

Estimates of Heavy Metals Exposure from Toxic Waste Sites: A Ghanaian Case Study

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Abstract

Background: Exposure to heavy metals at unregulated contaminated sites remains a significant source of adverse health outcomes in many low- and middle-income countries. Progress has been made in identifying contaminated land over the past three decades in the Global North. Efforts in developing countries, however, remain nascent. One such effort is Pure Earth's 'Toxic Sites Identification Program' (TSIP), which has documented over 3,200 sites across 49 countries.

Objectives: Though to our knowledge TSIP is the most comprehensive database of its kind, it is far from complete. As of December 2015, there are currently 255 contaminated sites located in Ghana within the TSIP database. Therefore, an extrapolation of possible sites can be a valuable tool to obtaining a 'capture rate' within the database and help to further elucidate the potential scale of toxic waste sites in Ghana. Using area and population statistics from Ghana Statistical Service, we searched for heavy metals contamination within a random sample of administrative districts in Ghana. An extrapolation of possible heavy metals contaminated sites was then calculated to estimate the number of heavy metals contaminated sites nationwide.

Methods: This study employed two alternative methodologies to estimate the number of heavy metals contaminated sites in Ghana. The first was a cluster random sampling analysis that relied on a 50% weighted mixture of area and population statistics. The second was an analysis involving simple random sampling that relied on the mean number of sites found per sample. Regional estimates were then calculated by giving equal weight (33.3%) to the number of sites found in the exercise, area, and population.

Results: The cluster random sampling analysis estimates that there are 1,561 heavy metals contaminated sites in Ghana (CI: 1,134 to 1,987). The random sampling analysis estimates that there are 1,944 sites in Ghana (CI: 812 to 3,075). These estimates are based on an extrapolation of heavy metals contaminated sites within Ghana. They are an apparent underestimation of the total number of contaminated sites in the country, as they do not include organics, pesticides, or other notable sources of pollution.

Conclusions: Our current extrapolation shows that there are an estimated 1,561 to 1,944 heavy metals contaminated sites within Ghana (CIs: 812 to 3,075). This is approximately nine times the number of contaminated sites previously documented by the Pure Earth Toxic Sites Identification Program.

Key Words

Environmental health; Ghana; Toxic waste sites; Heavy metals; Chemical exposures

Introduction

Pollution is greatly linked to poverty and has disproportionate effects on low-income communities.ⁱ On the global scale, low-income as well as middle-income countries face barriers to infrastructural and inclusive economic development due to challenges borne from pollution and associated environmental health issues.^{ii,iii} The very process of development has led to unintentional adverse environmental health effects. Rapid industrialization, population growth, environmental contamination, and exploitation of natural resources are all key commonalities among developing low- and middle-income countries (LMICs). Also similar among LMICs are the characteristics of limited governmental capacity and limited incentives to formally regulate environmental impacts. Even in cases where regulations exist, the capacity to manage or impose laws can be limited.

Contamination from toxics presents a unique problem. Pollution from heavy metals — through processes such as battery recycling, natural resource extraction, and electronic waste recovery and disposal — often goes unnoticed.^{iv,v} Limited regulatory policies as well as the ubiquity of small-scale informal practices make identifying active and legacy contaminated sites a challenge for intervening policy and healthcare professionals.

Lack of best practices in unregulated and small-scale industries often lead to an increased risk of exposure to toxicants. The practice of artisanal gold mining typically involves panning gold-containing rock amalgams with elemental mercury. This amalgam is then heated with a blowtorch to volatize the mercury (Hg) and leaves behind both gold and some residual Hg.^{vi} Large amounts of Hg vapor are deposited locally and can be re-emitted from water and soil surfaces or can be methylated, bioaccumulate, and biomagnify in food chains.^{vii,viii} Surface soils, water bodies, and sediments are the major biospheric sinks for Hg.^{ix} Artisanal gold mining often involves the use of elemental mercury, which poses significant risks for human health as mercury is a potent neurotoxin.^x

Lead and other metals such as cobalt and manganese can be hazardous to human health as a result of unregulated and often informal industries. In particular, lead contamination can lead to numerous adverse health outcomes such as cognitive impairment, anemia, hypertension, kidney damage, and, in extreme cases, death.^{xi} The source of exposure is often traced to gasoline, paint, air, water, interior dust, soil and food.^{xii} In areas within the vicinity of mining and industrial establishments, ingestion of soil and dust contaminated with heavy metals is a primary source of lead exposure.^{xiii,xiv} Lead can also be ingested via drinking water when soluble forms are present in surface or groundwater.^{xv} The risks of exposure to such heavy metals are high.

