A Comparison of Burden of Disease from Toxic Waste Sites with other Recognized Public Health Threats in India, Indonesia and the Philippines

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Introduction

Exposure to chemicals from toxic waste sites is a serious and insufficiently examined contributor to the global burden of disease.⁴ Although toxic waste sites have been well investigated in many developed countries, their prevalence and health impact have not been well documented in low and middle-income countries where risks attributable to environmental pollution are generally higher than in developed nations.⁵

DALYs can be thought of as lost years of "healthy" life and represent the sum of 2 components: years lived with disability (YLD), which corresponds to disease-related morbidity, and years of life lost (YLL), which represents the premature mortality from disease.⁶ The analysis of the burden of disease from toxic waste sites expressed in DALYs can assist LMICs identifying the impact of chemical pollution from these sites.⁷

Background. Although toxic waste sites have been well investigated in many developed countries, their prevalence and health impact have not been well documented in low and middle-income countries where risks attributable to environmental pollution are generally higher than in developed nations.

Methods. We compared the burden of disease from toxic waste sites expressed in disability-adjusted life-years (DALYs) with the same measurement for other threats in India, Indonesia and the Philippines. We used Blacksmith Institute for a Pure Earth’s DALY estimates for chemical exposure at 373 toxic waste sites in the 3 countries and World Health Organization (WHO) DALY estimates for different health conditions in the same countries.

Results. Chromium VI causes the majority of DALYs among chemicals in India, while lead does so in the Philippines and Indonesia. In India, exposure to chromium VI showed higher DALY estimates than health conditions such as multiple sclerosis, Parkinson’s disease and various cancers. In Indonesia, exposure to chromium VI and lead presented higher DALYs than conditions such as upper respiratory infections. In the Philippines, lead had higher DALYs than most of the examined conditions, including malaria and human immunodeficiency virus (HIV)/AIDS.

Conclusions. This study highlights that the burden of disease expressed in DALYs from toxic waste sites may be greater than previously recognized and greater than other well addressed public health threats. We call attention to the need for surveillance of toxic waste sites, epidemiological analysis of the associations between exposure to toxic chemicals and outcomes, and remediation of chemical contamination in India, Indonesia and the Philippines.

Competing Interests. The authors declare no competing financial interests.

Keywords. Global burden of disease, DALY, WHO, Toxic site, Comparison, India, Indonesia, Philippines, Lead, Mercury, Pesticides.

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in low- and middle-income countries. Pure Earth identifies and screens toxic waste sites in 47 countries through the Toxic Sites Identification Program (TSIP). The TSIP focuses exclusively on sites where there exists a reasonable suspicion of point source pollution affecting human health. The evaluation instrument for data collection and assessment of these sites is the initial site screening (ISS), which is a modified and simplified version of the U.S. Environmental Protection Agency’s (EPA) Hazard Ranking System. The ISS includes information on the concentration of the key pollutant, the exposure pathway, size of the population at risk, and the severity of exposure.

Blacksmith Institute for a Pure Earth has compiled DALYs from different toxic chemicals at waste sites, including the 8 chemicals analyzed in this paper: aldrin, asbestos, cadmium, chromium VI, dichlorodiphenyltrichloroethane (DDT), lead, hexachlorocyclohexane (lindane) and inorganic mercury. This information was used by Chatham-Stephens et al. (2013) to calculate the burden of disease from toxic waste sites, in which pooled data for each chemical was published for India, Indonesia and the Philippines. The data for the calculations of the DALYs in these countries was collected through the TSIP.

Chatham-Stephens calculated the DALYs for exposure to industrial pollutants for 373 toxic waste sites in India, Indonesia and the Philippines with a methodology that had not been attempted previously by any organization. The YLD and YLL for exposure to each contaminant was calculated through each relevant environmental medium (air, soil and water) by combining estimates of disease incidence from these exposures with population data. For YLD, they used the same method to calculate disease incidence for all chemicals with the exception of lead, given the availability of lead-specific modeling tools and dose-response relationships. Chatham-Stephens multiplied the risk per person by the level of the contaminant in the relevant environmental medium. The risk was determined for cancer and non-cancer effects. For carcinogens, the U.S. EPA’s Regional Screening Level Calculator for Chemical Contaminants was used to calculate the long-term cancer risk per unit toxicant. For non-cancer health effects, reference doses and concentrations from the U.S. EPA’s Integrated Risk Information System database were applied to the exposure pathways and contamination levels at each site. The YLD for lead was calculated for mild mental retardation and anemia in children, and cardiovascular disease in adults. Additionally, Chatham-Stephens calculated the YLL only for carcinogens using cancer incidence and survival data to calculate the number of deaths. All cancers were assumed to last 5 years before either going into remission or resulting in death. Prior to this study by Chatham-Stephens, calculations of the burden of disease from toxic exposures had not included estimates from toxic waste sites due to the absence of data on exposures and health impacts.

Chatham-Stephens et al. (2013) estimated 828,722 DALYs from exposure to industrial pollutants at toxic waste sites in India, Indonesia and the Philippines in 2010, which they found comparable to the estimated burden of disease for outdoor air pollution (1,448,612 DALYs) and malaria (725,000 DALYs) in these countries. For this reason, this study aimed to compare the DALYs of aldrin, asbestos, cadmium, chromium VI, DDT, lead, lindane and inorganic mercury with other recognized and well addressed public health threats (communicable, perinatal and nutritional conditions, noncommunicable diseases and injuries) in and between the 3 countries. This assessment of the trends of DALYs within and between this group will further an understanding of the importance of the chemical pollution from toxic waste sites given that these kind of sites and their risks have not been well assessed and recognized by governments and health organizations in LMICs.

