviations			
AAS	atomic absorption spectrophotometry	*GPS*	geographic positioning system
ASV	anodic stripping voltammetry	*ICP-MS*	inductively coupled mass spectrometry
BLL	blood lead level	*LOD*	limit of detection
CDC	Centers for Disease Control and Prevention (U.S.)	*QA/QC*	quality assurance/ quality control
CV	coefficient of variation	*ULAB*	used lead-acid battery
ET-AAS	electrothermal AAS	*USGS*	United States Geological Survey
GF-AAS	graphite furnace AAS	*WHO*	World Health Organization

Methods

Literature Review and Data Selection

The authors collected published children's blood lead data as well as unpublished data from Blacksmith Institute. The published literature was searched using PubMed and terms including "lead" in combination with words describing children (e.g., "infant", "toddler", etc.), contamination sources (e.g., "smelter", "battery recycling", etc.), and health outcomes of lead poisoning (e.g., "mortality", "poisoning"). Any papers returned by the search terms that were not relevant to children's lead exposure (e.g., occupational exposures) were excluded. The reference lists of key papers were studied to identify additional studies not cited in PubMed. Additionally, the authors obtained unpublished data from two sites where Blacksmith Institute recently worked to reduce environmental lead contamination.

Eligible studies and Blacksmith Institute datasets were those published in English, Spanish, French, or Portuguese between 2000-2010 that reported concurrent BLLs in children < 18 years of age measured in a laboratory using atomic absorption spectrophotometry (AAS), anodic stripping voltammetry (ASV), and/ or inductively coupled plasma mass spectrometry (ICP-MS), or in the field using the LeadCare® instrument (Magellan Biosciences, Chelmsford, MA, USA). The authors excluded studies reporting only time-averaged BLLs for individual children, such as lifetime average BLLs,[8] because they do not indicate the child's concurrent level of lead exposure at the reported study location. Studies using filter paper samples or coagulated blood were excluded because these are not currently considered reliable for measuring BLLs due to the potential for contamination during drying and the lack of standard reference materials.[9] Studies using either venous blood draws and/or capillary/finger stick blood samples were eligible.

For each eligible study and Blacksmith Institute dataset, the authors reviewed the reported quality assurance/quality control (QA/QC) procedures to determine whether or not the reported BLLs were of sufficient quality to be included in the map. At a minimum, for laboratory measurements (e.g., AAS, ASV, ICP-MS measurements), descriptions of at least two standard QA/QC procedures or indicators of analytical performance (e.g., inter-laboratory validation, recoveries of spiked or certified concentrations, blanks analysis, etc.) were required. For LeadCare® measurements, a description of at least one of the following was required: validation of LeadCare® measurements with a laboratory-based method, calibration of each new test kit, analysis of low and high control samples with each set of analyses, periodic analysis of certified reference materials, or repeat measurements of low or high test results.

Data from the published studies and Blacksmith datasets was extracted into a database specifying citation and publication information, study location, suspected lead source(s), participant's age, laboratory methods, QA/QC procedures, limit of detection (LOD), method for imputing values below the detection limit, and summary statistics. The geometric mean, arithmetic mean, median, minimum, maximum, and sample size when reported were recorded. Where these measures were not reported but the raw data was, the measures were calculated directly by the authors. Studies where the authors could not record nor calculate at least one mean or median, or the sample size for the mean or median was not reported, were excluded. SAS 9.2 (SAS Institute, Cary, NC, USA) was used for all summary statistics.

Geocoding of Data Locations

The authors downloaded a world map shape file from VDS Technologies,[10] obtained an ocean background layer from ArcGIS 9 (ESRI Inc., Redlands, CA) and downloaded shape files of administrative units in Bangladesh, Canada, China, Ecuador, and Russia and waterways in the U.S. from DIVA-GIS.[11] The base map consisted of the ocean background layer showing a 30° graticule and a world map layer showing the boundaries of each country.