Zamfara State of northwestern Nigeria experienced a catastrophic lead poisoning event in 2010 that was associated with artisanal gold ore processing.^{xvi} In May 2010, the Nigerian Federal Ministry of Health convened a multidisciplinary team to support Médecins Sans Frontières (MSF) in investigating the problem. The team of experts

included representatives from the Nigerian Field Epidemiology and Laboratory Training Program (NFEELTP), Zamfara State Ministry of Health, United States Center for Disease Control (CDC), and the World Health Organization (WHO).

Prior to MSF involvement, approximately 400 cases of child deaths were reported.^{xvii} Between May and June 2010, the MSF team surveyed the two most affected villages and confirmed lead from gold ore processing inside major family compounds as the cause.^{xviii} Among these two villages, 25% of children under 5 years of age had died during the previous 12 months.^{xix} Two-thirds of households reported processing gold ore inside family compounds, and soil-lead levels in 85% of family compounds exceeded the U.S. Environmental Protection Agency (EPA) soil-lead standard [400 parts per million (ppm)] for areas of bare soil where children play.^{xx} The Zamfara disease outbreak is perhaps the most severe contemporary example of the associated health risks of heavy metals contamination.

As mentioned, a challenge to identifying toxic sites in the informal sector is that they typically operate with little regulatory oversight. In the Zamfara case, these informal industries operated inside village homes. Identifying and assessing unregulated operating sites requires funding and training for individuals who can work on the ground to evaluate site contamination levels. Pure Earth and Johns Hopkins University have developed a tool for rapid assessment in low- and middle-income countries to address some of these challenges.

Likely the most comprehensive database to date in this area is that maintained as part of the Toxic Sites Identification Program (TSIP) of Pure Earth, formerly Blacksmith Institute.^{xxi} As of December 2015, approximately 3,200 sites across 49 countries have been identified, putting an estimated 63 million people at risk of exposure to toxic pollution. A modified Hazard Ranking System (HRS) developed by Pure Earth utilizes a predefined methodology to determine the population at risk. Heavy metals represent the vast majority of pollutants found in the TSIP database, followed by persistent organic pollutants (POPs) and pesticides. Using data collected as part of this effort Chatham-Stephens et al. estimate as many as 828,000 Disability Adjusted Life Years (DALYs), a measure of overall disease burden that incorporates both years of life lost and years of life disabled, result from exposures to contaminated sites in India, Indonesia and the Philippines alone.^{xxii} The estimates indicate that point-source pollution poses a significant and credible health risk to low- and medium-income countries.

Risk assessment of chemical hazards focuses on addressing pathways of human exposure, namely inhalation, ingestion, or dermal contact. To confirm this pathway, environmental or biological sampling must be conducted, and detailed information about the pollutant, relevant pathway of exposure, and population impacted must be gathered. U.S. EPA uses a similar, albeit more robust, model to assess contaminated sites in the United States. This U.S. EPA Hazard Ranking System also requires information on spatial attenuation, pollutant persistence, migration potential, and likelihood of future release. Gathering all of this information can be prohibitively costly and time consuming

in low- and middle-income countries. Within this context, the TSIP was developed to carry out rapid risk assessments that are cost-effective in low-resource settings.

Contaminated sites are identified through several methods including knowledge and expertise of local staff, investigation of previously identified legacy sites, collaboration with local governments or research organizations, and nominations. In Ghana, Pure Earth has a strong partnership with a local nongovernmental organization and a strong relationship with both the Ghana Environmental Protection Agency (EPA) and Ghana Health Service. Therefore, the majority of sites in Ghana found in the TSIP database are a direct result of local knowledge, partnerships, and expertise.

Once a potential site has been identified, a network of local environmental investigators conducts on-site investigations, and the data is reviewed by an experienced environmental health professional for quality control before approval. All assessed sites go through several levels of formal review with ongoing communication between field staff, research staff, and quality control staff to identify and rectify any inconsistencies or inaccuracies in the data. The program focuses entirely on sites where there exists a reasonable suspicion that point source pollution might be affecting human health. Initial lists of sites that meet this general description are developed, and visits are scheduled to sites based on their presumed severity.