**Methods**

In the present study, we used Blacksmith Institute for a Pure Earth’s DALY estimates for chemical exposure at 373...
Research in India, 7 in Indonesia and 3 in the Philippines), DDT (3 in India and 1 in Indonesia), lead (24 in India, 28 in Indonesia and 27 in the Philippines), lindane (9 sites in India) and inorganic mercury (20 in India, 36 in Indonesia and 36 in the Philippines). The database was developed by a study by Chatham-Stephens et al. (2013).

This database is available in Microsoft Excel format and has information for each toxic site identified and analyzed during 2010 in each of the 3 countries. The database has information for DALYs calculated with and without weighting factors. For this study, DALYs that include a 3% discount rate (to account for the fact that individuals tend to give more value to current health events, as compared to future health events) and the full age weight (to reflect the value of different age groups) were gathered from this database.

WHO Database
The WHO has developed DALY estimates for communicable, maternal, perinatal and nutritional conditions, noncommunicable diseases and injuries. The YLL calculation of the WHO is the number of deaths multiplied by the standard life expectancy at the age at which death occurs. The YLD estimates of the WHO correspond to the number of incident cases in a period multiplied by the average duration of the disease and a weight factor that reflects the severity of the disease on a scale from 0 (perfect health) to 1 (dead). The WHO has calculated DALYs based on the evidence available for each of the health conditions and consultations with the WHO member states (including India, Indonesia and the Philippines); however, they represent the best estimates of the WHO, rather than the official estimates of the member states. These estimates use standard categories and methods to ensure cross-national comparability.

The WHO publishes DALY estimates by country and regions for communicable, maternal, perinatal and nutritional conditions, noncommunicable diseases and injuries for year, gender and age groups. For this study, the database available for 2012 for both genders and all ages was selected given that this is the most recently database that contains information on DALYs by country. This database has information for 172 member states. The data on DALYs for 109 health conditions for India, Indonesia and the Philippines was taken from the spreadsheet "DALYs All Ages." The information on DALYs for communicable, maternal, perinatal and nutritional conditions,

| Conditions | India | Indonesia | The Philippines |
|------------|-------|-----------|----------------|
| All communicable, maternal, perinatal and nutritional conditions | 200,140,100 | 23,988,400 | 9,946,200 |
| All noncommunicable diseases | 272,321,100 | 47,634,600 | 19,709,000 |
| All injuries | 66,769,700 | 6,674,100 | 3,108,900 |
| All chemicals | 281,002 | 158,116 | 401,607 |
| Chromium VI | 220,230 | 78,221 | 206 |
| Lead | 54,432 | 79,870 | 401,400 |
| Asbestos | 5,190 |
| Mercury, inorganic | 62.1 | 17.8 | 2.9 |
| Aldrin | 1,024 |
| Cadmium | 14.5 | 0.05 | 0.7 |
| DDT | 10.9 | 11.4 |
| Lindane | 99.5 |

Table 1 — DALYs for Exposure to Chemicals Per Country

toxic waste sites in India, Indonesia and the Philippines, and the World Health Organization’s (WHO) DALY estimates for different health conditions in the same countries.

Blacksmith Institute for a Pure Earth’s Database
Pure Earth maintains an extensive database of estimated DALYs for 373 toxic waste sites in India, Indonesia and the Philippines for the chemicals of interest in this paper: aldrin (5 sites in India), asbestos (3 in India), cadmium (39 in India, 1 in Indonesia and 13 in the Philippines), chromium VI (118 in India, 7 in Indonesia and 3 in the Philippines), DDT (3 in India and 1 in Indonesia), lead (24 in India, 28 in Indonesia and 27 in the Philippines), lindane (9 sites in India) and inorganic mercury (20 in India, 36 in Indonesia and 36 in the Philippines). The database was developed by a study by Chatham-Stephens et al. (2013). This database is available in Microsoft Excel format and has information for each toxic site identified and analyzed during 2010 in each of the 3 countries. The database has information for DALYs calculated with and without weighting factors. For this study, DALYs that include a 3%
### Table 2 — DALYs Per Country for Exposure to Chemicals and Communicable, Maternal, Perinatal and Nutritional Conditions

