Determination of heavy metals in dust from selected nursery and kindergarten classrooms within the Kumasi metropolis of Ghana

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Abstract: The exposure potential of children in nursery and kindergarten schools to metals in dust in the Kumasi Metropolis was studied. Dust samples from 20 selected schools were analyzed for heavy metal levels using atomic absorption spectrophotometry. The results showed that concentrations were in the range of below detection −9.710 μg/g for cobalt, below detection to 33.291 μg/g for chromium, below detection to 41.909 μg/g for lead, below detection to 1.383 μg/g for mercury, while cadmium levels were below detection for all samples. The mean levels of metals therefore decreased in the order: Cr > Pb > Co > Hg and Cd. Geographical variation correlated with heavy metal load. Health risk assessment using hazard quotient (HQ) and hazard index (HI) calculations indicated that ingestion contributed more to exposure than dermal contact. However, the values obtained by HQ and HI do not pose any immediate health risk but the cumulative effect is a matter of concern.

Subject: Earth Sciences; Environment & Agriculture; Environmental Studies & Management

Keywords: dust; classroom; heavy metals; health risk

1. Introduction
Dust composition has a potential effect on human health. Urban surfaces receive deposits from sources such as vehicular emissions, industrial discharges, domestic heating, waste incineration, and other...
anthropogenic activities through atmospheric transport and local activities (Bris et al., 1999; Christoforidis & Stamatis, 2009; Groleenec, Lucas, Mandin, & Le Bot, 2012; Mingkui & Hao, 2009). Both outdoor and indoor dust have different compositions and are likely to pose health problems through direct inhalation (principally the finest particle sizes e.g. <10 μm) and unintentional consumption due to hand-to-mouth contact by children. Consumption of poorly washed fruits and vegetables are also ingestion routes of dust exposure (<250 μm) (Lorenzi, Entwisie, Cave, & Dean, 2011). Heavy metals are usually non-degradable and their homeostasis mechanism is not well understood. Thus, elevated levels of heavy metals are a potential threat to life. They may accumulate in the fatty tissues of the human body and affect the central nervous system. They may also disrupt the normal functioning of the body’s internal organs and sometimes act as cofactors in other diseases (Tong & Lam, 2000). Metals released into the environment may find their way into classrooms possibly through wind action of dust within the school compounds as the kids play around and in dust on footpaths along which they walk to school (Kurt-Karakus, 2012). These metals in dust from kindergarten and nursery classrooms may further accumulate on the skins of the children and other teaching aids the children interact with (Darus, Nasir, Sumari, Ismail, & Omar, 2012). The interaction of children with their classroom environment results in direct interaction by dermal contact or through ingesting (Darus et al., 2012). Young children are more likely to ingest large quantities of dust than adults because of the behavior of licking non-food objects and repetitive hand/finger sucking. Children have a much higher absorption rate of heavy metals from the digestive system and higher hemoglobin sensitivity to heavy metals than adults (Meza-Figueroa, De la O-Villanueva, & De la Parra, 2007).

There is no record of research on the levels of metals in dust from nursery and kindergarten classrooms within the Kumasi metropolis. It is therefore necessary to determine the levels and assess the health implications of the metals on the pupils.

2. Materials and methods

2.1. Study area

2.1.1. Sampling and analysis
Dust samples were collected randomly from nursery and kindergarten schools in the Kumasi metropolis (Figure 1). A total of 20 samples were collected using a small plastic brush (20-cm long) and a small stainless steel (50 ml size) scoop and stored in labeled brown paper envelopes. The dust samples obtained were stored at room temperature in the laboratory.

2.1.2. Sample preparation
Dust samples were air dried at room temperature for 48 h, ground with mortar and pestle. The samples were then passed through a 250 μm sieve to remove the coarse dust components. A mass of 1.0 g of oven-dried lump-free dust samples were subjected to acid digestion using aqua regia, cooled, filtered through No. 42. Whatman filter paper, and analyzed using atomic absorption spectrophotometry (AAS).

2.1.3. Atomic absorption spectrophotometer (AAS) determination and quality assurance
Standard solutions of the heavy metals of interest (Sigma–Aldrich) were prepared and analyzed to obtain calibration curves. The analyte metals (Co, Cr, Hg, Pb, and Cd) were identified with the accurate detection of absorbance of standards. Quantification of heavy metals was obtained using the external calibration curves, and calculations of analyte concentrations were expressed as the dry weight of dust samples. For every sample, a procedural blank, a matrix-spiked sample consisting of all chemicals and matrix-spiked replicates were run to check the interference, and minimize any errors due to losses during the digestion procedure.

