Assessing Levels of Lead Contamination in Soil and Predicting Pediatric Blood Lead Levels in Tema, Ghana

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Background. Tema, Ghana’s main industrial city, has many areas that are suspected to be contaminated by lead. Elevated lead levels can affect, among many other issues, mental development, kidney function and blood chemistry. Children are particularly at risk.

Objectives. The objective of this study was to determine the concentration of lead in soil from selected sites in Tema and how these levels relate to local pediatric blood lead predictions.

Methods. A total of 47 surface soil samples were taken from 9 different sites. Energy dispersive X-ray technique was employed to determine the levels of lead. Pediatric blood lead levels were estimated using the Integrated Exposure Uptake Bio-Kinetic Model For Lead in Children, developed by the U.S. EPA.

Results. The study revealed that the selected sites are highly contaminated by lead. In particular, the concentration of Pb in soil at a used lead acid battery recycling facility exceeded regulatory limits for industrial soil as set by the U.S. EPA. The model for predicting concentrations of lead in the blood of age-specific children showed extremely high probabilities of BLLs exceeding regulatory limits.

Conclusions. Based on the results of soil testing, sites that were expected to reveal lead exposure positively demonstrated high levels of contamination, in some areas exceeding U.S. and other national regulatory limits. This information is expected to help authorities make informed clean-up decisions.

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the vicinity of mining and industrial establishments, ingestion of soil and dust contaminated with heavy metals is a primary source of lead exposure.\(^4\) It can also be absorbed through the skin if people come into direct contact with contaminated soil and from drinking water when soluble forms are present in surface or groundwater.\(^5\)

**Materials and Methods**

Several predictive models for assessing human exposure to lead have been developed over the past few decades.\(^7-11\) The Integrated Exposure Uptake Biokinetic Model for Lead in Children—Windows version (IEUBKwin) was used to predict the pediatric blood lead levels (BLL) in this work. The model utilizes 4 inter-related modules (exposure, uptake, biokinetic, and probability distribution) to estimate blood lead levels in children exposed to lead-contaminated media.

IEUBKwin allows the user to estimate levels for a hypothetical child or population of children. The geometric mean BLL is predicted from available information about the child’s or children’s exposure to lead. From this distribution, the model estimates the risk (i.e., probability) that a child or a population of children will have their BLL concentrations exceed a certain level of concern (typically 10 µg/dl).\(^5\) Although the IEUBKwin has been used in several countries to estimate pediatric blood levels, no such study has been undertaken in Ghana.\(^12-14\)

As stated previously, Ghana does not currently have safe reference levels for pediatric blood lead; a generic value of 10 µg/dl was used for comparison.

A total of 9 sampling sites were selected. These included: 2 steel processing plants in a heavy industrial-use area; a used-lead acid battery (ULAB) recycling plant; mechanic workshops in a residential community; a waste-oil recycling plant at a light industrial-use area; a municipal waste disposal site which accepts both industrial and domestic waste; a municipal playground; a school park in a residential area; and the Ashaiman Fitter Line, which comprises residential facilities, schools, auto workshops and scrap yards. Currently, there are no known lead poisoning episodes that can be traced directly to the sites under study.

The sampling sites are shown in Figure 1.

The 47 top surface soil samples were collected using previously cleaned plastic spoons from the 9 sampling locations. The samples were collected and kept in separate pre-cleaned and labeled Ziploc polythene bags that were then sent to a laboratory for analysis. The samples were air-dried and sieved using 200 µm-sized mesh, then pulverized. Of the pulverised samples, 10 g were made into thick pellets of 2.5 cm in diameter using a hydraulic press with an applied load of 10 metric tons.\(^15\)

