



Soil concentrations of polybrominated diphenyl ethers and trace metals from an electronic waste dump site in the Greater Accra Region, Ghana: Implications for human exposure



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ARTICLE INFO

Keywords:

PBDEs
Trace metals
e-waste
Soil
Geoaccumulation
Ghana

ABSTRACT

Unregulated electronic waste (e-waste) recycling operations have become a significant environmental issue as well as human health risk in developing countries across the world. The present study evaluated the extent of pollution in Agbogbloshie e-waste recycling site in Accra, Ghana. The concentrations of polybrominated diphenyl ethers (PBDEs) and some selected trace metals were determined using gas chromatography electron impact ionization mass spectrometry and flame atomic absorption spectrophotometry, respectively. The concentrations of Σ PBDEs ranged from 15.6 to 96.8 ng g⁻¹ dry weight, with an overall mean of 54.8 ng g⁻¹ dw. BDE-28 was the dominant congener followed by BDE-209 and BDE-47. The order of mean concentrations of the abundant trace metals was Fe > Cu > Pb >> Mn, with a mean range of .531–289 mg kg⁻¹. Geoaccumulation index suggested that the surface soils deteriorated from moderate to high metal pollution, particularly for Cu, Pb and Fe. Of the trace metals analysed, Fe exhibited the highest concentration ranging from 3.97 to 918 mg kg⁻¹. Correlation and principal component analyses suggested possible interactions between PBDEs and the trace metals analysed, while source assessment suggested that PBDEs and trace metals were mostly derived from inputs from the e-waste recycling activities. Average daily dose (ADD) was estimated using concentrations corresponding to 5th percentile, median and 95th percentile. Hazard quotients of 380 and 862 were obtained for adults and children respectively, for Cu and Pb which is a cause for concern especially for local children.

1. Introduction

Soil is a significant environmental matrix composed of organic and inorganic materials. It plays an important role in the distribution and fate of pollutants, since it serves as a major reservoir and sink for pollutants due to its large absorption capacity (Wang et al., 2012; Cetin, 2014). Soil properties are often affected by past land use, current activities and proximity to pollution sources. Human activities such as urban-industrial expansions, mining activities and most recently, uncontrolled electronic waste recycling have intentionally and unintentionally led to serious environmental challenges (He, 1995; Brigden et al., 2008; Wu et al., 2008; Luo et al., 2011) due to the release of various hazardous substances incorporated in e-waste, including toxic trace metals and halogenated persistent organic pollutants (POPs) such as brominated flame retardants (BFRs). Of all the contaminants, BFRs, particularly PBDEs have received a lot of attention because of their carcinogenicity, neurotoxicity and endocrine disruption (Costa and

Giordano, 2007).

PBDEs are industrial compounds extensively used as additive flame retardants in a variety of consumer products such as electronic casings, synthetic textiles, plastics, polyurethane foams and building materials to enhance fire inhibition. PBDEs are likely to adhere to solids (e.g. soil, sediment and particles in the atmosphere) and may bioaccumulate following their release into the environment (Yun et al., 2008; Cetin, 2014). The major industrial sectors that have incorporated PBDEs in their products include the electrical and electronic equipment (EEE) sector, manufacturers of textiles, carpets, furniture as well as the transportation, construction, and recycling industries (SSC, UNEP, UNIDO, UNITAR, UN, 2012). It is estimated that between 90% and 95% of commercial penta-BDE was used in the treatment of polyurethane foam (PUF) (Vyzinkarova and Brunner, 2013), mainly for furniture upholstery (Sjodin et al., 2003) and automotive applications (European Chemicals Bureau, 2000). The remaining minor uses (totaling 5%) include printed circuit boards, insulation foam, lacquers, cable

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sheets, conveyor belts, and possibly oil drilling (UNEP, 2007). The global distribution of penta-BDE use was approximately 36% and 60% in the transportation and furniture industries, with the remaining 4% deployed in other articles (UNEP, 2010).

Wastes from electrical and electronic equipment (WEEE) have become a major environmental concern since a large number of WEEE may have been treated with PBDEs and other hazardous substances (UNEP, 2006). The situation is exacerbated in developing countries where e-waste has been exported by developed countries (mostly illegally) as “second-hand-goods” (Wittsiepe et al., 2015). These are often dumped following their useful lives and recycled using inappropriate and unregulated methods under the guise of retrieving some valuable components integrated in these goods (Wittsiepe et al., 2015; Tue et al., 2016; Kyere et al., 2016; Srighoh et al., 2016). Apart from PBDEs, it is also well known that electrical and electronic equipment (EEE) generally contains metals, some of which are toxic. Therefore, uncontrolled dismantling and acid treatment of wastes emanating from EEE can often result to the leaching of toxic trace metals into the soil (Leung et al., 2007; Luo et al., 2009; Atiemo et al., 2012; Fujimori et al., 2016; Kyere et al., 2016) and consequent accumulation in human tissues (Asante et al., 2012; Wittsiepe et al., 2015; Srighoh et al., 2016). Exposure to high levels of toxic trace metals can result in acute and chronic toxicity, such as damage to the central and peripheral nervous systems, blood composition, kidney, liver, lungs and at some point death (Leung et al., 2008; Caravanos et al., 2011). Consequently, e-waste recycling is currently seen as a big environmental challenge, particularly in developing countries and the infrastructure to properly manage them is still not well developed (Osibanjo and Nnorom, 2007; Ahn et al., 2006; Leung et al., 2007; Wang et al., 2007; Chen et al., 2009; Srighoh et al., 2016).