For the published studies, the authors used the "What's Here?" option in the Google Maps™ mapping service (Google, Inc., Mountain View, CA) to obtain geographic coordinates for the study city, town, village, or neighborhood. When the study combined data from two or three cities, each city was mapped in Google Maps™ and a central location between the cities estimated. When study populations were sampled from a geographic area larger than a single city, neighborhood, town, or village, we obtained the latitude/longitude of the centroid of the smallest geographic unit specified (e.g. state, province, district, etc.). Centroids were obtained from shape files using ArcGIS,9 with the exception of the centroid of the contiguous United States, which was obtained from USGS.[12]

For the unpublished data from Blacksmith Institute's Dominican Republic study sites, the institute provided global positioning system (GPS) coordinates for each child's household (Blacksmith Institute, unpublished data). The authors used ArcGIS to map each household and the ArcGIS midpoint tool to estimate a central location for inclusion on the global children's BLL map. For Blacksmith Institute's Mexico study (Blacksmith Institute and FONART, unpublished data), household results were pooled by state and the centroid of each state plotted. Using the geographic coordinates for each published study location and Blacksmith site, the authors plotted the largest of the geometric mean, arithmetic mean, or median BLL. For multi-site studies each site was plotted separately. For studies with multiple populations showing significantly different exposures (such as exposed and control groups), or for which an overall mean or median BLL was not reported, each population was plotted separately. The authors refer to individual plotted sites as populations, but there may be several populations at a single location. For studies that reported BLLs in the same population over time, the most recent data was used. Mean and median BLLs are classified into three categories using small, medium, and large circles to represent each, respectively: 1) < 10 μg/dL, the CDC level of concern,[13] 2) 10-19 μg/dL, and 3) ≥ 20 μg/dL, the BLL at which CDC recommends environmental investigation and lead hazard control for children with elevated blood lead levels.[14]

The hotspot of lead exposure was defined for the purposes of the map as a site with a mean or median BLL ≥ 10 μg/dL. This definition was chosen to capture those populations in which the average child (or the majority of children) has elevated BLLs. The authors reported the number of hotspot populations and the number of unique locations represented by these populations, stratified by the suspected source of lead reported and the mean or median BLL using classes 2 and 3 from the map. It was also noted in which WHO Mortality Stratum (http://www.who.int/ choice/demography/regions/en/index.html) specific hotspots were found

Results

Figure 1 summarizes the studies included and excluded in the creation of the map, according to the authors' criteria for selecting studies. Details (e.g. authors, publication year, location, study population, children's ages, suspected lead sources, and BLL summary statistics) on each of the groups we included are provided in Table S1 of the Supplemental Material. Inclusion criteria resulted in the exclusion of 88% of the articles reviewed from the literature, including the preliminary reports from the Senegalese and Nigerian outbreaks. Data from 120 publications and datasets representing a total of 62,275 children, sampled from 242 distinct populations, were included. BLL measurements in these populations spanned 24 years, from 1984 to 2010; the date of data collection was not reported in 43 populations. Urban populations numbered 164, and 18 were both urban and rural.

Figure 2 presents the global map of children's BLLs. The majority of BLL data collected came from North America, Western Europe, the Caribbean, India, Bangladesh, South Korea, and China. BLL data was noticeably lacking from Africa, Eastern Europe, Central Asia, the Middle East, Southeast Asia, the Pacific Islands, and parts of South America. Of the populations included, 57 (24%) were identified as lead exposure hotspots,