| Schistosomiasis | Leishmaniasis | Diphtheria | Trachoma | Mercury, inorganic | Chlamydia | Leprosy | Chromium VI | Lead | Gonorrhoea | Chlamydia | Asbestos | Trachoma | Diphtheria | Trichomoniasis | Lower respiratory infections | Meningitis | Maternal conditions |
|-----------------|-----------------|-------------|----------|-------------------|------------|---------|-------------|-------|------------|-----------|-----------|---------|------------|-------------|----------------------|------------------------|------------|------------------|
| 0.0 | 0.0 | 1.4 | 6.2 | 1.0 | 85.4 | 198.0 | 220.2 | 54.43 | 70.0 | 320.3 | 325.9 | 434.4 | 440.6 | 495.9 | 652.9 | 690.3 | 774.6 | 1,044.9 | 1,161.5 | 1,537.0 | 1,543.1 | 1,595.0 | 2,043.1 | 2,716.5 | 3,074.7 | 3,494.3 | 3,541.1 | 3,669.4 | 4,311.8 | 8,041.3 | 10,661.4 | 11,497.6 | 14,785.7 | 15,922.8 | 26,310.6 | 29,771.1 | 35,589.8 | 36,589.8 |
| 10.9 | 0.0 | 14.5 | 62.1 | 1.024 | 1.900 | 6.200 | 26.70 | 17.8 | 299.0 | 321.02 | 1.31 | 0.0 | 2,716.5 | 3,074.7 | 3,494.3 | 3,541.1 | 3,669.4 | 4,311.8 | 8,041.3 | 10,661.4 | 11,497.6 | 14,785.7 | 15,922.8 | 26,310.6 | 29,771.1 | 35,589.8 | 36,589.8 |
| 14.5 | 14.5 | 14.5 | 14.5 | 14.5 | 14.5 | 14.5 | 14.5 | 14.5 | 14.5 | 14.5 | 14.5 | 14.5 | 14.5 | 14.5 | 14.5 | 14.5 | 14.5 | 14.5 | 14.5 | 14.5 | 14.5 | 14.5 | 14.5 | 14.5 | 14.5 | 14.5 | 14.5 | 14.5 | 14.5 | 14.5 | 14.5 | 14.5 | 14.5 | 14.5 | 14.5 | 14.5 | 14.5 | 14.5 |
noncommunicable diseases and injuries was analyzed with the DALYs for toxic chemicals extracted from the Pure Earth database for the 3 countries in this analysis.

Study Design
This study was a cross-sectional pooled trend analysis. DALYs for chemicals from toxic waste sites were compared with DALYs of the different health conditions estimated by the WHO. All conditions were sorted by DALY value from the lowest to the highest separately for communicable, maternal, perinatal and nutritional conditions, noncommunicable diseases and injuries. This was done to assess trends within each country. In order to compare the value of DALYs between the 3 nations, per capita DALYs were obtained by dividing the value of a DALY by the population in the respective country in 2012 (for the health conditions listed by the WHO) and 2010 (for chemicals from toxic waste sites). Given that the values of DALYs per capita were small, the values were multiplied by 1,000. After this process, comparative bar graphs were created using Microsoft Excel to graphically illustrate the differences between the burden of disease expressed in DALYs for some of the health conditions and for the sum of all chemicals, lead and chromium VI in the 3 countries. We used information on the total population in each country available at the World Bank webpage (http://www.worldbank.org/).

Results
Table 1 shows the DALY estimations for each chemical and the sum of all communicable, maternal, perinatal and nutritional conditions, noncommunicable diseases and injuries per country. There were no data for DDT in the Philippines, or for asbestos, aldrin and lindane in Indonesia and the Philippines. Among the 8 chemicals studied, chromium VI and lead showed the highest DALYs for the 3 countries. The Philippines presented the greatest value for lead (401,400 DALYs) and India the highest value for chromium VI (220,230 DALYs). The sum of all noncommunicable diseases showed the highest value of all conditions in the collective group: India (272,321,100 DALYs), Indonesia (47,634,600 DALYs) and the Philippines (19,709,000 DALYs).

Tables 2, 3 and 4 display the distribution of DALYs for exposure to chemicals at toxic waste sites and other public health threats (communicable, maternal, perinatal and nutritional conditions, noncommunicable diseases and injuries) in India, Indonesia and the Philippines. All conditions were sorted by DALY value from lowest to highest.

Comparisons
Comparison of DALYs of exposure to chemicals at toxic waste sites with communicable, maternal, perinatal and nutritional conditions in India, Indonesia and the Philippines
Table 2 displays the distribution of DALYs for exposure to chemicals at toxic waste sites and communicable, maternal, perinatal and nutritional conditions in India, Indonesia and the Philippines. In India, the majority of the communicable, maternal, perinatal and nutritional conditions have higher results for DALYs as compared with exposure to chemicals at toxic waste sites. However, chromium VI (220,230 DALYs) presented a higher value than leprosy, chlamydia, gonorrhea, trichuriasis, diphtheria, trichomoniasis and trachoma. Lead (54,432 DALYs) also showed a higher value than the DALYs for trichuriasis, diphtheria, trichomoniasis and trachoma. The conditions in this group with the highest DALYs were pre-term birth complications (35,589,800) and diarrheal diseases (29,771,100).

Similar results in the Philippines show that most communicable, maternal, perinatal and nutritional conditions have higher results for DALYs compared with the exposure to cadmium, DDT and inorganic mercury from toxic waste sites. On the other hand, chromium VI (78,221 DALYs) and lead (79,870 DALYs) showed higher values than many public health conditions such as upper respiratory infections (75,300 DALYs) and tetanus (45,500 DALYs), and the DALYs for the sum of all chemicals (158,116) were higher than the DALYs for conditions such as hepatitis B (121,400).

The results in the Philippines show that most communicable, maternal, perinatal and nutritional conditions have higher results for DALYs compared with the exposure to cadmium, inorganic mercury and chromium VI from toxic waste sites. However, lead—with 401,400 DALYs—had a higher value than most health conditions (e.g. malaria: 42,900 DALYs and human immunodeficiency virus (HIV)/AIDS: 9,800 DALYs).

Figure 1 graphically illustrates the distribution of DALYs per capita for chromium VI, lead, the sum of all chemicals and some communicable conditions in the studied countries. Most of the communicable diseases in this figure presented higher DALYs per capita than chromium VI. However, the data in the Philippines indicates higher DALYs per capita for lead than tetanus, acute hepatitis B, malaria, measles, meningitis and whooping cough (Pertussis) in the 3 countries.

