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Assessment of the Levels of Brominated Flame Retardants in Computers and Televisions in Selected Regions of Eritrea

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Abstract

During recent years, electronic waste (e-waste) around the world is growing at a fast rate and has become a matter of concern due to the presence of toxic brominated flame retardants (BFRs) and certain heavy metals. Currently, in Eritrea there is low awareness on the harmful effects of e-wastes, lack of proper storage facilities and no proper policy and legislative framework related to e-wastes. Thus, in most cases e-wastes still reside in homes, offices, and some are stored with other materials in different places. Therefore, the objective of the present study was to assess the levels of BFRs in obsolete as well as in lately imported computers and televisions using hand held hazardous substances analyzer—Genius 3000 XRF. The survey was done in selected regions of Eritrea and thus a total of 223 samples of computers and TVs from 78 different products were screened. Three readings at forty seconds were conducted for each sample and the average value was calculated. From 173 sampled computers, both oldest and lately imported products, different levels of Br were measured varying from the lowest detectable amount (0.3689 ppm) to the highest (87,821 ppm). Similarly, out of 50 screened old and new models of TVs various levels of Br were determined with minimum detectable level (1.5793 ppm) and highest level (80,916 ppm). The analysis displayed high levels of Br both in the obsolete and lately manufactured products. The concentration of Br didn't show any consistency either to the product type or manufacturing time. This is a very first preliminary study conducted related to the levels of BFRs in electronic wastes in the country and thus in order to evaluate the environmental impacts and health hazards caused by BFRs and other toxic materials of e-wastes, further study using advanced analytical methods is mandatory.

Subject Areas

Composite Material

Keywords

Electronic Waste, Polybrominated Flame Retardants, Genius 3000 XRF, Eritrea

1. Introduction

During recent years, one special type of waste has raised a great concern in most of the developed and in developing countries is the electronic waste (e-waste). Currently, waste of electrical and electronic equipment (WEEE) or e-waste is one of the fastest growing waste streams in the world but it has not yet got the compulsory attention [1] [2]. Rapid economic growth and changes in technology coupled with urbanization, falling prices, and planned obsolescence have resulted in a fast growing surplus of e-waste around the globe, and have raised great concerns as many components in these products are hazardous heavy metals, toxic chemicals and non-biodegradable plastics [3] [4].

The amount of e-waste generated globally is growing at a rate nearly three times faster than the growth of overall municipal solid waste. The amount of e-waste generated in 2016 was 44.6 million tons, and expected to project in an annual growth rate of 4% - 5%. From the most recent comprehensive study in 2014, the United Nations University (UNU) estimated global WEEE generation to be 41.8 million metric tons, and forecasted an increase to 50 million metric tons by 2018 [5] [6]. Although it is illegal under the Basel Convention of 1992, it is estimated that 75% to 80% of that produced in developed countries is shipped to developing countries where the environmental standards are low or nonexistent and working conditions are poor; especially in Asian and African countries for cheaper recycling and disposal [1] [7] [8]. Another large fraction of the e-waste generated in the world is treated as general municipal solid waste, and is thus incinerated in waste incineration facilities or just dumped on landfills [9] (SEPA, 2011). It contains both valuable and hazardous materials that require special handling and recycling methods to avoid adverse environmental and human health impacts [10] [11].

E-waste is highly complex to handle since it is made up of multiple components and usually contains precious metals; especially copper, silver, gold and platinum [12] [13], and various plastics. However, the greatest concern about e-waste is that the presence of potential environmental contaminants, especially persistent organic compounds, such as brominated flame retardants (BFRs), phthalates, and polychlorinated biphenyls (PCBs) [14]. Moreover, the presence of lead, antimony, mercury, cadmium, nickel, barium, arsenic, and beryllium has serious consequences [1] [8] [9]. Burning e-waste may generate polybrominated dioxins and furans [4] which are classified as "known carcinogens" by world health organization [1], polycyclic aromatic hydrocarbons (PAHs) and polyhalogenated aromatic hydrocarbons (PHAHs) [10]. Such harmful substances can be deposited into the surrounding soil, water and air during waste treatment or when they are dumped in landfills or kept in stores [15] [16].

