Asian Journal of Environment & Ecology

5(4): 1-8, 2017; Article no.AJEE.39500
ISSN: 2456-690X

Evaluation of the Heavy Metals Composition of Soil at E-waste Dumping Sites

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Authors' contributions

This work was carried out in collaboration between all authors. Author BA designed the study, performed the statistical analysis, wrote the protocol, and wrote the first draft of the manuscript. Authors EA and OPFO managed the analyses of the study. Author OPFO managed the literature searches. All authors read and approved the final manuscript.

Article Information

DOI: 10.9734/AJEE/2017/39500
Editor(s):
(1) Adamczyk Bartosz, Department of Food and Environmental Sciences, University of Helsinki, Finland.
Reviewers:
(1) Joshua Emmanuel Oluwagbemi, University of Ibadan, Nigeria.
(2) Dal Singh Kharat, India.
Complete Peer review History: http://www.sciencedomain.org/review-history/23441

Original Research Article

Received 19th November 2017
Accepted 6th February 2018
Published 5th March 2018

ABSTRACT

Electronic waste (e-waste) has become a subject of growing ecological concern in developing nations due to legal/illegal import of electronics from developed countries. Soil samples were collected from e-waste dumping sites in Arakale and Karakata, Akure, Ondo State, Nigeria. The samples were analysed for heavy metals with the aid of Atomic Absorption Spectroscopy. The mean concentrations of cadmium, lead, chromium, zinc and copper from the two locations range from 4.24±0.31 to 9.73±0.39; 113.66±1.03 to 261.63±3.58; 21.42±0.27 to 56.92±0.53; 108.71±0.82 to 197.98±2.22 and 19.79±0.32 to 62.88±0.91 mg/kg respectively. There was a gradual decrease in heavy metals concentrations at various distances away from the study site. The mean concentrations of metals observed in this study were found below the recommended standard limits of heavy metals in soil by United States Environmental Protection Agency, and the European Union. However, cadmium was found above the recommended standard limits of heavy metals in soil, thus their potential availability and possible effects on human, plants and the ecosystem at large.

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Keywords: E-waste; heavy metals; pollution; soil.

1. INTRODUCTION

Electronic waste has been defined as an electronic or electrical appliance that has been rejected by their original users such as computers, televisions, cellular phones, telecommunications equipment among others [1,2]. E-waste products comprises of sophisticated blends of plastics and chemicals, which, when not properly handled can be injurious to people and the environments [3]. The composition of e-waste is very diverse and varies in products across different dumping sites. It comprises different substances, which fall under ‘hazardous' and ‘non-hazardous' classes. The occurrence of components like lead, mercury, arsenic, cadmium, and selenium beyond threshold quantities in e-waste classifies them as hazardous waste [4].

It is estimated that 50 million tons of e-waste are produced annually [5] of which 75-80% is transported to countries in Asia and Africa for reprocessing and dumping. Only 25% of all the electronics produced and sold worldwide can be recycled or re-used, thus 75% will end up as a waste [6]. In Asia and Africa, reprocessing of e-waste is accomplished with limited and often no ecological or worker's health safeguards. Activities at these sites often stance detrimental coercions in the form of soil pollution prominent to polluted water and food as well as air pollutants affecting the well-being of the workers and children at these sites [7]. In countries, where ecological enforcement laws may not be efficient, high concentrations of trace metals can be discharged from e-waste, thus producing widespread environmental destruction to people and their immediate environment [8].

In recent years, with the improvement in the global economy, both type and content of heavy metals in the soil were triggered by human activities, resulting in the deterioration of the surroundings [9-12]. The high absorption of heavy metals in soils is reflected by concentrations of metals in plants, water, animals, and humans [13]. Therefore, when contaminants from e-waste are washed into nearby water bodies by rain or flood, there will be an alteration in the level of heavy metal concentration and nutrient absorption of the water bodies [14].

Environmental pollution by heavy metals is an important environmental concern. This is owed to the fact that they are not easily decomposed or metabolized, thus precipitating far-reaching effects on the biological system such as humans, animals, floras and soil biota [15]. In order to understand the mobility of heavy metals caused by e-waste and to enable the development of appropriate environmental guidelines in e-waste dismantling areas, concentrations of selective metals and other priority pollutants in soils in Arakale and Karakata were monitored in this study, aiming at evaluating the status of heavy-metal contaminations and their lateral mobility.