TSIP has shown to be a useful tool in tracking toxic site identification and assessment. Yet, TSIP has been able to assess only a fraction of all contaminated sites worldwide. It is estimated based on analysis of the data and trends in the TSIP database that as many as 200 million people are effected by toxic pollution. The novel statistical approaches used in this study applies TSIP data to estimate the number of contaminated sites throughout Ghana.

The West African nation of Ghana (area 238,535 km²) is a lower middle-income country that is home to 26.8 million residents.^{xxiii} The population density is highest in the southern half of the country, where urban centers such as Kumasi and Accra attract more economic opportunities than the rural areas of the north. Chemical production and metals smelting and processing are among the largest contributors to the formal industrial economy. Car battery recycling, artisanal small-scale gold mining (ASGM), and scrap recycling are the most abundant industries of the informal sector.^{xxiv,xxv} These informal industries often operate with less regulatory oversight than the formal sector.

TSIP has served as a basis for identifying and characterizing contaminated sites globally. This study makes use of the site identification protocol designed under TSIP to focus on site assessments throughout Ghana's administrative districts. It then tests two approaches to extrapolating site identification data to estimate the number of contaminated sites nationwide.

Methods

Alternative Methodologies

This study uses two alternative methodologies to estimate the number of heavy metals contaminated sites in Ghana. While research on heavy metal-polluting industries within Ghana is well documented (e.g. small-scale gold mining and used lead-acid battery recycling), research on the countrywide extent of pollution and potential number of contaminated sites is deficient. Therefore, this endeavor is likely the first of its kind in the literature. Alternative methods were used to show two scientifically defensible approaches to estimating the number of heavy metals contaminated sites within Ghana.

District selection

Ghana is divided into ten regions that are further subdivided into 216 administrative districts. Two regions, Upper East and Upper West, each represent less than five percent of the country's total population and were not included in the data collection process. One district from each of the remaining eight regions was randomly selected in October 2014 for analysis. The information collected from each district was then used to estimate the number of toxic sites found per region and countrywide. The following eight districts were randomly selected for inclusion into this study: Amansie West, Tano South, Abura/Asebu/Kwamankese, Afram Plains South, Ningo Prampram, Yendi, Ho, and Juabeso. Districts selected for screening are highlighted in [Figure 1](#).

All population and area data were collected from the Ghana Statistical Service (GSS).^{xxvi} GSS conducts censuses every ten years and presents data in aggregate level by district and region. The data is high quality and GSS is a well functioning public service organization in the Ghanaian government.

Toxic site screenings

A visible site identification protocol was established to effectively identify toxic contaminated sites. While this methodology targets the sampling in place of randomized techniques, it is important to note the unique conditions in which most toxic sites emerge. Informal mining and recycling of metals and scraps often occur with little regulatory oversight from the government in low-income areas and informal settlements. As well, legacy sites in industrial centers that pose no risk to human health can stand for long periods without mitigated risk treatment. Therefore, randomly sampling throughout a district to confirm toxic site status is not time or cost-effective, i.e. numerous areas such as high-income neighborhoods would produce few sites if any. Additionally, randomly sampling in areas where population will not be at risk of exposure is not a worthwhile endeavor. The visible site identification protocol was developed with these conditions in mind.

The visible site identification protocol defined two levels of toxic site identifiers: primary and secondary. The identifiers were given a scoring rubric including two (2) points for primary identifiers and one (1) point for secondary identifiers. In order to assess a potentially toxic site, investigators were instructed to review all available identifiers and only begin site assessment upon achieving a minimum required score of six (6). Site

assessments used x-ray fluorescence spectrometry (Innov-x Systems Handheld XRF Analyzer - Alpha Series 6500) to evaluate the level of contamination of various heavy metals.

The list of primary identifiers included: documentation of abandoned or legacy site status (i.e. confirmed by community or public records), tailings piles, visible particle emissions, and confirmed industry activity. Confirmed industry activity for the purposes of this study could be active or a legacy site used for mining/ore processing, battery recycling, chemical manufacturing, dye industry, electronic waste recycling, heavy industry, industrial or municipal dumpsites, lead mines, lead smelting, pesticide manufacturing, petrochemical industries, product manufacturing, recycling, ship-breaking, or tannery operations. Secondary identifiers were: visibly stressed vegetation, mechanical tools or supplies (including baghouses and filtering equipment), industrial equipment in disrepair, olfactory cues (particularly the smells of chemicals or oil), visibly stained soil (i.e. oil), and visibly-discolored water.