Table 3 shows the distribution of...
| India | Indonesia | The Philippines |
|-------|-----------|----------------|
| DDT 10.9 | Asbestos 0.0 | Asbestos 0.0 |
| Cadmium 14.5 | Aldrin 0.0 | Aldrin 0.0 |
| Mercury, inorganic 62.1 | Lindane 0.0 | Lindane 0.0 |
| Lindane 99.5 | Cadmium 0.05 | Cadmium 0.7 |
| Aldrin 3.02 | DDT 11.4 | Mercury, inorganic 2.9 |
| Gout 3.80 | Mercury, inorganic 17.8 | Chromium VI 206.0 |
| Asbestos 5.19 | Gout 2.70 | Gout 80.0 |
| Lead 54.432 | Multiple sclerosis 15.30 | Multiple sclerosis 9.800 |
| Melanoma and other skin cancers 60.400 | Appendicitis 16.900 | Bladder cancer 9.800 |
| Multiple sclerosis 96.200 | Cleft lip and cleft palate 21.900 | Cleft lip and cleft palate 10.900 |
| Appendicitis 109.000 | Eating disorders 38.600 | Eating disorders 12.300 |
| Parkinson’s disease 130.600 | Peptic ulcer disease 38.900 | Parkinson’s disease 12.400 |
| Eating disorders 134.500 | Parkinson’s disease 39.600 | Parkinson’s disease 13.600 |
| Cervix uteri cancer 147.900 | Urolithiasis 39.900 | Corpus uteri cancer 14.300 |
| Cleft lip and cleft palate 168.300 | Melanoma and other skin cancers 40.900 | Infertility 18.400 |
| Chromium VI 220.230 | Corpus uteri cancer 56.000 | Osteopagocancer 19.000 |
| Prostate cancer 251.000 | Oesophagus cancer 58.100 | Non-malignant headache 23.100 |
| Bladder cancer 266.700 | Non-malignant skin cancers 63.300 | Urolithiasis 21.100 |
| All Chemicals 281.002 | Chromium VI 78.221 | Appendicitis 26.500 |
| Inferility 296.400 | Infertility 78.800 | Pancreas cancer 36.700 |
| Non-malignant headache 304.400 | Lead 79.870 | Idiopathic intestinal disability 36.900 |
| Pancreas cancer 318.000 | Bladder cancer 82.400 | Neural tube defects 39.200 |
| Down’s syndrome 393.000 | Down’s syndrome 85.100 | Stomach cancer 45.700 |
| Urolithiasis 497.600 | Idiopathic intellectual disability 85.500 | Ovarian cancer 49.700 |
| Ovarian cancer 718.400 | Rheumatoid arthritis 101.100 | Rheumatoid arthritis 53.400 |
| Hyperplasia of prostate 749.300 | Stomach cancer 144.100 | Lymphomas, multiple myeloma 58.000 |
| Idiopathic intellectual disability 753.200 | Neural tube defects 147.100 | Alzheimer’s disease and other dementias 60.000 |
| Rheumatoid arthritis 804.800 | Pancreas cancer 148.700 | Prostate cancer 68.900 |
| Liver cancer 859.500 | Prostate cancer 150.600 | Cervix uteri cancer 82.000 |
| Alzheimer’s disease and other dementias 890.000 | Hyperplasia of prostate 153.200 | Mouth and oropharynx cancers 94.900 |
| Lymphomas, multiple myeloma 906.100 | All Chemicals 1,065.100 | Childhood behavioural disorders 138.300 |
| Childhood behavioural disorders 1,084.700 | Oesophagus cancer 196.100 | Osteosarthritis 108.300 |
| Oesophagus cancer 1,206.700 | Childhood behavioural disorders 235.800 | Pervasive developmental disorders 109.800 |
| Pervasive developmental disorders 1,576.000 | Ovarian cancer 236.600 | Gynecological diseases 134.700 |
| Leukaemia 1,457.300 | Alcohol use disorders 250.700 | Drug use disorders 153.800 |
| Colon and rectum cancers 1,634.300 | Pervasive developmental disorders 279.900 | Cardiomyopathy, myocarditis, 156.300 |
| Schizophrenia 1,921.900 | Cervix uteri cancer 320.600 | All Chemicals 158.116 |
| Osteosarthritis 1,956.000 | Drug use disorders 360.600 | Leukaemia 164.900 |
| Trachea, bronchus, lungs cancer 1,976.800 | Lymphomas, multiple myeloma 360.900 | Leukaemia 165.800 |
| Gynecological diseases 2,231.300 | Gynecological diseases 363.500 | Bipolar disorder 168.300 |
| Bipolar disorder 2,323.400 | Mouth and oropharynx cancers 385.900 | Oral conditions 194.800 |
| Drug use disorders 2,330.700 | Leukaemia 418.400 | Peptic ulcer disease 201.700 |
| Cervix uteri cancer 2,471.400 | Cardiomyopathy, myocarditis, endocarditis 424.600 | Colon and rectum cancers 207.300 |
| Breast cancer 2,708.600 | All Chemicals 463.900 | Liver cancer 213.500 |
| Cardiomyopathy, myocarditis, endocarditis 2,797.300 | Rheumatic heart disease 486.400 | Rheumatic heart disease 213.700 |
| Oral conditions 2,837.700 | Epilepsy 492.500 | Epilepsy 273.900 |
| Peptic ulcer disease 2,842.400 | All Chemicals 492.500 | Colon, bronchus, lungs cancer 291.400 |
| Congenital heart anomalies 3,030.200 | Colon and rectum cancers 514.500 | Breast cancer 292.600 |
| Mouth and oropharynx cancers 3,096.000 | Oral conditions 580.800 | Breast cancer 296.000 |
| Skin diseases 3,264.600 | Endocrine, blood, immune disorders 583.100 | Malignancy 356.100 |
| Epilepsy 3,351.100 | Skin diseases 607.000 | Anxiety disorders 356.300 |
| Neural tube defects 3,447.800 | Epilepsy 654.800 | Cirrhosis of the liver 400.700 |
| Alcohol use disorders 3,509.900 | Breast cancer 700.700 | Breast cancer 401.400 |
| Rheumatic heart disease 3,723.600 | Malignancy 811.000 | All Chemicals 401.607 |
| Hypertensive heart disease 4,016.400 | Neurological diseases 865.400 | Alcohol use disorders 413.700 |
| Endocrine, blood, immune disorders 4,289.900 | Trachea, bronchus, lungs cancer 879.500 | Endocrine, blood, immune disorders 446.000 |
| Anxiety disorders 4,397.600 | Asthma 901.000 | Sensory organs 544.300 |
| Migraine 4,502.800 | Anxiety disorders 994.400 | Congenital heart anomalies 608.380 |
| Asthma 6,319.800 | Hypertensive heart disease 1,348.700 | Hypertensive heart disease 613.200 |
| Kidney disease 7,208.700 | Kidney disease 1,348.700 | Kidney disease 627.800 |
| Cirrhosis of the liver 7,910.100 | Back and neck pain 1,608.200 | Back and neck pain 646.000 |
| Back and neck pain 8,147.700 | Cirrhosis of the liver 1,707.500 | Asthma 708.100 |
| Diabetes mellitus 9,795.500 | Sensory organs 1,956.300 | Chronic obstructive pulmonary disease 1,213.900 |
| Unipolar depressive disorders 12,183.000 | Chronic obstructive pulmonary disease 2,173.900 | Unipolar depressive disorders 1,127.200 |
| Unipolar depressive disorders 13,582.000 | Unipolar depressive disorders 2,914.500 | Diabetes mellitus 1,223.700 |
| Diabetes mellitus 13,370.200 | Diabetes mellitus 2,996.400 | Stroke 1,778.900 |
| Ischaemic heart disease 13,719.200 | Ischaemic heart disease 7,274.000 | Ischaemic heart disease 2,644.000 |