Several studies documenting the presence of toxic elements and POPs in environmental media such as soil, dust, ash and sediment collected from some e-waste recycling and burning sites (Leung et al., 2006; Bi et al., 2007; Li et al., 2007; Wong et al., 2007a, 2007b, 2007c; Brigden et al., 2008; Ma et al., 2009; Atiemo et al., 2012; Tue et al., 2016; Kyere et al., 2016) as well as biological samples from informal e-waste recyclers (Asante et al., 2012; Asampong et al., 2015; Wittsiepe et al., 2015; Srighoh et al., 2016) have been reported. Agbogbloshie, the main hub for e-waste in Ghana is a well-documented informal e-waste recycling site (EWRS) (Amoyaw-Osei et al., 2011) that is characteristic of immense pollution. While numerous studies have been conducted on PBDEs and trace metal concentrations in matrices from e-waste sites, information, particularly on the concentration of PBDEs and trace metals in a single matrix from e-waste dumpsites in developing countries where unregulated e-waste recycling is ongoing is scarce. Such information is very relevant to the global pursuit for data on the level of different pollutants released into the environment with respect to BFRs and other toxic chemicals. Furthermore, information on possible relationship between trace metals and PBDEs when they co-exist in the environment, particularly uncontrolled e-waste recycling environment is deficient. According to Kefeni and Okonkwo (2013), the co-existence of toxic trace metals and PBDEs in, say, soil may engender complex formation, and hence influence their respective concentrations in one way or the other. This is one of the few studies that assess the co-contamination of PBDEs and trace metals in soils from an informal e-waste dump site in Ghana and possibly Africa. Although efforts are being made to improve the current e-waste recycling techniques in Agbogbloshie, the legacies of the crude recycling techniques, as well as environmental contamination are still much of a concern.

The objectives of the study were, therefore to (1) determine the levels of PBDEs and trace metals in soil from Agbogbloshie informal e-waste dump site and evaluate their possible sources, (2) to examine the correlation and likelihood of complex formation between PBDEs and toxic trace metals in the same matrix, and (3) to evaluate the extent of contaminant pollution due to e-waste processing activities and risks posed to human health.

2. Materials and methods

2.1. Study area and sampling

Agbogbloshie scrap market which is located within the Accra Metropolitan Assembly (AMA) jurisdiction is the main hub in Accra, for e-waste. This is an area spanning about .12 square miles of decrepit wetlands, and home to about 40, 000 inhabitants, living and working around the e-waste dump site. Situated on the banks of the Odaw River and in the upper reaches of the Korle Lagoon, the Agbogbloshie scrap market began as food stuff market and later metamorphosed into a slum with inhabitants dealing with all manner of scrap recycling on a large scale. As a result of these informal ‘scrap recycling’ activities near the residential areas as well as the heavy vehicular traffic, air and land pollution have become one of the major environmental challenges of the region with significant impact on public health. The site comprises mainly an open burning and smoldering area (BA), personal computers and TV repairers’ shop (RP), scraps dismantling area (DA), core burning and charring site (BC), a mosque (MQ), homes and a police post (HP).

Surface soils (0–5 cm) were randomly collected from six different operational locations of the site in triplicates each (N=18), by using stainless steel hand trowel during the first quarter in 2015. All the samples were wrapped in aluminium foil, placed in labelled Ziploc bags, transported to the laboratory on ice and stored at –20 °C until onward shipment to the Environmental Chemistry Research Group laboratory at the Tshwane University of Technology in Pretoria, South Africa for analysis. The description of the area is shown in Fig. 1.

2.2. Chemicals and reagents

Pure standards (1.2 mL of 50 mg L⁻¹) of each certified standard solutions of the sixteen PBDEs congeners (BDEs- 28, –47, –66, –77, –85, –99, –100, –118, –126, –138, –153, –183, –209 and ¹³C-BDE-139, –77 and –209) were purchased from Wellington Laboratories (Guelph, Ontario, Canada). Copper powder (purity 99.98%, from Saarchem (Pty) Ltd., Muldersdrift, South Africa), silica gel (100–200 mesh), sodium sulphate (purity 99.9%), glass wool and HPLC grade solvents: hexane, acetone, dichloromethane and toluene (Sigma-Aldrich, Chemie GmbH, Steinheim, Germany), were purchased from Aston Manor, South Africa. Pesticarb was purchased from Separations (Pty), South Africa. High purity nitrogen gas (99.999% purity) was supplied by Afrox (Pty.), Pretoria, South Africa. Pure standards containing 1000 mg L⁻¹ of trace metals in .5 M nitric acid were purchased from C.C. Imelmann (Pty) Ltd, South Africa.

2.3. Sample preparations and analysis

After removing large stones and pieces of debris, soil samples were air-dried, homogenized thoroughly and sieved separately with 250 µm mesh sieves and stored at –20 °C prior to extraction and analysis. Physicochemical parameters such as pH and conductivity were measured ex-situ in a soil-de-ionized water suspension (soil: water, 1:2.5 by volume) with a calibrated pH meter, and total organic carbon contents (TOC) of the soils were determined after pre-treatment of samples. Loss-on-ignition (LOI) was employed for the determination of TOC of soil samples in a procedure similar to one previously described by Daso et al. (2016).

For trace metals, a method previously described by Cetin (2014) was applied with some minor modifications. Approximately, 1.5 g of each sieved soil sample was weighed into previously acid-washed digestion vessels. The samples were pre-digested with 6 mL concentrated nitric acid (HNO₃, 65%), 3 mL concentrated hydrochloric acid (HCl, 35%) and .25 mL of hydrogen peroxide (H₂O₂, 30%) was added to each sample in a fume chamber and was then loaded on the microwave carousel. The microwave assembly was calibrated to a temperature of about 400 °C and digested for 30 min at a pressure of 100 psi (Milestone

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