2.1.4. Pollution assessment indexes
Assessment of heavy metal contamination offers some insight into the levels of contamination of dust from selected nursery and kindergarten classrooms within the Kumasi Metropolis.
The pollution levels of heavy metals in the dust samples were assessed with geo-accumulation index (Igeo), contamination factor (CF), and pollution load index (PLI) as described below.

2.1.4.1. Geoaccumulation index (Igeo): The Igeo was introduced by Muller (1979) and has been used to evaluate the intensity of heavy metal pollution in dust. The Igeo was estimated with the equation below:

\[
I_{geo} = \log_2 \left( \frac{C_{m,\text{Sample}}}{1.5 \times C_{\text{ref}}} \right)
\]

where \( C_{m,\text{Sample}} \) is the concentration of the metal in the dust samples, \( C_{\text{ref}} \) is the concentration of the metal in the reference or background sample, and 1.5 is the background matrix correction factor due to lithogenic effects. The Igeo classification as proposed by Muller (1979) is summarized in Table 1.

2.1.4.2. Contamination factor. The level of contamination of the dust samples by metals was assessed with CF as proposed by Forstner and Wittmann (1983). CF was calculated as:

\[
\text{Contamination factor} = \frac{C_{m,\text{Sample}}}{C_{\text{ref}}}
\]

where \( C_{m,\text{Sample}} \) is the concentration of the metal in the dust and \( C_{\text{ref}} \) is the concentration of the metal in the reference or background sample (Forstner & Wittmann, 1983). Details on the formulae for calculation are presented in Table 2.

2.1.4.3. Pollution load index. PLI for the dust samples was evaluated by the equation below, as proposed by Tomilson, Wilson, Harris, and Jeffrey (1980).

\[
PLI = (CF_1 \times CF_2 \times CF_3 \times CF_4 \times \ldots CF_n)^{1/n}
\]
where, \( n \) is the number of metals and CF is the contamination factor of each metal in the dust sample. Details on the classification are presented in Table 3.

### 3. Results and discussion

#### 3.1. Heavy metal concentrations

The results of the analysis of the dust samples for Co, Cr, Hg, Pb, and Cd are presented in Table 4. Detection limits for the metals were 0.001 mg/g for Pb, Cr, Hg, and 0.005 mg/g for Co. Additional statistical distribution of the metals is presented in Tables 5a and 5b.

**3.1.1. Concentration of cobalt in samples**

The concentration of Co was below detection for 15 of the samples. However, the highest level of Co was 9.716 μg/g for sample FT. In addition to FT, only four schools AS, BY, EM, and DB contained cobalt. Calculation of the average cobalt concentration over the recorded values gave a concentration of 0.576 μg/g dry soil (Table 5a). This average concentration is higher than the levels obtained for all the other samples except FT. This result is in line with an earlier study by Gault et al. (2010), Gault et al. (2010) who indicated that, exposure level for Co is generally very low. And it is normally throw food or skin contact with substances containing small amounts of cobalt (Gault et al., 2010). According to Tvermoes et al. (2013) the European Food Safety Authority guideline value for non-carcinogenic effects is maintained at 600 μg Co/day. This value was based on a lowest-observed-adverse-effect level of 23 mg Co/kg daily. This dose would represent a maximum lifetime daily Co dose that would be considered “safe” for all age groups and most potentially sensitive subpopulations. The maximum permissible level of cobalt in dust is found to be 20 mg/kg (AbdulRahman, Kusag, & Hassein, 2013). Therefore, it may be said that recorded values of cobalt in this study may not pose any harm.
3.1.2. Concentration of chromium in samples
Chromium concentrations ranged from below 0.001 mg/g (detection limit) to 33.291 μg/g (Table 4). The average concentration of chromium for all the samples in this study was determined to be 9.912 μg/g of dry soil (Table 5a). Comparing to a similar work done by Darus et al. (2012) in Shah Alam Malaysia, the average concentration in the current study was two times that recorded in Shah