Table 3 — DALYs Per Country for Exposure to Chemicals and Noncommunicable Diseases
Figure 1 displays the distribution of DALYs per capita (multiplied per 1,000) for exposure to chemicals at toxic waste sites (lead, chromium VI and all chemicals) and some communicable conditions in India, Indonesia and the Philippines. Blue columns indicate India, red columns indicate Indonesia and green columns indicate the Philippines.

**Figure 1 — DALYs per 1,000 persons of exposure to chemicals at toxic waste sites and some communicable conditions in India, Indonesia and the Philippines**

| India | Indonesia | The Philippines |
|-------|-----------|----------------|
| Exposure to forces of nature | 0.0 | 0.0 | Asbestos 0.0 |
| DDT | 10.9 | 0.0 | Aldrin 0.0 |
| Cadmium | 14.5 | 0.0 | DDT 0.0 |
| Mercury, inorganic | 62.1 | 0.0 | Lindane 0.0 |
| Lindane | 99.5 | 0.0 | Cadmium 0.7 |
| Aldrin | 1,024 | 0.0 | Mercury, inorganic 2.9 |
| Asbestos | 5,190 | 0.0 | Chromium VI 206 |
| Collective violence and legal intervention | 53,900 | 11.4 | Poisonings 17,900 |
| Lead | 54,432 | Mercury, inorganic 17.8 | Collective violence and legal intervention 39,400 |
| Chromium VI | 220,230 | Chromium VI 78,221 | Fire, heat and hot substances 82,100 |
| All Chemicals | 281,002 | Lead 79,870 | Exposure to forces of nature 91,700 |
| Poisonings | 2,195,200 | All Chemicals 158,116 | Self-harm 152,700 |
| Fire, heat and hot substances | 3,641,200 | Poisonings 158,300 | Falls 329,900 |
| Interpersonal violence | 4,039,100 | Interpersonal violence 253,800 | Drowning 379,600 |
| Drowning | 6,008,200 | Fire, heat and hot substances 364,800 | Lead 401,400 |
| Falls | 10,217,900 | Drowning 407,000 | All Chemicals 401,607 |
| Road injury | 14,413,100 | Self-harm 435,300 | Road injury 728,200 |
| Self-harm | 15,000,400 | Falls 933,800 | Interpersonal violence 878,000 |

Table 4 — DALYs Per Country for Exposure to Chemicals and Injuries
DALYs for noncommunicable diseases and exposure to chemicals at toxic waste sites in India, Indonesia and the Philippines. Most of the noncommunicable diseases in India have higher DALYs compared with exposure to chemicals at toxic waste sites. Nevertheless, chromium VI showed higher DALYs (220,230) than conditions such as multiple sclerosis, appendicitis, Parkinson’s disease and cancers of the corpus uteri and skin. Chromium VI presented the highest value of DALYs among the chemicals from toxic waste sites. The noncommunicable diseases with the greatest results for DALYs in Indonesia were stroke (7,274,000) and ischaemic heart disease (3,484,000).