The total lead concentrations were determined using energy dispersive X-ray fluorescence (EDXRF) with a secondary target arrangement. EDXRF provides a rapid and non-destructive method for the analysis of trace and major elements in the samples.\(^16,17\) The Compact 3K5 X-ray Generator EDXRF Spectrometer which was used for the elemental analysis had a molybdenum anode and operated at 800W (40kV and 20mA). The irradiation was done using a molybdenum secondary target arrangement coupled to a Peltier-cooled silicon drift detector (SDD) with a 12.5 µm beryllium window thickness. The SDD has a resolution of 136 eV for 5.9 KeV x-ray energy. Sample pellets were placed at an angle of 45° to the primary beam and irradiated for 600 seconds. IAEA Soil 7 Standard reference material was used for the validation of the analytical procedure. The EDXRF Ka line intensities were measured for all

### Abbreviations

| Symbol | Description |
|--------|-------------|
| µg/dl  | Microgram per deciliter |
| µm     | Micrometer |
| BLL    | Blood lead level |
| EPA    | Environmental Protection Agency |
| IQ     | Intelligence quotient |
| eV     | Electron volts |
| keV    | Kiloelectron volts |
| EDXRF  | Energy dispersive X-ray fluorescence |
| g      | Gram |
| ULAB   | Used-lead acid battery |
| WHO    | World Health Organization |
elements except lead and mercury, for which the Lb line intensities were measured.\textsuperscript{17} MCDWIN- (MC-A\textsuperscript{(1)}) software was employed for data collection. The linear least squares fitting technique of the AXIL software program was used for the spectrum de-convolution.\textsuperscript{18,19} The evaluation model used for quantification of the elements was the fundamental parameters approach in the IAEA’s Quantitative X-Ray Analysis System package.\textsuperscript{20} The lead concentrations obtained were subjected to IEUBKwin analysis to produce the pediatric BLL-concentration predictions.

**Results and Discussion**

The study was designed as a routine environmental monitoring project to assess the levels of contamination based on prior knowledge of activities undertaken at the chosen sites. The concentrations of lead obtained from the various sites are shown in Table 1.

Lead was detected in all soil samples from all sampling sites, with the highest and lowest levels obtained at Gravita (GVTA), a lead-acid battery recycling site, and the Community 8 school yard, respectively. The high concentration of lead found at GVTA can be compared to levels observed at Thiaroye Sur Mer, in Dakar, Senegal (400,000 mg/kg) where similar activity is carried out.\textsuperscript{21} About 70% of the samples from the waste dump (WD), Tema Steel (TS), Special Steel (SS), Community 9 light industrial area (LI 9), Ashaiman Fitter Line (AFL) and GVTA had lead concentrations exceeding the optimum and action values of 85 mg/kg and 830 mg/kg, respectively, of the new Dutch list.\textsuperscript{22} This can be attributed to the ongoing activities (waste dumping with continuous burning, metal processing/recycling, auto workshops, etc) at these sites. Community 12’s light industrial area (LI 12), the playground (PG) and Community 8’s school yard (C8) had lead concentrations below the optimum and action levels from the new Dutch list.

The lead concentration at SS and GVTA, both located within the industrial enclaves of Tema, exceeded...
the U.S. EPA average for industrial soil by thousands of orders of magnitude. The lead concentrations at AFL, located within a residential area, exceeded the EPA levels for soil concentration by over 200%. Within the vicinities of the sampling area, children were most often found either playing or engaged in some form of social activities, increasing the chances of exposure to lead. At the waste dump site, where a concentration of 715.7 mg/kg was recorded, children as young as 2 years old—the offspring of scavengers—could be found, sometimes even engaged in the activity of their parents.

It is based on the above that the IEUBKwin was used to predict the BLL for children between the ages of 0.5 to 7 years. The models conservatively assume that soil dust is the only means by which children come in contact with lead. This assumption makes it easy to determine BLL due to soil dust and effectively plan mitigation measures. The result of the IEUBKwin model analysis is shown in Table 2.