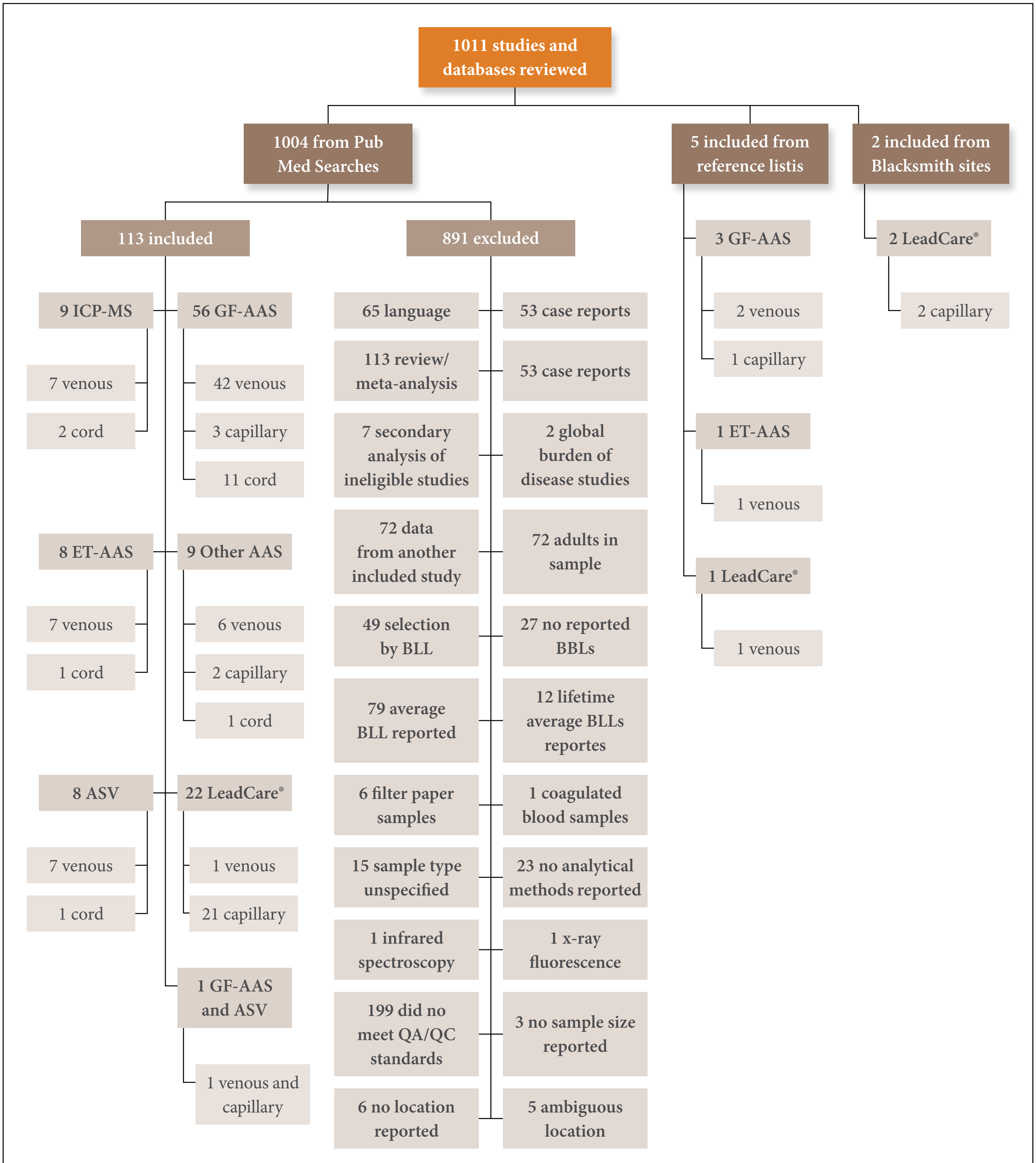

Figure 1 — Summary of studies included and excluded in children's BLL map.
ICP-MS=inductively coupled mass spectrometry; AAS=atomic absorption spectrophotometry; GF-AAS=graphite furnace AAS; ET-AAS=electrothermal AAS; ASV=anodic stripping voltametry; BLL=blood lead level; QA/QC=quality assurance/quality control

while 42% and 43% of populations reported a minimum and maximum BLL, respectively. Of these, 1 percent of minimum BLLs and 81% of maximum BLLs were ≥ 10 μg/dL.

Of the 242 populations included, 57 hotspot populations were identified, representing 8,345 children. Table 1 presents the number of hotspot populations and the number of unique locations they represent, stratified by the suspected lead source and the mean or median BLL. The most common suspected lead sources were metal smelters or foundries, leaded gasoline or traffic, lead in paint, battery recycling, and lead-glazed pottery. Hotspots in which metal smelters or foundries and battery recycling were the suspected lead source were widely distributed throughout the world. However, half of the hotspots in which leaded gasoline or traffic was the suspected lead source were from two countries, Bangladesh and Senegal. Similarly, hotspots associated with lead in paint were only located in three cities (Valencia, Venezuela; Nagpur, India, and Oporto, Portugal) and hotspots associated with lead-glazed pottery were almost exclusively located in Latin America.