A local team of trained site investigators was assigned to locate and assess various potentially toxic sites throughout the eight administrative districts. Trained site investigators obtained street maps for each district and worked with local officials to strategize and plan the most effective route for mapping. Individual towns, villages, and neighborhoods were targeted. Highways and main roads between populated areas were overlooked. The purpose of the exercise was to assess contaminated sites that have an apparent pathway of human exposure.

Estimates of the number of sites found per district within these regions were determined after data collection. Statistical analysis was performed as if random sampling was performed and a variance and 95% confidence interval were determined for the mean number of toxic sites per district sampled. Standard statistical techniques were used to extrapolate the mean and variance of the sample to the entire country of Ghana.

Although statistical analysis relies on random sampling techniques, the sampling was targeted, which has likely biased our estimates of the number of toxic sites in Ghana away from zero. The size of this bias is difficult to ascertain, but we have chosen this methodology to include the widest possible corridor in our 95% confidence interval to reflect both the variation in the sampling results and the uncertainty regarding the assumption of independence between the samples. Data collection occurred from January to May 2015.

Data Cleaning and Inclusion of Toxicants

The collected data set was truncated to include only sites where the key pollutant was a heavy metal with credible health impacts, and sites where the level of contamination exceeded U.S. EPA standards or equivalent for exposure. Raw data was compared against U.S. EPA standards three times to ensure quality control. These criteria narrowed the focus of the dataset to include the toxicants lead, chromium, arsenic, cobalt, and manganese at concentrations that would pose a threat to human health. The

five heavy metals are each heavily cited in the literature as causing adverse health effects from exposure and intake at relatively low quantities. Mercury, also a key toxicant, was not included in the final data capture due to measuring limitations in the equipment used. The focus on heavy metals also limits the scope of the analysis. Therefore, the results are not an estimate of all contamination countrywide, but rather an estimate solely of heavy metals contamination.

Cluster Random Sampling Analysis

A first attempt at extrapolating the collected data from the district level to the regional level used a cluster random sampling method. In this approach the total estimate of toxic sites per region is the average of the number toxic sites estimated by area and the number of toxic sites estimated by population. Site estimates by area are calculated using the number of sites found in a given sampling district (x_i) divided by the total area of the district ($Area\ Dst_i$). The result is then multiplied by the total area of the region to which the district belongs ($Area\ Rgn_i$). Estimates for population are calculated in the same manner, replacing area figures with population totals for each respective district and region. Table 1 contains information for area and population numbers by region.

Due to budgetary and time constraints, not every region contained a district that was mapped as part of this exercise. These ‘unmapped’ regions that are not sampled are still included in the final site extrapolation by totaling the number of sites found in all mapped districts and dividing this number by the total area of the mapped districts. The result is then multiplied by the area of the unmapped region in question. Estimates for population are calculated in the same manner, replacing area figures with population totals for each respective district and region. A final value for the unmapped regions is achieved by calculating the average of the number toxic sites estimated by area and the number of toxic sites estimated by population. A total estimate of toxic sites countrywide (T) is equal to the sum of the sampled and not sampled extrapolations.

Regional and Countrywide Calculations

$$T = u + v$$

$$\text{where } u = \frac{1}{2} \left[\sum_{i=1}^N \left(\frac{x_i}{Area\ Dst_i} \right) * Area\ Rgn_i + \sum_{i=1}^N \left(\frac{x_i}{Pop\ Dst_i} \right) * Pop\ Rgn_i \right]$$

$$\text{and } v = \frac{1}{2} \left[\sum_{i=1}^M (Avg\ Sites\ Per\ Area\ Sampled) * Area\ Rgn_i + \sum_{i=1}^M (Avg\ Sites\ Per\ Pop\ Sampled) * Pop\ Rgn_i \right]$$

u is the ‘sampled district extrapolation’

v is the ‘not sampled district extrapolation’

x_i is the number of sites found in district i

N is the number of regions sampled

M is the number of regions not sampled

Area Dst_i is the area of district *i*

Area Rgn_i is the area of region *i*

Pop Dst_i is the population of district *i*

Pop Rgn_i is the population of region *i*

Simple Random Sampling Analysis

q

A second analysis estimated the total number of toxic sites per region using a weighted measure for three categories: number of sites found by region, area by region, and population by region. Each category was weighted equally. A total estimate of toxic sites countrywide (*T*) was calculated using the arithmetic mean number of confirmed toxic sites combined for all districts (\bar{x}) and the total number of districts (*b*).