The distribution of DALYs in the Philippines shows that inorganic mercury, cadmium and chromium VI had lower DALYs than all of the noncommunicable diseases reviewed in this study. DALYs of chromium VI (78,221) and lead (79,870) had higher values than many noncommunicable diseases such as different types of cancers (esophageal, corpus uteri and skin). The noncommunicable diseases with the greatest values for DALYs in Indonesia were stroke (7,274,000) and ischaemic heart disease (3,484,000).

In Indonesia, cadmium, DDT and inorganic mercury had lower DALYs than all of the noncommunicable diseases reviewed in this study. DALYs of chromium VI (78,221) and lead (79,870) had higher values than many noncommunicable diseases such as different types of cancers (esophageal, corpus uteri and skin). The noncommunicable diseases with the greatest values for DALYs in Indonesia were stroke (7,274,000) and ischaemic heart disease (3,484,000).

The distribution of DALYs per capita for chromium VI, lead, the sum of all chemicals and some noncommunicable diseases. Almost all of the noncommunicable diseases in this figure presented higher DALYs per capita than lead, chromium VI and all chemicals in India and Indonesia. Nevertheless, DALYs per capita for lead in the Philippines were higher than those for recognized diseases such as breast cancer, leukemia, prostate cancer and appendicitis in the 3 countries.

Comparison of DALYs of exposure to chemicals at toxic waste sites with injuries in India, Indonesia and the Philippines

Table 4 shows the distribution of DALYs for injuries and exposure to chemicals at toxic waste sites in India, Indonesia and the Philippines. In India and Indonesia, with the exception of exposure to forces of
nature and collective violence and legal intervention, all injuries estimated by the WHO had higher DALYs than those for chemicals at toxic waste sites.

In the Philippines, inorganic mercury, cadmium and chromium VI had lower DALYs than all injuries. However, lead presented higher DALYs than the majority of injuries and only road injury (728,200 DALYs) and interpersonal violence (828,000 DALYs) presented higher values than lead.

Figure 3 graphically illustrates the distribution of DALYs per capita for chromium VI, lead, the sum of all chemicals and injuries in the 3 countries. Lead in the Philippines presented DALYs per capita similar and even higher than many types of injuries, which was contrary to what was found for lead in India and India. DALYs per capita for lead in the Philippines were similar to those for falls in Indonesia, and interpersonal violence and drowning in India.

Discussion

Our comparison of DALYs from exposure to chemicals at toxic waste sites with other recognized public health threats in India, Indonesia and the Philippines showed that most of the conditions analyzed by the WHO present higher DALYs estimations than those from exposure to toxic chemicals in India and Indonesia. However, in India, the exposure to chromium VI shows higher DALY estimates than many recognized health threats such as multiple sclerosis and some types of cancers. Likewise, in Indonesia, chromium VI and lead present higher DALYs than conditions such as Parkinson’s disease and the sum of the DALYs of all chemicals is greater than the estimated DALY for different types of cancers.

The comparison in the Philippines showed that lead has a higher DALY estimate than the majority of conditions. Exposure to lead presents a larger DALY value than many recognized health conditions, including malaria and HIV/AIDS. These results suggest that lead is an important contributing factor of disease in the Philippines, as has been found in previous studies of lead exposure in that country. However, our results could be influenced by the under-reporting of notifiable diseases and health-related events in the Philippines, which could falsely show sites contaminated with lead to be a bigger problem than in reality.

Our results suggest that of the 8
toxic chemicals analyzed in this study, chromium VI is the pollutant of biggest concern in India, along with chromium VI and lead in Indonesia. Chromium VI has been identified as one of the major pollutants from the tannery industry in Kanpur, India, despite the fact that this industry is required to comply with the regulations of pollution control systems that ban discharging chromium VI into the environment.15-17 During our literature search we were not able to find studies that analyzed the exposure of the general population to lead or chromium VI from point source contamination in Indonesia. However, different studies of air pollution showed high levels of lead contamination18 and demonstrated that levels have decreased since lead was banned in gasoline.17, 18 In the Philippines, chromium VI presented a low DALY value compared with India and Indonesia, which could be explained by the fact that in the Philippines, only 3 contaminated sites were analyzed for the DALY estimation of this chemical.

Figures 1, 2 and 3 present the DALYs per capita for the chemicals with the highest DALYs for the 3 countries (Chromium VI and lead), the sum of all chemicals analyzed in this study and some of the most well recognized health conditions by the WHO. This analysis aimed to determine the trend in the distribution of DALYs in Tables 2, 3 and 4 remained similar after taking into consideration the population in each of the countries for 2012 (for the conditions taken from the WHO) and 2010 (for the chemical exposures at toxic waste sites). Our results showed that the distribution of DALYs was similar and that even though most of the health conditions had higher DALYs than chemical exposure at toxic waste sites in India and Indonesia, there were some recognized diseases with lower DALYs than chemicals at toxic waste sites, especially for lead in the Philippines.

