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Impact of informal electronic waste recycling on metal concentrations in soils and dusts

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ABSTRACT

Electronic and electrical equipment contains over 1000 different substances, including metals. During informal e-waste recycling some of these substances such as metals, are released into the environment causing environmental pollution. This study assessed the impact of different informal e-waste recycling activities (burning, dismantling, and repairing) on metal concentrations in top soils and various dust.

A comparative cross-sectional study design was adopted to assess metal concentrations in top soils and in various dust samples from multiple e-waste recycling sites. Metal concentrations at e-waste recycling sites were compared to the concentrations at control sites in three study locations in Nigeria (Lagos, Ibadan, and Aba). In the three study locations, mean metal concentrations at the e-waste recycling sites exceeded the concentrations at the control sites and the Nigerian standard guideline values by 100 s to 1000 s times. Burning sites showed the highest pollution level, followed by dismantling sites, then repair sites.

Our findings show serious environmental and public health concerns. The metal concentrations were also higher than levels reported in other studies at the same locations in Nigeria, indicating that the situation is worsening. This study provides scientific evidence for an urgent need to develop effective strategies to strengthen enforcement of existing e-waste regulations in Nigeria.

1. Introduction

Information Communication Technology (ICT) has revolutionized our everyday life, consequently causing an increasing demand for ICTs. This growing importance of ICT coupled with rising obsolescence due to rapid technological advancements and decreasing electrical electronic equipment (EEE) lifetime has led to a rapid increase in the volume of waste electrical electronic equipment (e-waste) generated around the globe. E-waste refers to all items of EEE and its parts that have been discarded by its owners as waste without the intent of re-use. It includes any product that is powered by electricity or battery (STEP Initiative, 2014; Balde et al., 2017), including all separate components (such as wires, cables, batteries, circuit boards) which are at the end of their useful life (Baldé et al., 2015). The global estimate of *e*-waste to be generated for 2018 is 50 million metric tons (Baldé et al., 2015), and is expected to increase to 52.2 million metric tonnes by 2021(Balde et al., 2017). *e*-waste consists of electrical and electronic devices *e*-waste is one of the most complex waste streams because of the wide variety of components, compositions, and rapidly changing product designs. It is also one of the fastest growing municipal waste streams in the world.

There is a high level of transboundary movement of both second-hand EEE and e-waste from developed countries to developing countries. Only 20% of e-waste generated is properly collected and recycled (Balde et al., 2017). About 80% of the *e*-waste generated globally is recycled in developing countries such as Nigeria, Ghana, Brazil, Mexico, China, India, Vietnam, and the Philippines in informal settings (Perkins et al., 2014; Awasthi et al., 2016a). For example, in 2005, about 25–75% of the second-hand computers imported into Nigeria were non-functional or unrepairable and therefore were recycled informally (Ogungbuyi et al., 2012). Informal *e*-waste recycling processes have provided income and employment opportunities, affordable access to electronics and parts for repairs, and conservation of natural resources and energy required to manufacture new electronics from virgin resources. However, informal e-waste recycling is unsafe, unregulated, unorganised and often overlooked. Moreover, informal e-waste recycling activities release large quantities of hazardous substances (Brigden et al., 2008; Asante et al., 2012), causing environmental pollution. This is mainly due to lack of infrastructure for environmentally

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sound management of *e*-waste, lax environmental laws/regulations, and weak enforcement of existing laws/regulations (Terada, 2012; Strategic Approach to international Chemicals Management SAICM, 2009; UNEP, 1991).

Electronic and electrical equipment contains over 1000 different substances, some of which are hazardous elements such as lead, mercury, cadmium, arsenic, beryllium and persistent organic pollutants (polychlorinated biphenyls and brominated flame retardants) (UNEP-DTIE, .2007). These mixtures of different substances, covering both chemicals present in EEE components and chemicals released during *e*-waste combustion, may pose significant threat on the environment (Brigden et al., 2008; Asante et al., 2012). In addition, there may be negative consequences on human safety, given that these substances persist in the environment and have a great potential to accumulate in human and animal tissue (Akortia et al., 2017; Project SBCA and Pwamang, 2011; Ogungbuyi et al., 2012; Zheng et al., 2013).

In the environment, soil and dust are the main receptors of emissions from informal e-waste recycling. Therefore, they are the most important environmental media that can reveal the distribution and fate of the contaminants present in the terrestrial environment (Leung et al., 2008). Moreover, dust is a good indicator for metal levels in the atmosphere (Ackah, 2017; Tang et al., 2015, 2013; Xu et al., 2015; Lu et al., 2014; Wuana and Okieimen, 2011; Banerjee, 2003).

Hence, the aims of this study were to: (1) quantitatively assess the metal pollution in soil and dust because of different e-waste recycling activities (burning, dismantling, and repair sites) in three locations (Lagos, Ibadan, Aba) in Nigeria (2) determine the extent of the pollution (exceedance) at each activity site compared to the corresponding control sites. (3) evaluate factors that may influence metal concentrations at the sites (4) determine the activities that contribute most to the metal pollution to the environment. Our findings could be a wake-up call to relevant stakeholders to devise effective interventions to reduce environmental degradation caused by e-waste recycling. Our findings are likely to be applicable to other locations or countries where informal e-waste recycling is practiced.