2. MATERIALS AND METHODS

2.1 Sample Location

Akure is a city in south-western Nigeria and the capital of Ondo State, it lies at latitude 70º15' north and longitude 50º15' east (Fig. 1). Akure is the trade midpoint for a farming region where cocoa, yams, cassava, corn, cotton, and tobacco are sold [16]. Arakale and Karakata are part of the unique hubs of economic activities in Akure and sites for electronic and electrical materials which draws several patronages within and outside Akure.

2.2 Sample Collection and Preparation

The top soil samples were collected from two locations (Arakale and Karakata) where e-wastes were constantly dumped and burnt. The samples were labeled as Arakale and Karakata. Other samples were taken at a distance of 20, 50 and 80m away from each site. Samples were stored in polyethylene bags (zip locks) and stored at ambient temperature until when required. The samples were sorted to eliminate stones and other unwanted materials. Samples were then placed in desiccators to get rid of moisture and grinded into fine powder. Dry samples were sieved with 2 mm sieve and homogenized.

2.3 Soil Sample Analysis

The digestion method by Francek et al. [17] was used for the extraction of metals in the study. The soil was crushed and 1g was perfectly weighed and digested with 10 ml concentrated HNO_3. The mixture was evaporated to near dryness on a hot plate and cooled. The procedure was repeated with concentrated HCl (15 ml). The extracts were filtered through No. 40 Whatman filter paper and

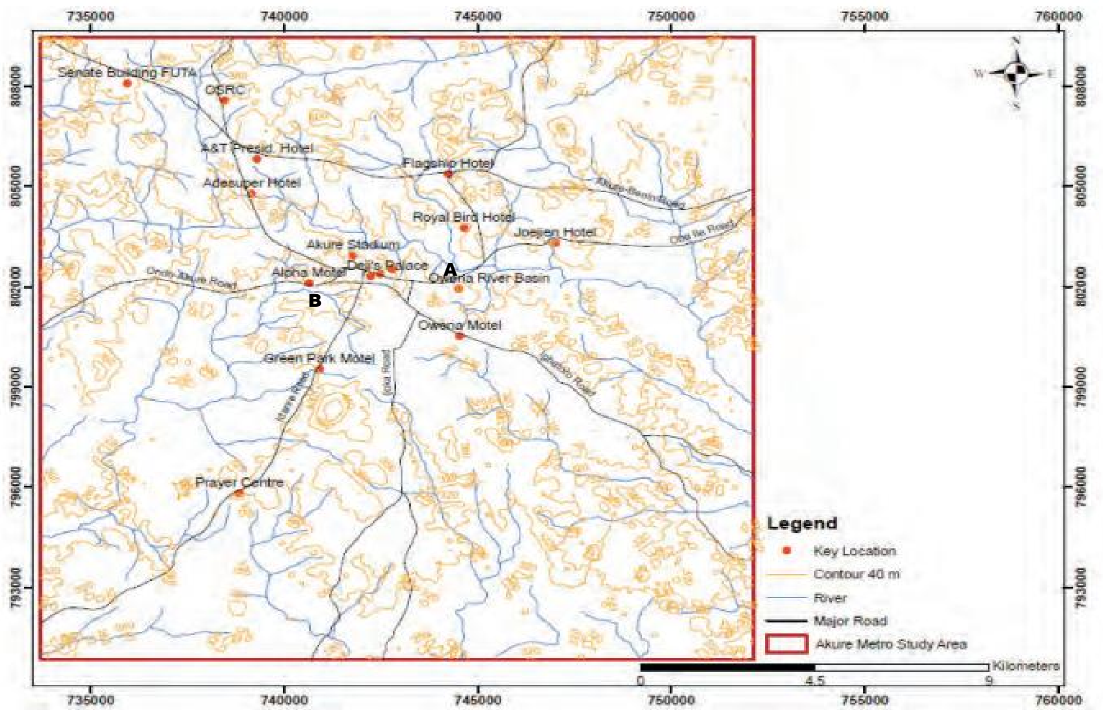

Fig. 1. Map of Akure showing different locations and the study areas represented by letter A and B

then made up to 100 ml with 2% HNO_3. Determination of heavy metals (Cd, Cr, Cu, Pb, and Zn) in the soil samples were performed using the atomic absorption spectrometer (AAS) (Model 210 VGP) at the Central Laboratory of Federal University of Technology Akure, Ondo State, Nigeria. The experiments were repeated in triplicate. The data obtained for heavy metals concentrations were represented in line graph and analysis of variance was done using Statistical Package for Social Sciences (SPSS) version 22 to generate the mean and standard error.