Pruss-Ustun et al. (2008)19 estimated that between 13% and 37% of a country’s total disease burden could be prevented by achieving environmental improvements.19 The comparison made in this study shows that the exposure to chromium VI and lead at toxic wastes sites is an important factor in the burden of disease in India, Indonesia and the Philippines. Our results bring attention to the need for chemical exposure characterization at toxic waste sites, as well as remediation of these sites in developing countries. Pruss-Ustun et al. (2011) argued that governments could improve public health by collecting information on hazardous chemicals to which their populations are exposed in order to take action on the most important problems.20

Clean-up interventions in toxic waste sites are a cost-effective investment that removes environmental exposure to hazardous chemicals.21 These interventions would be beneficial for the communities living close to toxic waste sites in India, Indonesia and the Philippines. However, this is a difficult goal given the historical allocation of funds for health problems in the world. The allocation of the WHO’s budget has been greatly skewed toward infectious diseases. For example, the WHO allocated 87% of its total budget to infectious diseases, 12% to non-communicable diseases, and less than 1% to injuries and violence in 2006-2007.22 The budgetary allocations of the WHO provide an opportunity to understand the priority that is given to different disease categories worldwide, because it has a global perspective and covers all aspects of human health.22

Our analysis has important limitations. The databases of DALYs that we used for our comparison are from different years. The database of DALYs for exposure to chemicals from the Blacksmith Institute for a Pure Earth is from 2010 and the database of DALYs from the WHO is from 2012. DALY estimates represent a “snapshot” for a specific year, thus our analysis might have been different if we had reviewed databases from the same year.20 Our study also retains all of the limitations of the calculation of DALYs for different health conditions and the exposure to chemicals at toxic waste sites, due to quality of data and methodological choices.4 Chatham-Stephens et al. (2013) explained the limitations of the estimation of burden of disease from toxic waste sites. Some of these limitations include the fact that the screened sites represent only a portion of the total existing sites in these countries; the assignment of only one cancer and one non-cancer health effect to the DALY estimation per chemical; and the analysis of only one chemical per site, although people living near toxic waste sites are often exposed to multiple chemicals simultaneously.

One of the most important limitations of the data collected through the ISS is the extrapolation of results of limited environmental sampling to the entire population at risk, given that this causes an estimation of DALYs under the worst-case scenario. In addition, it is important to consider that the model used for DALY calculations is new, and therefore has not been previously assessed by other organizations or researchers. This fact made it impossible to validate the accuracy of the results for DALYs estimation for chemical exposure at toxic waste sites. These limitations and the fact that the number of contaminated sites analyzed differed per country could be responsible for our results showing substantial differences in the impact of each chemical analyzed in this study.
Despite these limitations, this study offers insight into the comparison of the burden of disease for recognized public health threats with the burden of disease from chemical exposure from toxic waste sites. The results of this study should alert policy makers regarding the importance of chemical pollution in developing countries and encourage governments to allocate funds to collect information on hazardous chemicals and to take action on contaminated sites. Surveillance and bio-monitoring of these sites are needed for future studies. Further epidemiological research in this field is necessary to identify statistically significant associations between exposure to chemicals and outcomes at toxic waste sites, which would allow for a better understanding of the burden of disease caused by these sites.\(^\text{17}\)

**Conclusions**

This study highlights that the burden of disease expressed in DALYs from chemical exposure at toxic waste sites may be greater than recognized and well addressed health threats such as HIV/AIDS and malaria in the Philippines and multiple sclerosis, Parkinson’s disease and some types of cancers in India and Indonesia. Chromium VI constitutes the majority of DALYs from toxic agents in India, while lead has the highest DALYs in the Philippines and Indonesia. Our results call attention to the need for surveillance and bio-monitoring of toxic waste sites, epidemiological analysis of the associations between exposure to toxic chemicals and outcomes, and remediation of chemical contamination in India, Indonesia and the Philippines. Further research should compare the burden of disease from toxic waste sites with other public health threats with DALYs from a single year, given that the databases used for this study came from different years (2012 and 2010). However, despite these limitations, this study promotes public awareness regarding the importance of chemical exposure from toxic waste sites for the total burden of disease in developing countries.