Nine hotspots had mean or median BLLs ≥ 20 μg/dL, and the most common suspected lead sources in these severe hotspots were metal smelters and foundries, battery recycling, and lead-glazed pottery. Three hotspots had mean or median BLLs ≥ 40 μg/dL, and these were associated with production of lead-glazed pottery in La Victoria, Ecuador (arithmetic mean 40 μg/dL),[15] battery recycling and repair shops in Manila, Philippines (arithmetic mean 49.9 μg/dL),[16] and a scrap yard in Mumbai, India (geometric mean 69.2 μg/dL).[17]

The map (*Figure 2*) indicates that high average BLLs were most commonly reported from Mexico and countries in the Caribbean, South America, and South Asia. Only three hotspots were located in countries in WHO Mortality Strata A (i.e., those in which both children and adult mortality rates are very low; in this case; Australia and Portugal), but the dates of data collection were unknown for two of these hotspots (the third was collected in the 1990s).

Discussion

Using rigorous inclusion criteria, the authors identified 57 hotspots representing over 8,000 children. Many studies in which hotspot exposures were reported, but which did not meet quality standards, were excluded. Some of these were preliminary reports, such as those from the Senegalese[4] and Nigerian[5-7] outbreaks that did not include detailed descriptions of BLL measurement procedures, but nonetheless provide valuable information about severe lead poisoning incidents. Some were published in foreign languages, especially Chinese, and may have otherwise met the inclusion criteria. Others may have simply omitted descriptions of quality control procedures that would have met the criteria. The decision to report only the most recent data sometimes resulted in reporting BLLs after lead remediation was already underway. For example, BLLs at the Blacksmith cleanup site in Haina, Dominican Republic, peaked at a mean of 71 μg/dL in 1997, but remediation efforts had lowered BLLs to a mean of 12.2 μg/dL by 2010 (Blacksmith Institute, unpublished data). In some cases, hotspots may also have been concealed within aggregate data. For example, Safi et al.[18] reported higher BLLs in children living near battery manufacturing or recycling plants and smelters in Gaza, but the locations of these lead sources could not be mapped separately. In short, there are likely to be many valid hotspot studies that were not included in the map because of the rigorous exclusion criteria. However, as a result of these criteria, the authors do have considerable confidence in the reliability of the data and the hotspots included, and generally the data are indicative of the distribution, severity and sources of hotspots. In addition, there is a dearth of published BLL data from Africa, Eastern Europe, Central Asia, the Middle East, Southeast Asia, the Pacific Islands, and parts of South America. Increased numbers of hotspots of lead exposure undoubtedly exist in these regions, but they are not well represented in the published literature. Based on this observation, there are likely to be many more children living in hotspots worldwide. Children living in lead hotspots in the developing world are at high risk of severe disease and death, and lead poisoning prevention and treatment are not well established in many of the regions where BLL data is lacking.[1] In order to more accurately characterize lead hotspots and to direct lead poisoning prevention efforts, rigorous studies of children's BLLs in hotspots are needed, especially in regions of the world where BLL data are currently lacking.

After excluding nearly 90% of the studies and datasets reviewed, and with little BLL data available for many parts of the world, most of the hotspots the authors did include were located in countries in WHO Mortality Strata B-E, defined as countries in which child and adult mortality rates ranged from low to high and very high. Metal smelters and foundries were the most common and widespread lead sources in the hotspots identified, suggesting that control measures at these facilities have not been or are not adequate in many parts of the world. Battery recycling, both formal and informal, was also a common and widespread

