Ecological Risk and Human Health Implications of Heavy Metals Contamination of Surface Soil in E-Waste Recycling Sites in Douala, Cameroun

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Introduction

Due to rapid development in the 20th century, the information and communication sector is the largest and fastest growing manufacturing industry in developing nations and throughout the world.1 Rapid growth in technology has led to frequent upgrades of electronic products and a high rate of discarded obsolete products, and this has resulted in a fast growing stream of municipal solid waste in the industrialized world over the last decade.2-4 Electronic waste (e-waste) is comprised of discarded electronic/electrical equipment such as computers, cellular phones, stereos, refrigerators, air conditioners and other consumer durables.

Approximately 41.8 million tons of e-waste was generated globally in 2014, out of which 6.5 million was handled by the national electronic take-back systems.5 In order to manage e-waste, many developed countries export approximately 50% - 80% of this e-waste to developing countries (e.g., China, India, Africa) for recycling and disposal due to lower labor costs and less stringent environmental regulations.2,3 According to the Basel Action Network, a Seattle-based environmental group, an estimated 500 shipping containers with a load equal in volume to 400,000 computer monitors or 175,000 large TV sets enter Lagos, Nigeria each month and 75% of such shipments are categorized as e-waste.6

E-waste is not hazardous waste by itself, but some components of e-waste can be harmful.7 E-waste may be comprised of rubber, glass, ceramics, ferrous and non-ferrous metals, plastics, printed circuit boards and other items. Iron and steel make up a large quantity of e-waste, followed by plastics, non-ferrous metals and other components.8 Precious metals like silver, gold, platinum and palladium are present in small quantities in equipment. E-wastes are hazardous
Heavy metals are of great concern due to their toxicity, mobility and non-biodegradability in environmental media such as soil, water and air. For example, heavy metals present in soil can be washed away by rainfall and end up in water bodies in the environment; they can contaminate groundwater through leaching, especially under acidic conditions.15-18 Since local residents usually rely on surface water and groundwater for irrigation and drinking, respectively, ecological risk assessment of heavy metals in the vicinity of e-waste recycling sites is needed.

Humans are exposed to heavy metals in soil through several routes, such as ingestion, inhalation and dermal absorption. It has been estimated that adults may ingest up to 100 mg dust/day.23 Children are usually exposed to greater amounts of dust than adults as a result of pica and play behavior.22 Exposure to high levels of heavy metals can lead to acute and chronic health effects, such as damage to central and peripheral nervous systems, blood, lungs, kidneys, liver and even death.21

Based on recent studies in China, elevated amounts of heavy metals and persistent toxic substances have been found in the blood of children and workers at e-waste recycling sites.23,24

The objectives of the present study were to investigate the levels of heavy metals present in surface soils from recycling sites in Douala, Cameroon and to estimate the potential ecological effects and health risks to adults and children.

**Methods**

Makea, Ngodi and New Bell e-waste recycling sites are located in Douala, Cameroun. Makea has a population of 261,407 inhabitants, with 356,951 hectares of occupied space. The primary economic activity that takes place is informal e-waste recycling. Ngodi is approximately 265,102 hectares, with minor economic activities such as waste recycling and produce markets. There is a permanent population of 10,440 people, living directly within the area where e-waste activities take place daily. New Bell has a population of 55,587 inhabitants, with minimal economic activities such as e-waste recycling and produce markets. The area affected by e-waste site activities is approximately 233,937 hectares.
Sampling
Makea, Ngodi and New Bell are the sites with the highest concentration of e-waste recycling activities in Douala. These three sites were chosen because of the population at risk and the intensity of activities, including open burning and dismantling of e-waste. Ten composite samples were collected from each site. Sampling was done between February and June 2017 and followed the method of the United States Environmental Protection Agency (USEPA). The surface soil samples (0-20 cm depth) were collected randomly from three informal e-waste recycling sites (Ngodi, Makea and New Bell) and a control site in Douala, Cameroun using manual coring. At each sampling site, composite samples were collected in clean polyethylene bags. Samples were stored in ice-filled coolers and transported to the laboratory. The soil samples were dried and sieved to <2 mm particle size.