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**References**

1. Caravanos J, Chatham-Stephens K, Ericson B, Landrigan PJ, Fuller R. The burden of disease from pediatric lead exposure at hazardous waste sites in 7 Asian countries. *Environ Res* [Internet]. 2013 Jan;120:119-25. Available from: http://www.sciencedirect.com/science/article/pii/S0013935112001892 Subscription required to view.
2. Yan ez L, Ortiz D, Calderon J, Batres L, Carrizales I, Mejia J, Martinez L, Garcia-Nieto E, Diaz-Barriga F. Overview of human health and chemical mixtures: problems facing developing countries. *Environ Health Perspect* [Internet]. 2002 Dec;110(Suppl 6):901-9. Available from: http://www.ncbi.nlm.nih.gov/pmc/articles/PMC1241270/
3. Briggs D. Environmental pollution and the global burden of disease. *Br Med Bull* [Internet]. 2003 [cited 2014 Sep 15];68(1):1-24. Available from: http://bmb.oxfordjournals.org/content/68/1/1.full.pdf
4. Polinder S, Haagsma JA, Stein C, Havelaar AH. Systematic review of general burden of disease studies using disability-adjusted life years. *Popul Health Metr* [Internet]. 2012 Nov 1;10(1):21. Available from: http://www.ncbi.nlm.nih.gov/pmc/articles/PMC3554436/
5. Murray CJ, Lopez AD. Global mortality, disability, and the contribution of risk factors: global burden of disease study. *Lancet* [Internet]. 1997 May 17 [cited 2014 Sep 16];349(9063):1436-42. Available from: http://www.thelancet.com/journals/lancet/article/PIIS0140-6736(96)60749-5/fulltext Subscription required to view.
6. World Health Organization. Health statistics and information systems [Internet]. Geneva: World Health Organization; c2014 [cited 2014 Feb 15]. Available from: http://www.who.int/healthinfo/global_burden_disease/publications/en/
7. Chatham-Stephens K, Caravanos J, Ericson B, Sanga-Amparo J, Susilorini B, Sharma P, Landrigan PJ, Fuller R. Burden of disease from toxic waste sites in India, Indonesia, and the Philippines in 2010. *Environ Health Perspect* [Internet]. 2013 Jul;121(7):791-6. Available from: http://www.ncbi.nlm.nih.gov/pmc/articles/PMC3702002/pdf/ehp.1206127.pdf
8. Blacksmith Institute. Blacksmith’s strategy [Internet]. New York: Blacksmith Insitute; c2014 [cited 2014 Feb 16]. [about 2 screens]. Available from: http://www.blacksmithinstitute.org/our-strategy.html
9. Ericson B, Caravanos J, Chatham-Stephens K, Landrigan P, Fuller R. Approaches to systematic assessment of environmental exposures posed at toxic waste sites in the developing world: the toxic sites identification program. *Environ Monit Assess* [Internet]. 2013 Feb;185(2):1755-66. Available from: http://link.springer.com/article/10.1007%2Fs10661-012-2665-2 Subscription required to view.
10. World Health Organization. Health statistics and information systems: disease and injury country estimates, 2004-2008 [Internet]. Geneva: World Health Organization; c2014 [cited 2014 Feb 20]. Available from: http://www.who.int/healthinfo/global_burden_disease/estimates_country_2004_2008/en/
11. Riddell TJ, Solon O, Quimbo SA, Tan CM, Butrick E, Peabody JW. Elevated blood-lead levels among children living in the rural Philippines. *Bull World Health Organ* [Internet]. 2007 Sep [cited 2014 Sep 16];85(9):674-80. Available from: http://www.ncbi.nlm.nih.gov/pmc/articles/PMC2636405/
12. Suplido MI, Ong CN. Lead exposure among small-scale battery recyclers, automobile radiator mechanics, and their children in Manila, the Philippines. *Environ Res* [Internet]. 2000 Mar [cited 2014 Sep 16];82(3):231-8. Available from: http://www.sciencedirect.com/science/article/pii/S0013935199040240 Subscription required to view.
13. Sharma P, Bihari V, Agarwal SK, Verma V, Kesavachandran CN, Pangtey BS, Mathur N, Singh KP, Srivastava M, Goel SK. Groundwater contaminated with hexavalent chromium (Cr(VI)): a
13. Beg KR, Ali S. Chemical contaminants and toxicity of Ganga River sediment from up and down stream area at Kanpur. *Am J Environ Sci* [Internet]. 2008 Jul [cited 2014 Sep 16];4(4):362-6. Available from: http://thescipub.com/PDF/ajesp.2008.362.366.pdf

14. Misra V, Pandey SD. Hazardous waste, impact on health and environment for development of better waste management strategies in future in India. *Environ Int* [Internet]. 2005 Apr [cited 2014 Sep 16];31(3):417-31. Available from: http://www.sciencedirect.com/science/article/pii/S0160412004001448. Subscription required to view.

15. Horton LM, Mortensen ME, Iossifova Y, Wald MM, Burgess P. What do we know of childhood exposures to metals (arsenic, cadmium, lead, and mercury) in emerging market countries? *Int J Pediatr* [Internet]. 2013 [cited 2014 Sep 16];2013:872596. Available from: http://www.hindawi.com/journals/ijpedi/2013/872596/

16. Browne DR, Husni A, Risk MJ. Airborne lead and particulate levels in Semarang, Indonesia and potential health impacts. *Sci Total Environ* [Internet]. 1999 Mar 9 [cited 2014 Sep 16];227(2-3):145-54. Available from: http://www.sciencedirect.com/science/article/pii/S0048969799000224. Subscription required to view.

17. Kondo A, Hamonangan E, Soda S, Kaga A, Inoue Y, Eguchi M, Yasaka Y. Impacts of converting from leaded to unleaded gasoline on ambient lead concentrations in Jakarta metropolitan area. *J Environ Sci* [Internet]. 2007 [cited 2014 Sep 16];19(6):709-13. Available from: http://www.sciencedirect.com/science/article/pii/S1001074207601181. Subscription required to view.

18. Pruss-Ustun A, Bonjour S, Corvalan C. The impact of the environment on health by country: a meta-synthesis. *Environ Health* [Internet]. 2008 [cited 2014 Sep 16];7:7. Available from: http://www.ehjournal.net/content/7/1/7

19. Pruss-Ustun A, Vickers C, Haeffiger P, Bertollini R. Knowns and unknowns on burden of disease due to chemicals: a systematic review. *Environ Health* [Internet]. 2011 [cited 2014 Sep 16];10:9. Available from: http://www.ehjournal.net/content/10/1/9

20. Guerriero C, Bianchi F, Cairns J, Cori L. Policies to clean up toxic industrial contaminated sites of Gela and Priolo: a cost-benefit analysis. *Environ Health* [Internet]. 2011 [cited 2014 Sep 16];10:68. Available from: http://www.ehjournal.net/content/10/1/68

21. Stuckler D, King L, Robinson M, McKee M. WHO’s budgetary allocations and burden of disease: a comparative analysis. *Lancet* [Internet]. 2008 Nov 1 [cited 2014 Sep 16];372(9649):1563-9. Available from: http://www.thelancet.com/journals/lancet/article/PIIS0140-6736(08)61656-6/fulltext