### Table 1 — Concentration of Pb from Selected Sampling Sites

| Site                          | Pb Concentration (in mg/kg) |
|-------------------------------|-----------------------------|
| Kpone Waste Dump (WD)         | 715.7                       |
| Tema Steel Processor (TS)     | 277.2                       |
| Special Steel Processor (SS)  | 4281.6                      |
| Playground (PG)               | 16.7                        |
| Community 9 Light Ind. Area (LI 9) | 192.0                     |
| Community 12 Light Ind. Area (LI 12) | 57.6                     |
| Ashaiman Fitter Line (AFL)    | 1051.1                      |
| Community 8 School Yard (C8)  | 16.7                        |
| Gravita (GVTA)                | 653,645                     |

### Table 2 — Estimated Blood Levels (µg/dl) for Children

| Age Group | Sampling Sites | 0.5–1 | 1–2 | 2–3 | 3–4 | 4–5 | 5–6 | 6–7 | % exceedance |
|-----------|----------------|-------|-----|-----|-----|-----|-----|-----|--------------|
|           | AFL            | 10.1  | 11.9| 11.1| 10.7| 8.8 | 7.3 | 6.3 | 43.42        |
|           | C8             | 0.2   | 0.3 | 0.2 | 0.2 | 0.2 | 0.1 | 0.1 | 0.00         |
|           | Gvta           | 349.2 | 352.8| 354.0| 354.1| 333.7| 316.6| 308.6| 99.4         |
|           | Li 12          | 0.7   | 0.9 | 0.8 | 0.7 | 0.6 | 0.5 | 0.4 | 0.00         |
|           | Li 9           | 2.3   | 2.7 | 2.5 | 2.4 | 1.9 | 1.5 | 1.3 | 0.04         |
|           | Pg             | 0.2   | 0.3 | 0.2 | 0.2 | 0.2 | 0.1 | 0.1 | 0.00         |
|           | Ss             | 26.2  | 30.1| 28.8| 28.5| 24.9| 21.8| 19.6| 97.45        |
|           | Ts             | 3.2   | 3.8 | 3.5 | 3.3 | 2.6 | 2.1 | 1.8 | 0.39         |
|           | Wd             | 7.4   | 8.7 | 8.2 | 7.8 | 6.3 | 5.2 | 4.5 | 19.92        |

**NB:** Blood lead level of 10µg/dl is used as generic regulatory limit.
Currently Ghana does not have safe reference levels for pediatric blood lead; a generic value of 10 µg/dl was used. This still gives compelling reason for action although applying the current CDC level of 5 µg/dl would have made the situation at the sites more extreme.5

In Table 2, it can be seen that about 43% of infants and children exposed to lead in soil dust from AFL are likely to have blood lead levels exceeding the generic regulatory limit. At WD, where children live with scavenging parents, it is estimated that about 20% are likely to have BLLs exceeding the limits. Both GVTA and SS recorded values significantly above the regulatory limits. The GVTA site resulted in predictive BLLs above 300 µg/dl for 99% of exposed children. The predictive pediatric BLL observed could easily cause severe ill-health effects if children were allowed unfettered access to the site.

An adult BLL value of 7.7 µg/dl was predicted at SS, quite below the set limit, while at GVTA, the predicted adult BLL value was 942.7 µg/dl. The concentrations of BLL found in this study were comparable with levels found in other works as reported by von Braun et al, Mielke et al, and Laidlaw and Taylor.13-15

Conclusion

This study demonstrated that all the sampled sites showed some levels of lead contamination. Areas found with significantly elevated levels are TS, SS, LI 9, AFL and GVTA, all having levels above the limits set by the Dutch list. The lead concentration in the soil at GVTA is also seen to exceed the regulatory limits for industrial soil as set by the U.S. EPA. The IEUBKwin model for predicting the concentration of lead in the blood of age-specific children showed very high probability of BLLs exceeding the regulatory limits in both children and adults at some of the sites. GVTA, which is a lead-acid battery recycling site, recorded the highest contamination levels with BLL concentration of over 300 µg/dl for all age groups with 99% chance of exceedances. It is recommended that any plans to remediate the contaminated sites should take into consideration the pediatric BLL and the protection of infants and children to reduce child morbidity and mortality.
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