The weighted estimates per region (*R_i*) were calculated each by dividing the product of the estimated total of toxic sites countrywide and the number of toxic sites for the sampled district, by the product of a categorical factor and statistical weight (33.3%). For the number of sites found per region, the categorical factor was the total number of sites identified across all districts. In the area-size analysis, the total area of Ghana in km² determined the categorical factor. For the population estimate, this study used Ghana's total population as the categorical factor. The weighted estimate for each region combined the results from each categorical analysis to determine a total number of hazardous sites. The base estimate for total sites was achieved by multiplying the total number of districts in Ghana and the mean number of confirmed toxic sites identified.

Regional and Countrywide Calculations

$$T = \bar{x} * b = \sum_{i=1}^P R_i$$

where $R_i = \frac{T}{3} \left[\left(\frac{x_i}{\sum_{i=1}^N x_i} \right) + \left(\frac{\text{Area Rgn}_i}{\text{Total Country Area}} \right) + \left(\frac{\text{Pop Rgn}_i}{\text{Total Country Area}} \right) \right]$

R_i is the estimated number of contaminated sites in region *i*

x_i is the number of sites found in district *i*

P is the total number of regions

Results

The team conducted data analyses between July and August 2015. In total, 72 toxic sites were confirmed via XRF analysis. For the purpose of this study, a confirmed toxic site was defined as having a soil sample containing one of our predefined heavy metals at a concentration above U.S. EPA standards (or equivalent). The breakdown of

contaminated sites by pollutant can be seen in [Figure 2](#). Lead samples were, on average, around 2,000 PPM (the U.S. EPA standard for lead in residential soil is 400 PPM). The highest lead reading in a mixed-use industrial/residential area was 97,835 PPM — more than 244 times the residential standard and 81 times the industrial standard. Chromium samples were typically below 1,500 PPM. The highest chromium sample recorded in the study was 4,216 PPM — more than 19 times the residential standard of 220 PPM. Arsenic samples were typically below 300 PPM. The highest sample recorded was 5,661 PPM — more than 470 times the standard for arsenic in residential soil.



Photos taken during the data collection phase. Local residents and livestock adjacent to a contaminated site; Children playing on an informal garbage dump; The remnants of tires at a burn site.

Results Using Cluster Random Sampling

Analysis from the cluster random sampling yielded totals of 1,521 and 1,601 contaminated sites for estimates based on area (km^2) and population, respectively. When combined for a fifty-percent mixture of area size and population, the mean number of contaminated sites was 1,561 (95% CI 1,135 - 1,987), with a range of sites between 8 and 311 by region.

Results Using Simple Random Sampling

The simple random sampling technique estimates 1,944 existing contaminated sites (95% CI 812 - 3,075) in Ghana. At the regional-level the range of estimated toxic sites is 51 - 444.

Discussion and Conclusion

Significance of Results

The extrapolation techniques outlined in this study are the first known in an attempt to estimate the scale of heavy metals contaminated sites countrywide based on district-level data. Our current extrapolation shows that there are an estimated 1,561 to 1,944 heavy metals contaminated sites within Ghana (CIs: 812 to 3,075). This result is approximately nine times the number of contaminated sites previously documented by the Pure Earth Toxic Sites Identification Program. Identification of toxic sites continues to be effective primarily through word of mouth and footwork. The extrapolation offers insight into the potential magnitude of heavy metals contaminated sites nationwide.

Ghana has made notable efforts to curtailing the impacts from heavy metals exposure. The Central Government has banned lead in paints and in 2003 successfully phased out lead in gasoline. In the same year, Ghana ratified the Basel Convention in support of controlling the transboundary movement of hazardous wastes and waste disposal. Yet, like in many LMICs, ensuring capacity to address the scale of contamination problems will require policy enforcement, funding, and thorough transitioning to best practices where necessary. Information regarding existing numbers of toxic sites and estimated projections are useful in determining a stepwise plan toward further site identification and eventual mitigation.