Sample digestion and analysis
Approximately 1.0 g of the soil sample was transferred into 50 mL digestion tubes, then 10 mL of 2 M nitric acid was added and samples were digested for 2 hours and shaken at 20 minute intervals. The digested samples were filtered into 25 mL flasks. The filtrates were diluted to the 25 ml mark with deionized water and stored in polyethylene bottles prior to instrumental analysis. The digested samples were analyzed for lead (Pb), nickel (Ni), zinc (Zn), cadmium Cd, chromium (Cr), copper (Cu) and cobalt (Co) using an atomic absorption spectrophotometer (AAS) (Buck scientific VGP 2010). Blank determination was also carried out without soil samples. The digested samples were analyzed in duplicates for quality control.

Statistical analysis
Descriptive statistics such as mean, standard deviation and coefficient of variation of heavy metals were determined using Statistical Package for the Social Sciences (SPSS) software, version 17.0 (IBM SPSS Inc., Chicago, USA).

Contamination factor and degree
In order to determine the contamination factor and degree of contamination in e-waste recycling sites, the formula of Thomilson et al. was used. The formulas for contamination factor and degree of contamination are as follows:

Equation 1

\[ CF = \frac{\text{Concentration of heavy metals in soil}}{\text{Concentration of background}} \]

Equation 2

\[ CD = \sum (CF) \]

Where CF is the contamination factor and CD is the degree of contamination.

Ecological risk assessment and potential ecological risk factor
The purpose of the ecological risk assessment is to assess the ecological effects of human activities in order to protect the environment. The assessment of the ecological risks of heavy metals in the soil samples was done using an ecological risk assessment and risk index proposed by Hakanson and reported in Huang et al. Environmental gradings by potential ecological risk index are presented in Table 1. The ecological risk factor quantitatively expresses the potential ecological risk of a given contaminant using the following equation:

Equation 3

\[ Erf = Tr \times CF \]

Where Erf is the ecological risk factor, Tr is the toxic-response factor for a given substance (the toxic-response factors for Pb, Ni, Zn, Cd, Cr and Cu are 5, 5, 1, 30, 2 and 5, respectively), and CF is the contamination factor.

Human health risk assessment
A health risk assessment is carried out by
out to estimate the type and magnitude of the exposure compared to the chemical elements present in soil. According to the USEPA methodology, risks for metal exposure are calculated by estimating direct exposure to soil. Three pathways are considered: (i) incidental ingestion of soil, (ii) inhalation of particulates emitted from soil, and (iii) dermal contact with soil. The chronic daily intakes (CDI) through the three pathways were estimated with Equations 4-6:

A. Ingestion of soil

\[ \text{Equation 4} \]
\[ \text{CDI} = \left( \frac{C_s \times IR_s \times EF \times ED}{BW \times AT} \right) \]

B. Dermal contact with soil

\[ \text{Equation 5} \]
\[ \text{CDI} = \left( \frac{C_s \times SA \times FE \times AF \times ABS \times EF \times ED}{BW \times AT} \right) \]

C. Inhalation of particulates emitted from soil

\[ \text{Equation 6} \]
\[ \text{CDI} = \left( \frac{C_s \times PEF \times IN \times EF \times ED}{BW \times AT} \right) \]

Where \( C_s \) is concentration of the heavy metal in soil, \( IR_s \) is the ingestion rate in soil, \( SA \) is the exposed skin surface area, \( FE \) is the dermal exposure ratio, \( AF \) is the soil to skin adherence factor, \( ABS \) is the dermal absorption factor, \( PEF \) is the particulate emission factor, \( IN \) is the inhalation rate, \( EF \) is the exposure frequency, \( ED \) is the exposure duration, \( BW \) is body weight and \( AT \) is the average time of exposure. The values for the parameters are given in Table 2.