Amounts of metal loss = Y – X

Where,

Y = Amounts of metal at the dumping site
X = Amounts of metal at a distance away from the site.

3. RESULTS

The results of the heavy metals composition from Arakale and Karakata soil samples as well as those of the samples at distances away from the sites are presented in Table 1. The soil sample from Arakale area had cadmium concentrations in the range of 5.24±0.13 to 9.73±0.39 mg/kg, while that of Karakata area range between 4.24±0.31 and 7.97±0.78 mg/kg. The highest values of cadmium were observed at Arakale (9.73±0.39). The cadmium concentrations in all the samples from both locations were found to decrease as we move distances away from each e-waste sites.

Lead concentrations from Arakale range from 113.66±1.03 to 228.97±3.55 while that of Karakata range between 122.68±0.92 and 261.63±3.58. The highest values of lead were observed at Karakata (261.63±3.58). In all the two locations, the concentrations of lead were found to decrease as we move distances away from each e-waste sites.

The experimental results of chromium in the Arakale sample range from 21.42±0.27 to 50.57±0.56 while that of Karakata range from 22.53±0.42 to 56.92±0.53. The highest values of chromium were observed in samples from Karakata (56.92±0.53). Concentrations of chromium were found to decrease as we move distances away from each e-waste sites.

The zinc concentrations in Arakale samples range from 108.71±0.82 to 182.95±3.29, while that of Karakata range from 117.29±0.52 to 197.98±2.22. The highest values of zinc were observed at Karakata (197.98±2.22). The concentrations of zinc in all the locations were also found to decrease as we move away from the e-waste sites.

Experimental results of copper at Arakale range from 22.38±0.71 to 58.59±2.31, while that of Karakata range from 19.79±0.32 to 62.88±0.91. The highest values of copper were observed at Karakata (61.88±0.91). The copper concentrations of samples from both locations were found to decrease with an increase as we move distances away from each e-waste sites.

The mean metals concentrations of all studied samples from e-waste dumping sites were compared with standard limits of heavy metals in soil in mg/kg and presented in Table 2. The results of all the metals were below the standard limits of heavy metals in the soil according to the United States Environmental Protection Agency (USEPA), European Union (EU) and the United State of America (USA) except for Cadmium that was found to be above the standard limits of heavy metals in soil.

Figs. 1 and 2 show the level of metal loss at distances away from Arakale and Karakata dumping sites, respectively. The concentrations of the metal loss increase as the distance away from each e-waste site increases. This is an indication that metals don't only leach horizontally, but as well do leach vertically [18].

4. DISCUSSION

The mean concentrations of cadmium in the two locations (Arakale and Karakata) were found to decrease as we move distances away from each e-waste sites. The decrease in cadmium concentrations with an increase as we move distances away from each e-waste sites may be attributed to the release of cadmium from e-wastes containing electrical and electronic equipment such as batteries, resistant and light-sensitive resistors. Also, fluorescent layers of cathode ray tube screens, printer ink, toners, and photocopying machines contain some elements of cadmium.

Table 1. Mean concentrations of the metals from at e-waste sites with their respective control Samples

Metals (m away)	Cd	Pb	Cr	Zn	Cu
Arakale	9.73±0.39	228.97±2.55	50.57±0.56	182.95±3.29	58.59±2.31
20	7.24±0.32	154.56±1.22	39.68±0.45	147.27±2.30	48.37±1.21
40	6.04±0.23	132.72±1.11	28.23±0.33	120.61±1.06	30.31±0.52
60	5.25±0.13	113.66±0.53	21.42±0.27	108.71±0.82	22.38±0.71
Karakata	7.97±0.78	261.63±2.58	56.92±0.54	197.98±2.22	61.88±0.91
20	6.13±0.54	175.76±1.97	47.90±0.42	154.26±1.09	47.79±0.72
40	5.03±0.24	142.24±1.23	33.42±0.53	122.17±0.67	29.18±0.63
60	4.24±0.31	122.68±0.92	22.53±0.42	117.29±0.52	19.79±0.32