Despite of their benefits for reducing fire-related injury and property damage, growing concern for BFRs has risen because of their occurrence and persistence in the environment, biota and humans [17]. Evidence of their persistence and capacity for bioaccumulation, coupled with concerns about their adverse health effects has led to widespread bans and restrictions on the manufacture and use [18]. The use of toxic BFRs especially polybrominated diphenyl ethers (PBDEs) as flame retardants (FRs) have been phased out or banned. However, exposure is expected to continue for several decades because of the reservoir of these chemicals that exist in consumer products that have long durations of use, and the environmental stability of PBDEs [19]. Humans particularly workers and local residents exposed to the WEEE are therefore highly liable to a wide range of toxic compounds via dust originating from these activities [20]. Most of what is known about the toxicity of BFRs arises from animal studies and in vitro assays, especially as ethical concerns prevent controlled studies on human subjects [21]. Therefore, PBDEs have been extensively investigated as possible TH disruptors in animal studies. Many in vivo toxicological studies in animal models have reported a reduction in total thyroxine (TT4) [22], neurological and developmental disorders, reproductive health effects, and cause endocrine disruption and thyroid gland dysfunction [21] [23].

In Eritrea, all the electrical and electronic equipments (EEEs) are imported from foreign countries, except the computers known as e-tech and NCC are assembled in the country. Since the government has been enhancing information and communication technologies (ICTs); EEEs especially computers became the most common and widely used gadget in all kinds of activities ranging from offices, elementary to higher schools, residences, manufacturing industries…etc. Additionally, as people are eager for newer technologies, the consumption of electronics is dramatically increasing, while the lifespan of electronics is becoming relatively short. Consequently, older and outdated products are becoming obsolete and being stored as e-waste in large quantities and at increasing rates. Therefore, the lack of clear framework for handling and treatment of e-waste has led to accumulated electronic and electrical waste in offices and warehouses throughout the country. In most cases, e-wastes still reside in homes, offices, stores and mixed with other items. This is because of low awareness of citizens on the harmful effects of WEEE on the environment and their health, lack of storage facilities and inadequate infrastructure for WEEE management, proper policy and legislative framework. As a solution to the storage problem, e-wastes from different governmental institutions are collected and stored at different places without adequate management. In this study, the preliminary assessment of BFRs found in computers and Televisions was conducted from diverse Zones in Eritrea including Central, Anseba and Northern Res-Sea. The concentration of bromine was determined to estimate indirectly the levels polybrominated flame retardants which are potential health hazard chemicals. Therefore, the results from this report will help to elaborate the current status and future trend of e-wastes in the country.

2. Materials and Methods

2.1. Instrumentation

The instrument used in this study, to determine the level of Br, in computers and TVs was the handheld hazardous substances analyzer Genius 3000 X-Ray Fluorescence (XRF) spectrometer (Skyray Company). It is small, easy to carry, and supports handheld field online analysis during raw materials inspection, process control and finished product inspection. It can measure the level of Br directly by placing the measurement window close to the sample to be analyzed.

2.2. Sampling and Data Collection

Different Governmental Institutions were selected due to the availability of stores of obsolete computers and large number of computers still in use. Therefore, the data for old and new computers was collected from diverse sites including University of Asmara, Asmara Technical School, Governmental Property Disposal Store, Eritrea Institute of Technology (EIT), Asha-Golgol, College of Marine Science and Technology, Authority of Port of Massawa, Ministry of Marine Resource Massawa, and Hamelmalo College of Agriculture. Moreover, in this study older and newly imported TVs were selected from various repairing shops and vocational training centers in Asmara. During the sample analysis different types of TVs, which have long range of life were selected. A typical electronic product is made up of hundreds of individual components. Complete testing of each product was usually impractical due to time and sample preparation constraints. This challenge was mainly addressed by focusing on the samples of known “high concern” materials like CRT casings (TVs and computer monitors) and printed circuit boards.