The basic equation for calculating systemic toxicity or non-carcinogenic hazard for a single substance/element is expressed as the hazard quotient:

Non-cancer hazard quotient = \( \frac{\text{CDI}}{\text{RfD}} \)

Where the non-cancer hazard quotient is a unitless number that is expressed as the probability of an individual suffering an adverse effect, CDI is the sum of the chronic daily intake of a toxicant expressed in mg/kg/day from different pathways, that is, soil, water, dermal and air, and RfD is the chronic reference dose for the toxicant expressed in mg/kg/day.

As a rule, the greater the value of CDI/RfD above unity, the greater the level of concern. The values for reference
The mean concentrations of heavy metals in the soil of the e-waste management sites compared with the control site are shown in Figure 2.

**Analysis of variance of heavy metals in soil**

There was significant variation in the concentration of the heavy metals in the soil samples collected in e-waste sites in Douala (Makea, Ngodi, and New Bell), based on the one-way analysis of variance (ANOVA), as shown in Table 5.

**Ecological risk assessment and risk index of heavy metals in soil**

The results of the ecological risk assessment and risk index of heavy metals in the soils are shown in Table 6. Across all of the e-waste sites (Makea, Ngodi and New Bell), the ecological risks of Pb, Ni, Cu and Cd were very high. The Cr risk was considerable across all of the e-waste sites, but Zn evidenced a very low risk. Altogether, the computed risk index of the three sites showed a high level of risk.

**Non-carcinogenic risk of heavy metals for adults and children**

The non-carcinogenic risk for adults and children in Ngodi, Makea and New Bell was calculated and the average daily intake values are presented Table 7. The results for ingestion, inhalation and dermal pathways are all presented in terms of hazard quotient, as shown in Figure 3. In Makea, Ngodi and New Bell, children had no cancer risk for Cd, unlike adults.
Discussion

The concentrations of Pb at the three study sites were higher than at the control site and greater than permissible limits in China. Elevated mean levels of Pb in soils may eventually migrate into human systems and produce toxic effects on various systems in the body, such as the central and peripheral nervous systems, genitourinary system and reproductive system. Elevated Pb levels at the e-waste site could have resulted from burning of e-waste, such as refrigerators, computers, cables, batteries and air conditioners, among others. The mean concentrations of Ni in the soil at Makea, Ngodi and New Bell were higher than the concentration at the control site and the permissible limits in Europe and China.

The mean concentrations of Zn in the soil at Makea, Ngodi and New Bell were higher than the concentration at the control site and lower than the permissible limits in Europe and China. Zinc is an important nutritional element, but is harmful in high quantities. Large amounts of Zn can cause metal fume fever. The mean concentrations of Cd in soil at Makea, Ngodi and New Bell were higher than the concentration in the control site and the permissible limits in Europe and China. Cadmium can accumulate in the human body, especially in the kidneys. Cadmium has been associated with progressive renal tubular dysfunction. The mean concentrations of Cr in the soil at Makea, Ngodi and New Bell were higher than the concentration in the control site. Toxicity of Cr is dependent on its oxidation state. When it exists in hexavalent form, it can cause disease, such as skin rashes, kidney and liver damage and cancer. The mean concentrations of Cu in soil at Makea, Ngodi and New Bell were higher than the concentration in control site and the permissible limits in Europe and China.

### Table 5 — Analysis of Variance of Heavy Metals in Soils

| Heavy Metal | Sum of Squares | df | Mean Square | F | p-value |
|-------------|----------------|----|-------------|---|---------|
| Pb          |                |    |             |   |         |
| Between groups | 544744.892    | 7  | 77820.699   | 56.693 | .000    |
| Within groups | 76868.801     | 56 | 1372.657    |        |         |
| Total       | 621613.693    | 63 |             |        |         |
| Ni          |                |    |             |   |         |
| Between groups | 14228.645     | 7  | 2032.664    | 78.362 | .000    |
| Within groups | 1452.609      | 56 | 25.939      |        |         |
| Total       | 15681.254     | 63 |             |        |         |
| Zn          |                |    |             |   |         |
| Between groups | 58772.728     | 7  | 8396.104    | 9.755  | .000    |
| Within groups | 48199.930    | 56 | 860.713     |        |         |
| Total       | 106972.658    | 63 |             |        |         |
| Cd          |                |    |             |   |         |
| Between groups | 5032.837      | 7  | 718.977     | 31.803 | .000    |
| Within groups | 1266.016      | 56 | 22.607      |        |         |
| Total       | 6298.853      | 63 |             |        |         |
| Cr          |                |    |             |   |         |
| Between groups | 166452.594    | 7  | 23778.942   | 21.285 | .000    |
| Within groups | 62561.945    | 56 | 1117.178    |        |         |
| Total       | 229014.539    | 63 |             |        |         |
| Cu          |                |    |             |   |         |
| Between groups | 65927.990     | 7  | 9418.284    | 8.728  | .000    |
| Within groups | 60427.975    | 56 | 1079.071    |        |         |
| Total       | 126355.965    | 63 |             |        |         |