	Mean or Median BLL			
Suspected Lead Source	**10-19**	**≥ 20**	**Total[a]**	**Location(s)**
Metal smelter or foundry	12 (8)[b]	3 (2)	15 (8)	San Luis Potosi (4) / Torreon (3), Mexico; Mumbai, India (2); Port Pirie, Australia (2); Adrianopolis (1) / Santo Amaro (1) / Capelinha and Vila Mota (1), Brazil
Traffic, leaded gasoline	13 (6)	1 (1)	14(7)	Krasnouralsk, Russia (1); Dhaka(5) / Tongi (1), Bangladesh; Lucknow (2) / Mumbai (2), India; Valencia, Venezuela (2); Dakar, Senegal (1); Oporto, Portugal (1)
Lead in paint	8 (3)	—	8 (3)	Valencia, Venezuela (5); Nagpur, India (2); Oporto, Portugal (1)
Battery recycling, formal or informal	5 (3)	2 (2)	7 (5)	Lucknow (3) / Mumbai (1), India; Manila, Philippines (1); Tongi, Bangladesh (1); Haina, Dominican Republic (1)
Use or production of lead-glazed ceramics or pottery	4 (3)	3 (3)	7 (6)	Mexico City (2) / Michoacan State (1) / Oaxaca (1) / Tlaxcala State (1), Mexico; Tongi, Bangladesh (1); La Victoria, Ecuador (1)
Informal sector	4 (2)	1 (1)	5 (3)	Lucknow (3) / Mumbai (1), India; Kingston, Jamaica (1)
Industrial Pollution	4 (3)	—	4 (3)	Mumbai (2) / Chennai (1) / Hyderabaad (1), India
Cosmetics	3 (2)	—	3 (2)	Nagpur, India (2); Karachi, Pakistan (1)
Car or boat repair	3 (2)	—	3 (2)	Valencia, Venezuela (2); Manila, Philippines (1)
Parent's occupation	2 (2)	—	2 (2)	Oporto, Portugal (1); Karachi, Pakistan (1)
Electronic waste	2 (1)	—	2 (1)	Guiyu, China (2)
Traditional medicine	1 (1)	—	1 (1)	Oaxaca, Mexico (1)
Water distribution system	1 (1)	—	1 (1)	Oaxaca, Mexico (1)
Mining	1 (1)	—	1 (1)	Vila Mota and Capelinha, Brazil (1)
Water storage vessels	1 (1)	—	1 (1)	Chennai, India (1)
Scrap yard	—	1 (1)	1 (1)	Mumbai, India (1)
Environmental tobacco smoke	1 (1)	—	1 (1)	Oporto, Portugal (1)
Unspecified	2 (2)	—	2 (2)	Araihazar, Bangladesh (1); Bangalore, India (1)
Total[a]	**48 (25)**	**9 (7)**	**57 (29)**	

Table 1 — Number of hotspot populations and unique locations by suspected lead source and mean or median blood lead level (BLL)

a. Rows and columns do not add to totals because multiple sources were reported in some populations and multiple populations were reported in some locations.
b. Number of hotspot populations (number of locations represented by these populations).

source. Considering the prevalence of these two lead sources in the hotspot studies reviewed, particularly in the most severely affected populations, metal smelters, foundries, and battery recycling are more than likely some of the major contributors to hotspot lead poisoning worldwide. Traffic or leaded gasoline, lead in paint, and lead-glazed pottery were also prominent lead sources in the hotspot studies reviewed, but these sources affected a more limited geographic area among studies published in the 2000-2010 timeframe. Several reports indicate that children's BLLs decreased dramatically after the removal of lead from gasoline,[19-21] and similar decreases in BLLs should be expected in all countries except the small number (such as North Korea, Myanmar, and Yemen), which have not yet phased out leaded gasoline.[22] The authors found hotspots in only three cities that were affected by lead in paint; however, little data is available regarding elevated blood lead levels from leaded paint in many countries, and this study's results may not reflect the true impact of lead in paint on children's BLLs in hotspots.

Lead-glazed pottery was a suspected lead source in hotspots almost exclusively in Mexico and adjacent Latin American countries but contributed to some of the most severely contaminated hotspots. Lead-glazed pottery is likely a major contributor to hotspot lead poisoning in Latin America in addition to metal smelters, foundries, and battery recycling.

The studies included in the map varied greatly in the number and type of reported quality-control measures. For example, Counter et al.[15] described cleaning subjects' skin prior to sample collection, performing five replicate analyses using the most sensitive method for measuring BLLs (ICP-MS), simultaneously testing 100 samples using graphite furnace AAS (GF-AAS), and testing procedural blanks and certified reference materials for procedural control of ICP-MS measurements. Conversely, Rojas et al.[23] reported performing duplicate analyses using a less sensitive method (flame AAS), and only briefly mentioned using internal and external quality controls. Few studies reported LODs (55%), detection frequencies (10%), or minimum BLLs (42%), while even fewer (24%) described imputation methods for BLLs < LOD. Because LODs ranged from 0.0001µg/dL[17,24-26] to 5 µg/dL[19,27,28], it is possible that some of the children in these studies had BLLs < LOD for which a higher value was substituted to calculate the mean. In such cases, the method of imputation could introduce some upward bias in the mean because of overestimation of some of the < LOD values. Further, few studies (24%) reported cleaning subjects' skin prior to sample collection. It is estimated that skin contamination can bias results upward by 11-42%[29]; it is possible that such bias is present in the means included in the map. Including LeadCare® measurements in the map limits our ability to accurately characterize upper-end BLLs in the most severely poisoned populations. The LeadCare® instrument can measure BLLs up to 65 µg/dL, but as seen in Senegal4 and Nigeria,[5] BLLs of children living in or near hotspots can be much higher than 65 µg/dL. LeadCare® measurements may have underestimated the severity of poisoning in the one population on the map whose maximum reported BLL was 65 µg/dL and in 24 populations for which maximum BLLs were not reported. Three studies reported LeadCare® measurements > 65 µg/dL,[18,30,31] but only one of these described confirmation of these results with laboratory measurements.[30]