| Sample sites | Co  | Pb  | Cr  | Hg  | Cd  |
|--------------|-----|-----|-----|-----|-----|
| BK           | b/d | 3.530 | 11.406 | 0.0525 | b/d |
| NW           | b/d | 2.419 | 0.996 | b/d |
| AS           | 0.235 | 4.751 | 21.193 | 1.087 | b/d |
| BY           | 0.927 | 0.360 | 5.149 | 1.383 | b/d |
| AG           | b/d | 0.365 | 0.357 | 1.139 | b/d |
| PK           | b/d | 3.717 | 21.211 | 1.225 | b/d |
| OT           | b/d | 3.651 | 33.291 | 0.910 | b/d |
| AH           | b/d | 0.607 | b/d | 0.087 | b/d |
| AM           | b/d | b/d | 5.173 | 0.138 | b/d |
| DP           | b/d | 0.847 | b/d | 0.035 | b/d |
| BR           | b/d | 1.218 | 11.406 | b/d | b/d |
| AT           | b/d | 9.602 | 2.419 | b/d | b/d |
| EM           | 0.353 | 1.22 | 21.193 | 0.035 | b/d |
| FB           | b/d | 4.268 | 5.149 | 0.088 | b/d |
| AD           | b/d | 3.758 | 0.357 | 0.052 | b/d |
| AY           | b/d | 6.457 | 21.211 | 0.088 | b/d |
| SM           | b/d | 41.909 | 33.291 | 0.175 | b/d |
| FT           | 9.716 | 6.917 | b/d | 0.262 | b/d |
| OH           | b/d | 2.907 | 5.137 | 0.296 | b/d |
| DB           | 0.293 | 0.243 | b/d | 0.105 | b/d |

Note: b/d denotes below detection.

| Metal | Co  | Pb  | Cr  | Hg  | Cd  |
|-------|-----|-----|-----|-----|-----|
| Maximum | 9.716 | 41.909 | 929.204 | 1.383 | b/d |
| Minimum | b/d | b/d | b/d | b/d |
| Mean | 0.576 | 4.816 | 381.302 | 0.407 | b/d |
| Median | 0.353 | 3.591 | 357.321 | 0.156 | b/d |
| Stdev | 3.714 | 9.219 | 280.682 | 0.486 | b/d |

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| Metal | Range | Mean ± Std. Dev | Ref. |
|-------|-------|-----------------|------|
| Co    | 0.24–9.72 | 2.30 ± 3.71 | 1.29 |
| Pb    | 0.24–9.73 | 5.35 ± 9.22 | 7.91 |
| Cr    | 0.36–33.29 | 12.52 ± 10.85 | 4.67 |
| Hg    | 0.04–1.38 | 0.45 ± 0.49 | 0.26 |

Note: Ref. denotes concentration metals in reference samples.
Alam. From the results indicated in Table 4, it is obvious that the concentration of SM (33.291) is about 3.4 times greater than the average recorded in the entire study. According to Shanker, Cervantes, Lozatavera, and Avudainayagam (2005) naturally occurring Cr in soil ranges from 10 to 50 mg/kg depending on the parental material. From the results, therefore, it could be seen that the concentration of chromium measured in SM which is the highest concentration of chromium recorded is within the range of expected amounts occurring naturally in the environment. According to Christoforidis and Stamatis (2009), the source of Ni and chromium in street dust is believed to be corrosion of cars. Therefore, the concentration of chromium at SM may be attributed to the siting of automobile shops within 10 meters radius of the school premises. Since the pupils appear to share the same playground with the shop, the dust at the playground is greatly polluted with emissions from the activities of these shops.

3.1.3. Concentration of mercury in samples
The Hg concentrations in the classroom dust are displayed in Table 4. The mercury concentrations in the topsoil ranged from below detection to 1.383 μg/g, with a mean concentration of 0.408 μg/g. The average concentration of Hg in this study is four times lower when compared to a similar work by Sun et al. (2014) in 69 kindergartens in Wuhan China. Schools BR and AT however measured concentration below the detection limit of 0.001 mg/l with BY recording the highest concentration of 1.383 μg/g. Normal levels in soil range from 0.05 to 0.08 μg/g. Mercury concentrations in soil normally do not exceed 0.1 μg/g (European Union, 1998). It is obvious that sample sites AG, BY, AS, and PK recorded values over 10 times the expected amounts in soil. There was no clear link between the levels of Hg and the human activities close to the school.