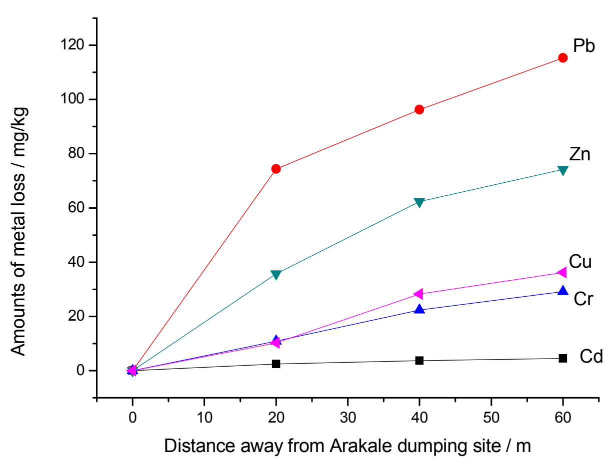

Fig. 2. Amounts of metal loss when moving away from Arakale dumping site

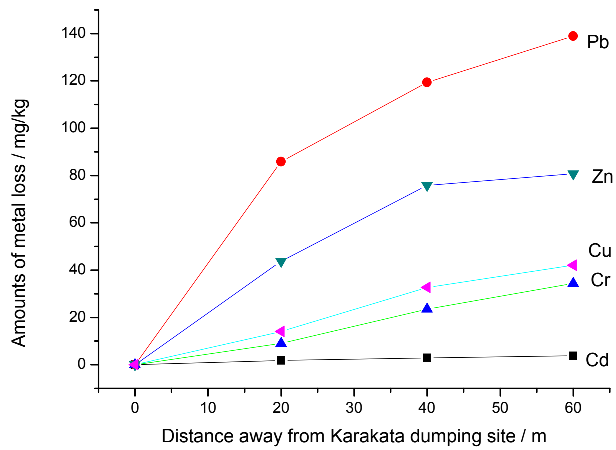

Fig. 3. Amounts of metal loss when moving away from Karakata dumping site

Table 2. Standard limits of heavy metals in soil in Mg/kg

Metals (mg/kg)	USEPA	EU	USA
Cd	3.00	3.00	3.00
Pb	300.00	300.00	300.00
Cr	100.00	150.00	180.00
Zn	300.00	300.00	200.00
Cu	250.00	140.00	80.00

USEPA= United States Environmental Protection Agency (1996), EU= European Union (2002), USA= United State of America

The concentrations of cadmium observed in this study were above the recommended standard limits of heavy metals in soil (3.0mg/kg) by the United States Environmental Protection Agency (USEPA), European Union (EU), and United State of America (USA). The concentrations of cadmium in this study ranges from 5.24±0.13 to 9.73±0.39 mg/kg (Arakale) and 4.24±0.31 to 7.97±0.78 mg/kg (Karakata). The differences in the concentration of the cadmium from the two sites are connected to the age of the dumping site and the frequency of dumping waste at the site. The rate at which cadmium reduced as we move away from dumping site varies from site to site (y=1.802ln (x) -2.923 and y=1.706ln (x) -3.292, for Arakale and Karakata, respectively). This rate is greatly influenced by soil components. The soil component in Arakale may be different from that of Karakata. The results of cadmium contents in soil samples from this study were higher than 0.11 to 1.65 mg/kg recorded by [19] and agreed with the findings of [20] (1.80 to 19.00 mg/kg). They reported that the soils of indoor dust and outdoor dust from Westminster electronic market in Lagos contained heavy metals. The profile of the metal content of e-waste in this study were found in the order lead>zinc>copper>chromium>cadmium. Exposure to cadmium is triggered by closeness to hazardous waste sites and workshops in the metal refining industry. Inhaling cadmium causes severe harm to the lungs and kidney [21]. Cadmium is a possibly long-term cumulative poison and lethal compounds of cadmium tend to gather in the human body triggering kidney and lung damage, it is known to be carcinogenic to human health [22].

The mean concentrations of lead in this study were found below the recommended standard limits of heavy metals in soil (300 mg/kg). The concentrations decrease as we move the distances away from each e-waste site, which could be as a result of the occurrence of lead-containing substances like cathode ray tubes, computer monitor glass, acidic batteries at these sites as reported by [23]. The concentrations of lead in this study ranged from 113.66±0.55 to 228.97±2.55 at Arakale and 122.68±0.92 to 261.63±2.58 at Karakata. The results observed in this finding were higher than 8.92 to 14.47 mg/kg, 2.20 to 12.50 mg/kg and 15.9 to 22.5

recorded by [19,24,20] respectively. Continuous exposure to lead-containing substances could be deadly. Short-term exposure to high levels of lead can cause nausea, diarrhea, convulsions, unconsciousness, or even death [25]. Other symptoms are appetite loss, abdominal pains, constipation, fatigue, sleeplessness, irritability, and headache. Lead is mostly hazardous to young children, because it readily affects their nervous systems [26].