Abbreviations: df, degree of freedom; F, F-test

### Table 6 — Ecological Risk Assessment and Risk Index of Heavy Metals in Soil from E-Waste Sites in Douala

| Heavy metals | Ecological Risk |
|--------------|-----------------|
|               | Ngodi | Makea | New Bell |
| Pb            | 223   | 220   | 215      |
| Ni            | 83.5  | 100   | 93.0     |
| Zn            | 3.12  | 3.24  | 3.35     |
| Cd            | 269   | 238   | 247      |
| Cr            | 14.3  | 18.4  | 14.4     |
| Cu            | 101   | 126   | 103      |

| Risk Index   | 840    | 854    | 833      |
It is clear that the heavy metals contamination at the e-waste recycling sites was the result of improper disposal methods. The concentrations of metals were higher than the permissible limits set for environmental quality standards for soils in Europe and China. Open dumping and dismantling are the most common methods of handling e-waste in recycling sites in Douala. This is due to weak laws and regulations against open burning or dismantling of e-waste and the lack of an e-waste management system. Ashes produced by open-burning sites require careful management because they are a source of heavy metal contamination.

### Ecological risk assessment and risk index of the elements in soil

The ecological risk of heavy metals for soil samples in all of the e-waste sites indicated that Pb, Ni, Cd and Cu could pose a very high risk. Zinc was of low risk and Cr was of considerable risk. The risk index of heavy metals for the soils across all e-waste sites suggested a very high risk for these metals in the environment.

### Non-carcinogenic risk of heavy metals for adults and children

The heavy metals used to calculate the non-carcinogenic risk included Pb, Ni, Zn, Cd and Cu. It has been established that the non-cancer risk is a hazard quotient ≥ 1. In Makea, Ngodi and New Bell, children and adults are at risk of Pb toxicity due to the large amounts of Pb found, most likely through ingestion pathways. As a result of the large amounts of Cd present in e-waste sites in Makea, New Bell and Ngodi, children are exposed to Cd toxicity through the ingestion and inhalation pathways. Therefore, the hazard coefficient indicates a high risk of health issues such as cancer, kidney and lung damage and high blood pressure. The hazard index for children

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**Table 7 — Average Daily Intake of Heavy Metals for Adults and Children in Soil from the E-Waste Recycling Sites in Douala for Non-Carcinogenic Risk Calculations**