Currently, GF-AAS is the standard laboratory method for measuring children's BLLs, with typical LODs of a few µg/dL or less.[32] ICP-MS is a more sensitive method, with typical LODs in the low ng/L to µg/L range, but is costly and not yet widely used for children's BLL analysis.[33] ASV, with typical LODs near 1 µg/dL,[34-36] is generally less sensitive than GF-AAS or ICP-MS, but still considered a reliable method for meeting BLL measurement standards in the United States.[33] In a laboratory proficiency study comparing GF-AAS and ASV measurements of 52 blood samples over one year,[37] both methods produced results that correlated strongly with certified reference concentrations and exhibited low bias (GF-AAS: r=0.996; ASV: r=0.982). ASV exhibited lower precision, however (F-test p<0.001; GF-AAS: 87% within 1 µg/dL of reference concentration; ASV: 52% within 1 µg/dL of reference concentration).[37] The LeadCare® instrument, which is based on ASV technology, has also been validated against GF-AAS. In one study, 108 samples (including 22 spiked with lead) were tested for lead with both the LeadCare® instrument and GF-AAS with good correlation and little bias between the methods (r=0.992).[38] Precision was evaluated by testing samples of four lead concentrations using six LeadCare® instruments over 20 days, resulting in pooled total coefficients of variation (CVs) and within-run CVs both ranging from 3.5%-12.2%. A clinical trial of the instrument included tests of 547 samples, 110 of which were spiked, at 10 sites over two months using the LeadCare® instrument and GF-AAS. During the trial, 95% of results were within the allowable total error range (≤ 40 µg/dL: GF-AAS result ± 6 µg/dL; > 40 µg/dL: GF-AAS result ± 15%) and none were in the erroneous results zone; however correlation decreased and bias between methods increased compared to the laboratory proficiency tests (r=0.976).[38] Given the high accuracy and limited bias of measurements with the LeadCare® instrument, meaningful bias in the average BLLs obtained from studies employing this method is not anticipated. However, capillary blood samples have been shown to exhibit a small positive bias of 0.75-1.5 µg/dL at 15 µg/dL compared to venous blood samples. This bias decreases as a proportion at higher BLLs, although the absolute bias increases.[29]

Conclusions

The authors compiled data from 120 studies and datasets representing 242 distinct populations, 57 of which were hotspots affecting 8,345 children. Metal smelters or foundries and battery recycling were common lead sources in these hotspots in locations distributed throughout the world, while leaded gasoline, lead in paint, and lead-glazed pottery affected more localized populations. Despite including only the most rigorous BLL measurements, many of the hotspots identified were located in countries in WHO Mortality Strata B-E. Most of the world's low- and middle-income countries fall into this category. Still, we found large regions in which BLL data was either unavailable, or was of insufficient quality for inclusion in the study. Many studies did not meet the study's criteria but nevertheless reported valid information on children's BLLs. Thus, the hotspots reported probably represent only a small proportion of the lead exposure hotspots throughout the world.