Cases such as those seen in Zamfara demonstrate the potential risks of high-level exposure to heavy metals. The costs of such events — both economic and at the micro, household-level — are great. However, prevention and early mitigation have demonstrated cost-effective solutions.

Study Limitations

Due to limitations with the XRF sampling equipment, mercury, a highly toxic transition metal, was not included in the sampling analysis. The Agency for Toxic Substances and Disease Registry (ATSDR) suggests a health safety limit of 1 ppm for elemental mercury. Sampling equipment was unable to detect mercury levels below 15 ppm.



Photos taken during the data collection phase. From the top: Used lead-acid battery recycling site; Electronic waste recycling site; Small-scale gold mining site.

Ghana's rich gold ore deposits make small-scale mining a viable economic source for many low-income families. In 2013, the country's total gold output stood at 97.8 tons.^{xxvii} One third of Ghana's annual gold production comes from the artisanal and small-scale industry and almost all of the gold is exported.^{xxviii} The estimates from this study are therefore an underestimate of the total potential heavy metals contaminated sites.

Conclusion and Recommendations

Our current extrapolation shows that there are an estimated 1,561 to 1,944 heavy metals contaminated sites within Ghana, excluding the transition metal mercury (CIs: 812 to 3,075). This is approximately nine times the number of contaminated sites previously documented by the Pure Earth Toxic Sites Identification Program. Such identification of contaminated sites allows health and environmental ministries to better allocate limited resources for improved health surveillance and remediation. However, due to the costly and time-consuming nature of toxic site identification and analysis, contaminated site extrapolations prove to be a valuable tool. The novel and simplistic statistical approaches utilized in this study can be replicated in other nations to further understand the prevalence of contaminated sites and influence policy accordingly.

Tables and Figures

Figure One: Map of Ghana

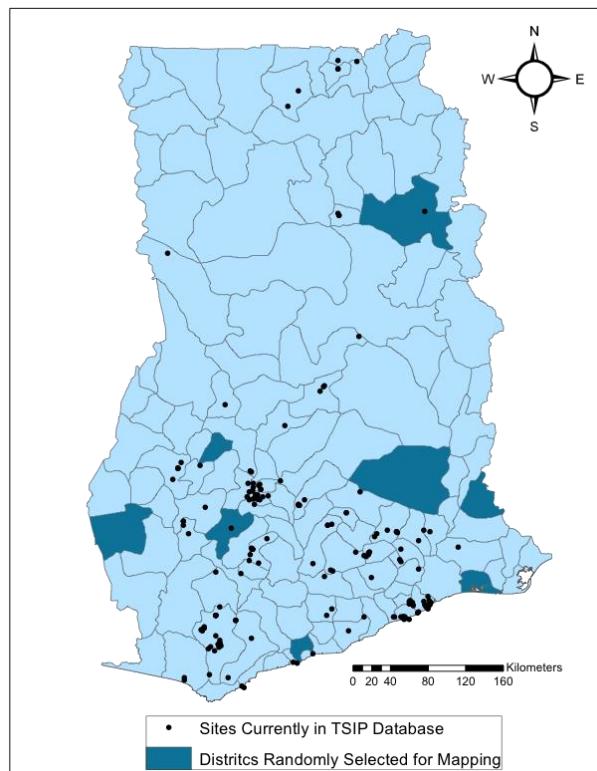
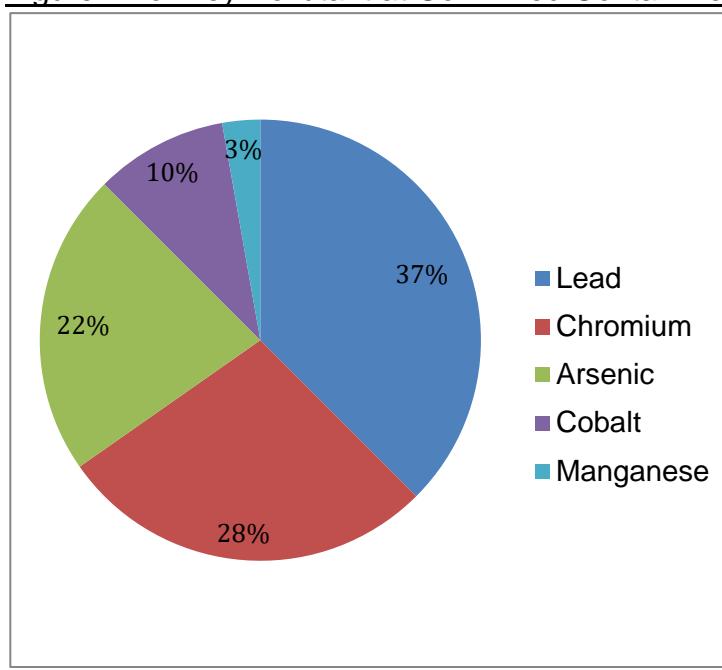