2. Methods

2.1. Study locations and sites

The study was conducted in three study locations (Ibadan, Lagos, and Aba) in Nigeria. (Fig. 1). The three study locations are some of the large cities where e-waste is recycled (Ogungbuyi et al., 2012). In Lagos, the selected sites were Alaba international market Ojor and Computer village, Ikeja. Alaba international market is the largest market for new and second-hand electronics in West Africa, with approximately ten to fifteen containers arriving daily from Europe and Asia (with each container containing about 400,000 second-hand units) (Osibanjo and Nnorom, 2007). Computer village Ikeja is a popular place where electronics and their parts (new and second hand) can be purchased and repaired in Lagos. In Ibadan, the selected sites were Ogunpa and Queens Cinema areas. Ogunpa area is known for its activities in scrap/second-hand businesses, which include electronics, while Queens cinema is known for sales and repair of both new and second-hand electronics. In Aba, the shopping center and Port-Harcourt Road/Cementary and Jubilee road/St Michael's Road were selected. The shopping center area is the biggest market for new and used electronics, while the Port-Harcourt road/Cemetery area is known as an area for scrap/second-hand metal businesses in Aba.

2.2. Study design

A comparative cross-sectional study design was adopted to gain an understanding on the metal pollution at the e-waste recycling sites compared with non-e-waste sites (control sites). In each study location, a multi-stage random systematic sampling technique was used to ensure representative inclusion of various e-waste recycling activities in the selected e-waste recycling areas. The control sites were between 100 and 500 m away from the e-waste recycling sites, and consisted of areas with reduced human activity such as play grounds, parks, fields, and a university garden. Three types of e-waste recycling activities sites (burning sites, dismantling sites, and repair sites/shops) were analyzed. In Alaba, Lagos, we found only one big e-waste burning site, which is the largest, oldest, and most studied e-waste burning and dismantling site in Nigeria. In Ogunpa, Ibadan and Cemetery area Aba, the burning sites/spots were much smaller but more spread out in small clusters around the areas. Soil and dust samples were collected from the selected sampling sites wherever possible, mostly from the burning and dismantling/scavenging sites. Dust samples were collected as "floor dust" from repairer/refurbishers workshops and control sites. We also collected direct dust from the electronics. The locations of the sampling spots were georeferenced using a global positioning system (GPS) application on a phone. Constraints including the absence of unpaved surfaces or otherwise representative conditions led to an unbalanced design in soil sample collection. Fig. 2 presents a schematic diagram of the sample collection from the various e-waste sites in the three study locations.

2.3. Sample collection and preparation

For soil sampling, each site was divided into grids of about 10 m radius, and samples were systematically collected from 3 to 6 points within the site. The samples were bulked together for the top soil (0–10 cm depth) to form a composite representative sample for the specific site. Soil samples were collected using a soil auger, and a soil trowel was used in the transfer of soil from the auger into sample wraps. To avoid cross contamination, the soil probe/auger and trowel were decontaminated (cleaned first with a brush and wiped thoroughly with wet wipes) before each sample collection at each sampling site. Dust samples were collected using plastic brushes to gently sweep the dust and collect it with a dustpan. The soil and dust samples were wrapped in an acetone treated aluminium foil, labelled, and transported to the laboratory. Soil and dust samples were air dried for 7 days, homogenized (ground with a mortar and pestle), and sieved through a 1 mm mesh sieve to remove bigger particles, transferred into treated aluminum foil and then into a zip-lock bag, and stored at −20 °C. The samples were collected between May and November 2015. A total of 82 samples (62 samples from the e-waste recycling sites and 20 samples from control sites) were analyzed. The samples consisted of 29 top soil (0–10 cm depth), 32 floor dust, 16 roadside dust, and 5 direct dust samples from electronics.

2.4. Soil analysis

Soil pH was measured using a calibrated pH meter (691, Metrohm AG) in a (weight: volume) ratio of 1:10 of soil and tap water, adopting the USEPA method 9054D (USEPA, 2004). The soil organic matter content (TOC) was determined as the weight loss of dried soil (3 h at 100 °C) at 550 °C for 5 h (Pansu and Gautheyrou, 2006). The total metal content in soil samples was analyzed for trace elements using an X-ray fluorescence (XRF) spectrometer. For the trace metal analyses, about 3 g of dry soil was introduced into a sample plastic cup with a 4-µm thick polypropylene film window, with the soil/dust samples settling on the film window. The samples were placed into the XRF spectrometer and analyzed for a fixed period of about 120 s. To check the accuracy of the analysis, each sample was analyzed at least twice. Acid-purified sand (quartz, SiO2) was used as the media blank for determining detection limits of major and trace elements and heavy metals.

2.5. Data analyses

In this paper, we considered twenty-two metals Ag, As, Ba, Cd, Cr,