In order to completely characterize hotspot lead exposures globally, more high-quality studies of lead-exposure hotspots are needed. Training and experience in conducting quality lead exposure surveys are often lacking in the data-deficient regions we identified, and experts from regions where children's BLLs are comparatively well-documented should be encouraged to assist public health and environmental

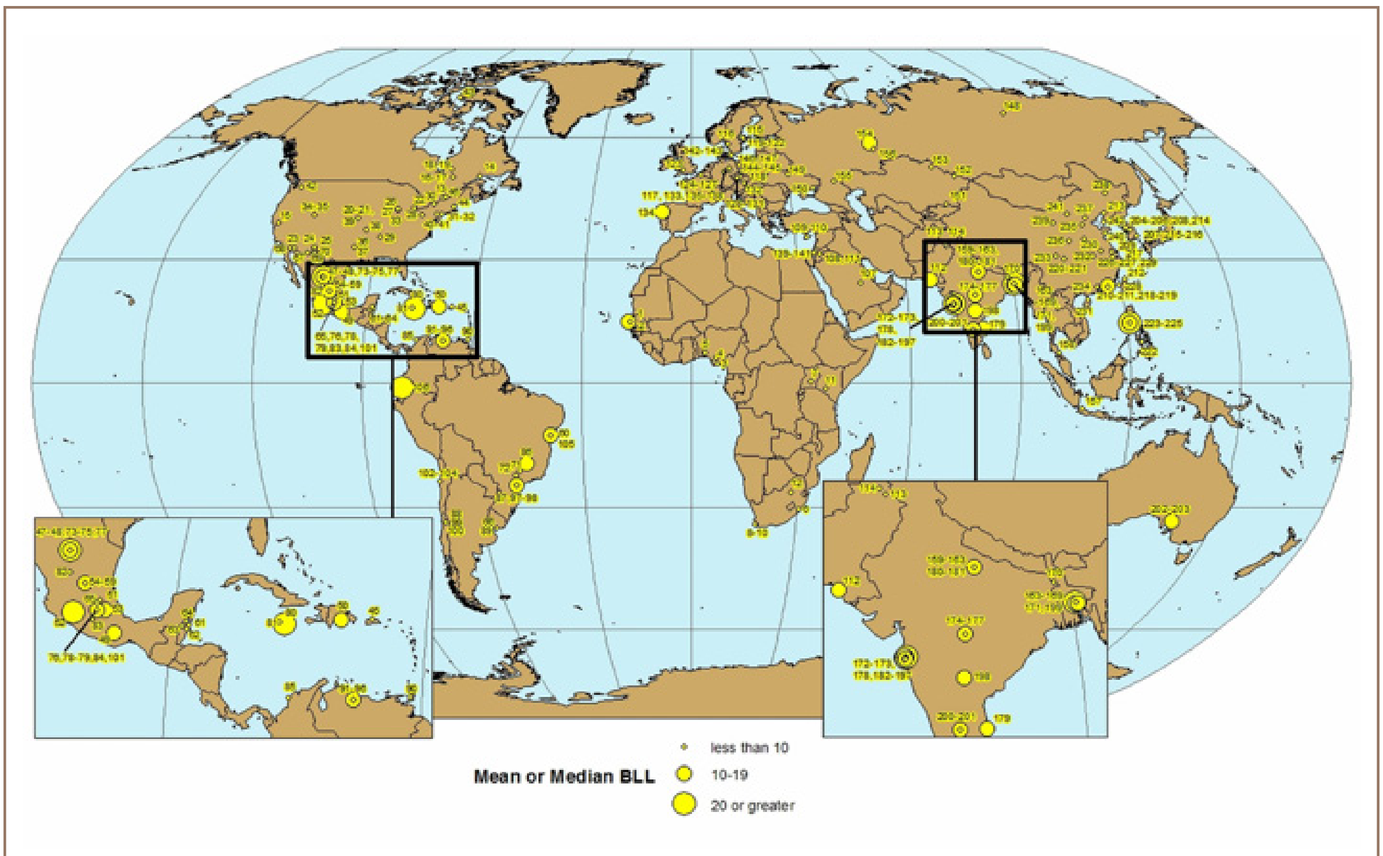

Figure 2 — Global map of children's average blood lead levels (ug/dl), studies published 2000-2010. Map numbers correspond to references in Table S1 of the Supplemental Material. For each reference, Table S1 lists authors, publication year, location, study population, children's ages, suspected lead sources, and blood lead level summary statistics.

professionals in data-deficient regions in rectifying this deficit. To properly allocate resources for lead poisoning prevention, public health and environmental professionals will need training in both conducting surveys and implementing effective lead remediation and control programs.

It is clear that hotspots can present profound threats to children's health, and in the instances sourced for this study, can result in long-term disability or death. Focused and effective public health programs and policies are necessary to protect children's health in these widespread and hazardous settings.

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