| Pathway | Average daily intake (mg/kg/day) |
|---------|---------------------------------|
| Makea   |                                 |
| Child   | ADI ing 3.71E-02, 7.16E-03, 2.95E-02, 3.84E-03, 5.25E-03, 1.66E-02, 8.39E-02 |
|         | ADI inh 3.71E-03, 7.16E-04, 2.95E-03, 3.84E-04, 5.25E-03, 1.66E-03, 8.39E-03 |
|         | ADI derm 4.75E-03, 9.17E-04, 2.62E-03, 3.28E-04, 2.13E-03, 1.07E-02 |
|         | Total 4.44E-02, 1.06E-02, 2.56E-02, 3.44E-03, 2.13E-02, 1.07E-01 |
| Adult   | ADI ing 3.97E-03, 7.67E-04, 2.19E-03, 2.74E-04, 1.78E-03, 8.99E-03 |
|         | ADI inh 3.97E-04, 7.67E-05, 2.19E-04, 2.74E-05, 1.78E-04, 8.99E-04 |
|         | ADI derm 9.84E-04, 1.90E-04, 5.43E-04, 6.79E-05, 4.41E-04, 2.23E-03 |
|         | Total 5.35E-03, 1.03E-03, 2.95E-03, 3.69E-04, 2.40E-03, 1.21E-02 |
| Ngodi   | ADI ing 3.96E-02, 6.39E-03, 1.92E-02, 3.84E-03, 1.02E-02, 7.93E-02 |
| Child   | ADI inh 3.96E-03, 6.39E-04, 1.92E-03, 3.84E-04, 1.02E-03, 7.93E-03 |
|         | ADI derm 5.08E-03, 8.19E-04, 2.46E-03, 4.91E-04, 1.31E-03, 1.02E-02 |
|         | Total 4.73E-02, 9.77E-03, 2.42E-02, 6.88E-03, 1.41E-02, 1.02E-01 |
| Adult   | ADI ing 4.25E-03, 6.85E-04, 2.05E-03, 4.11E-04, 1.10E-03, 8.49E-03 |
|         | ADI inh 4.25E-04, 6.85E-05, 2.05E-04, 4.11E-05, 1.10E-04, 8.49E-04 |
|         | ADI derm 1.05E-03, 1.70E-04, 5.09E-04, 1.02E-04, 2.71E-04, 2.10E-03 |
|         | Total 5.72E-03, 9.23E-03, 2.77E-03, 5.54E-04, 1.48E-03, 1.14E-02 |
| New Bell| ADI ing 3.58E-02, 6.78E-03, 1.98E-02, 2.56E-03, 1.02E-02, 7.32E-02 |
| Child   | ADI inh 3.58E-03, 6.78E-04, 1.98E-03, 2.56E-04, 1.02E-03, 7.32E-03 |
|         | ADI derm 4.59E-03, 8.68E-04, 2.54E-03, 3.28E-04, 1.31E-03, 9.63E-03 |
|         | Total 4.29E-02, 1.02E-02, 2.49E-02, 5.44E-03, 1.41E-02, 9.76E-02 |
| Adult   | ADI ing 3.84E-03, 7.26E-04, 2.12E-03, 2.74E-04, 1.10E-03, 8.05E-03 |
|         | ADI inh 3.84E-04, 7.26E-05, 2.12E-04, 2.74E-05, 1.10E-04, 8.05E-04 |
|         | ADI derm 9.50E-04, 1.80E-04, 5.26E-05, 6.79E-05, 2.71E-04, 1.99E-03 |
|         | Total 5.17E-03, 9.78E-03, 2.86E-03, 3.69E-04, 1.48E-03, 1.09E-02 |

Abbreviations: ADI, average daily intake; ADI derm, average daily dose through dermal contact; ADI ing, average daily dose through ingestion; ADI inh, average daily dose through inhalation; E, exponential.

**Figure 3 — Hazard quotient values for non-carcinogenic heavy metals in adults and children for soil from e-waste recycling sites in Douala, Cameroun**
decreased across the sites in the order of Ngodi > Makea > New Bell. The hazard index for adults increased across the sites in the order of New Bell < Makea < Ngodi. It is therefore recommended that further studies be carried out at these e-waste recycling sites in order to limit the adverse impacts of heavy metals contamination and facilitate the application of remediation measures.

Conclusions

Soil contamination by heavy metals due to e-waste recycling processes in Douala, Cameroun was observed. The uncontrolled processing of e-waste in Douala has likely resulted in the release of elevated levels of elements into the surrounding soil. The levels of heavy metals in soil were higher at the recycling sites compared to the control site and international standards. The ecological risk at all of the sites was high. The hazard quotient results also revealed that adults and children near the e-waste recycling sites are at risk of Pb and Cr toxicity through the ingestion and inhalation pathways. Findings from the present study demonstrate that urgent measures are needed in order to reduce heavy metals contamination resulting from e-waste recycling activities in Douala, Cameroun.

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