The concentrations of chromium observed in this study fell below the recommended standard limits of heavy metals in soil (100 mg/kg) by USEPA, (150 mg/kg) by the EU and (180 mg/kg) by the USA. The concentrations of chromium decreased as we move distances away from each e-waste sites which could be as a result of major sources of chromium in e-wastes, this include hardener in plastics and dye in pigments of some switches. The results of chromium observed ranged from 21.42±0.27 to 50.57±0.56 at Arakale and 22.53±0.42 to 56.92±0.53 at Karakata. The results observed in chromium were higher than 0.24 to 2.20, 16.84 to 38.21, 10.51±0.01± to 19.65±0.55 recorded by [24,19,23].

Chromium (VI) is simply absorbed by the human body and can produce numerous toxic effects within cells as chromium toxicity in the environs is relatively unusual. It still presents some hazards to human well-being as reported by [27]. Skin contact with some chromium (VI) compounds can lead to ulcers while hypersensitive reaction could result in redness and swelling of the skin. Chromium (VI) compounds have also been well-known to increase the risk of lung cancer and can also cause damage to DNA. Contact with chromium compounds can cause perpetual eye injury. Chromium may also cause DNA damage.

The concentrations of zinc in the two locations were also found to decrease as we move distances away from each e-waste sites. The mean value of zinc concentrations for all the soil samples analyzed were below the recommended standard limits of heavy metals in soil (300 mg/kg) by USEPA, EU and (200-300 mg/kg) by the USA. The results of zinc observed in this study ranged from 108.71±0.82 to 182.95±3.29 at Arakale and 117.29±0.52 to 197.98±2.22 at Karakata and it's higher than 40.53±2.20 to 98.62±7.27 mg/kg and 54.15 to 97.21 observed by [23,19], but were below 213.0 to 295.5 detected in indoor dust and outdoor dust from Westminster electrical market in Lagos State as reported by [20]. Zinc is an essential element, which is required by human body for healthy development. However, excessive exposure to zinc as dust or fumes can result into a temporary disease known as metal fume fever [20]. Persistent exposure to amounts greater than the acceptable upper intake level may subdue immunity, decrease high-density lipoprotein cholesterol levels, and cause copper deficiency [28].

The mean concentrations of copper in the two locations (Arakale and Karakata) were found to decrease as we move distances away from each e-waste sites. The mean concentrations fell below the recommended standard limits of heavy metals in soil (250 mg/kg) by USEPA, (140 mg/kg) by EU and (280-200 mg/kg) by the USA. The results of copper observed in this study range from 22.38±0.71 to 58.59±2.31 at Arakale and 19.79±0.32 to 62.88±0.91 at Karakata. The results observed were higher than 2.20 to 6.60 and 14.22 to 34.21 recorded by [24,19]. Copper also is an important trace element that is required in enzyme systems which are accountable for countless metabolic processes required to sustain life. Too much of copper buildup in the human body can cause numerous ailments and health complications such as fatigue and exhaustion, headaches, migraines, arthritis, constipation and anorexia [29].

5. CONCLUSION

This study revealed the level of concentrations of cadmium, lead, chromium, zinc and copper in two different locations (Arakale and Karakata, Akure, Ondo State, Nigeria) with respect to samples taken at different distances away from the e-waste sites. The nature of business around a dumping site determined the concentrations of the metals around the site. The age of the dumping site also has influence on the amount of the metal at the waste site. The results revealed that the concentrations of these heavy metals were high at each e-waste site and there is a gradual decrease in the concentrations at various distances away from each e-waste site. The rate at which metal leached away horizontally is different from location to location, and is determined by the soil component. Hence, regular dumping of e-waste at these locations will increase the concentrations of heavy metals in the soil, which may be dangerous to the health of people living around this area and ecosystem at large. The government should, therefore, provide better locations where e-waste can be dumped properly.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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Peer-review history:
The peer review history for this paper can be accessed here:
http://www.sciencedomain.org/review-history/23441