3.1.4. Concentration of lead in samples
Lead concentration ranged from below detection limit to 41.909 μg/g dry soil according to the results of this study (Table 4). The average concentration of lead was found to be 4.816 μg/g of dry soil samples. Sample schools AM and NW recorded concentration below the detection limit of lead while SM recorded the highest value of 41.909 μg/g which is over eight times higher than the metropolitan average calculated from the study. From Table 4, it can also be observed that apart from AT with lead concentration of 9.602 μg/g, the remaining 18 samples recorded values lower than 10 μg/g, an indication that a concentration of 41.909 μg/g is an outlier. This very high concentration compared to the amounts measured in the other schools may be an indication of an enhancement in the release of lead into the school’s environment. According to Karim, Qureshi, Mumtaza, and Qureshi (2013), engine exhausts produced by the fuel combustion, engine wear, the wear of tires, and the associated moving parts, leaks and spills from batteries and radiators greatly account for the release of lead into the environment. Therefore, the high concentration of lead recorded at SM may be partly due to activities of auto-mechanic shops sited just about 10 m away from the school such that these shops appear to share the school compound with the children.

Pupils in SM are at risk of the effect of Pb in the environment since the concentration of Pb measured is over two times the permissible levels of 20 mg/kg (AbdulRahman et al., 2013) in dust.

3.1.5. Concentration of cadmium in samples
From the results of the study, cadmium levels were all below the detection limit of 0.005 mg/l.

3.2. Correlation analysis
The relationship between heavy metal concentrations in dust samples were analyzed using Pearson’s correlation coefficient and the results are presented in Table 3. Significant correlation was found to exist between Pb and Cr ($R^2 = 0.521$) at 0.01 levels (two tailed). This indicates that Pb and Cr might originate from similar pollution sources (Table 6). The other metals were however not correlated.
3.3. Assessment of metal pollution

Pollution measurement indicators used for the assessment of dust in the study area included geo-accumulation index, CF and PLI. Calculated values of the pollution indices are presented in Table 7.

CFs for all the heavy metals in the dust samples ranged from low contamination (CF < 1) for Co and Pb to moderate contamination (1 < CF < 3) for Cr and Hg.

All the dust samples (n = 20) recorded PLI value of 1.02 (PLI < 1) indicating that only baseline levels of pollutants are present. The geo-accumulation index (Igeo) of the metals in this study ranged from unpolluted with Co and Pb (Igeo < 0) to moderately polluted with Cr and Hg which were consistent with the previous results calculated for CF. The order of contamination with these heavy metals is; Cr > Hg > Pb > Co.

3.4. Health risk assessment

In this study, the exposures of students to heavy metal contamination through two pathways (i.e. ingestion and dermal contact) were examined.

The chronic daily intake (CDI) and non-carcinogenic risk (Hazard quotient, HQ) were calculated and the results are presented in Table 8.

From the results, the CDIingest and CDIdermal for all the metals were found to be less than unity (CDI < 1). The HQ values for ingestion and dermal contact were < 1 for Pb, Co, Cr, and Hg indicating...
that the students may not experience any significant health risk as indicated in Table 8. The hazard index (HI) is the sum of calculated HQs. HI value > 1 shows that there is a chance that non-carcinogenic effects may occur, whereas a value of HI < 1 shows no significant risk of non-carcinogenic effects. Therefore, the greater the HI values the higher the probability of non-carcinogenic effects (Kurt-Karakus, 2012; Liu et al., 2013). The HI value for the heavy metals through ingestion and dermal contact as a means of exposure was (0.623) and (0.0005), respectively. Heavy metals in dust from selected nursery and kindergarten classrooms in the Kumasi Metropolis poses no significant health risk but the cumulative effect is a matter of concern.

4. Conclusion
This study has provided data on levels of heavy metals in dust from classrooms in selected nurseries and kindergartens in the Kumasi Metropolis. Metal concentrations are quite consistent with concentrations reported for a series of locations worldwide. The mean values of the metals is in the order Pb > Cr > Co > Hg > Cd. Assessment of metal pollution indicated less contamination and health risk assessment revealed that the levels of the metals do not pose any risk to the exposed school children but the cumulative effect of continuous exposure may be harmful.

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