Figure Two: Key Pollutant at Confirmed Contaminated SitesTable One: Regional Characteristics and District Selection

Region	Number of Districts	Area (Km ²)	Population (2010 census)	Population Weighting (%)	Population Density (Inhabitants/Km ²)	Number of Districts Chosen
Ashanti	30	24,889	4,780,380	19.39%	192.1	1
Brong-Ahafo	27	39,557	2,310,983	9.37%	58.4	1
Greater Accra	16	3,245	4,010,054	16.26%	241.8	1
Central	20	9,826	2,201,863	8.93%	136.3	1
Eastern	26	19,323	2,633,154	10.68%	1235.8	1
Northern	26	70,384	2,479,461	10.06%	35.2	1
Western	22	23,921	2,376,021	9.64%	103.0	1
Upper East	13	8,842	1,046,545	4.24%	99.3	0
Upper West	11	18,476	702,110	2.85%	118.4	0
Volta	25	20,570	2,118,252	8.59%	38.0	1
Total	216	239,033	24,658,823	100%	-	8

Table Two: Number of Contaminated Sites By District

District	Area (Km²)	Population	Population Density (Inhabitants/Km²)	Number of Confirmed Contaminated Sites
Amansie West	1,197	134,331	112.2	7
Tano South	699	78,129	111.7	7
Abura/Asebu/Kwamankese	368	117,185	318.4	6
Afram Plains South	4,882	218,235	44.7	1
Ningo Prampram	1,553	122,836	79.1	7
Yendi	4,090	199,592	48.8	21
Ho	978	271,881	278.1	5
Juabeso	2,050	111,749	54.5	18
Total				72

Table Three: Cluster Random Sampling Analysis

Region	Number of Confirmed Contaminated Sites	Regional Extrapolation by Area	Regional Extrapolation by Population	Final Extrapolation (50% Area, 50% Population)
Ashanti	7	145.52	249.11	197
Brong-Ahafo	7	395.88	207.05	301
Greater Accra	6	160.19	121.65	141
Central	1	3.96	12.07	8
Eastern	7	14.63	228.52	122
Northern	21	361.38	260.88	311
Western	18	105.20	38.96	72
Upper East	0	209.99	382.72	296
Upper West	0	40.25	60.09	50
Volta	5	84.10	40.31	62
Total	72	1,521.10	1,601.35	1,561

Sample variance: 32,496; 95% CI (lower bound): 1,135; 95% CI (upper bound): 1,987

Table Four: Simple Random Sampling Analysis

Basis	Countrywide Extrapolation
Districts Sampled	8.00
Mean sites per sample	9.00
Standard Deviation of the samples	6.82
Standard Error for mean	2.37
t-table value (5%)	2.36
95% CI (lower)	3.39
95% CI (upper)	14.61
Total Districts	216
Total Sites Estimated	1,944
Variance of total	228,852
95% CI (lower bound)	812.8
95% CI (upper bound)	3075.2

Table Five: Regional Site Estimates from Simple Random Sampling

Region	Number of Districts	Estimated Sites Weighting	Area Weighting (Km ²)	Population Weighting	Weighted Regional Estimate
Ashanti	30	63	67	125	255.21
Brong-Ahafo	27	63	107	60	230.54
Central	20	54	27	62	142.64
Eastern	26	9	52	69	130.09
Greater Accra	16	63	9	105	176.44
Northern	26	189	191	65	444.51
Volta	25	45	56	55	156.04
Western	22	162	65	62	288.85
Upper East	13	0	24	27	51.28
Upper West	11	0	50	18	68.41
Total					1,944.00

Equal weights (33.333%) were given to each factor

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