3. Results and Discussion

As the primary objective of this study was to measure the concentration of bromine and thus estimate the levels of BFRs in the electronic products, 223 samples of both computers and televisions of 78 diverse products were screened. The WEEE and/or EEE samples were manufactured from the late 1980s up to 2015; however the manufacturing time was not available in some products. Most of these products were imported from Asian countries including China, India, Japan, and Korea, and some were from Europe and USA and few were assembled in Eritrea. Different concentration of Br was detected in almost all the samples and there was high degree of variability within the products. Unexpectedly, high level of Br was also determined in the recently imported products. There has not been comprehensive data on the status of computers or other electronic equipments in Eritrea. Therefore, the e-waste generated can be estimated from the life span of those products and increasing use of EEEs. As observed during the field surveys and data collection, currently the main e-waste contributors are governmental sectors. Though there are not much e-wastes generated from individual households, they will become potential contributors in the future because the trend of consumption of electrical equipments in increasing.

3.1. Computers

From the 173 sampled computers of a wide range of manufacturers, a total of around 4 kilogram of Br was determined in both the old and lately imported products. The level and range of the concentration of Br analysed in the samples of computers found in different governmental sectors are also displayed in **Table 1** and **Figure 1** respectively. The level of Br was varying from the lowest detectable amount (0.3689 ppm) up to the highest (87,821 ppm). Generally, from the examined computers, 24 (15%) were in the range of 1000 - 10,000, 49 (29%) had Br concentration between 10,000 and 20,000 ppm, 29 (17%) in the range of 20,000 to 30,000 ppm, 21 (12%) were between 30,000 to 50,000 ppm and 24 (14%) computers had greater than 50,000 ppm. The overall tally of computers with high level (above the defined limit) of Br was about 147 (85%); this clearly indicates that the examined samples had high levels of brominated flame retardants. However, the level of Br was not detectable only in 7 (4%) computers, and the level of Br in 19 (11%) samples was below the limit (<1000 ppm). Various concentrations of Br were detected in the different samples and there was no uniform pattern in the levels of Br relative to the type and age of the electronic products. Relatively, large percentage of the computers had Br concentration in the range of 10,000-20,000 ppm and as shown in **Figure 1**, there was no uniform pattern in the increment of the range of Br concentration.

Most importantly, screening of the obsolete computers found in the Ministry of Marine Resource displayed relatively low Br concentration, with maximum value of 16,921 ppm, as compared to the other results. This could be due to the hot weather in Massawa; there is high possibility of volatilizing the brominated organic materials because the old computers are found in an open area. Therefore, these toxic substances can critically affect the health of community living in the vicinity of the open store by entering their body through respiratory tracts and marine foods. According to U.S Environmental Protection Agency (2006) [24], direct exposure to commercial PBDE mixtures is assumed to be the main source of PBDE uptake/accumulation in biota; it is plausible that PBDE mixtures may contribute to the loading of persistent PBDEs in marine food webs.

Samples of the screened obsolete computers of different brands and models manufactured at different times are displayed in **Table 2**. However, the concentration of bromine didn't show any consistency with the manufacturing time or type of the product. For example, the levels of Br (in ppm) in the screened IBM

Table 1. Variation of bromine concentrations (in ppm) obtained from various samples of computers.

Range (ppm)	UoA	ATS	GPDS	AG	EIT	MC	PoM	MMR	ZA	Total	%
<detection limit	1	1	0	1	0	2	0	1	1	7	4
>0 ≤ 1000	3	4	2	1	1	1	2	5	0	19	11
>1000 ≤ 10,000	2	3	2	2	2	7	2	2	2	24	15
>10,000 ≤ 20,000	7	2	6	14	3	6	4	2	4	49	29
>20,000 ≤ 30,000	11	3	7	4	0	0	1	0	3	29	17
>30,000 ≤ 40,000	2	2	3	0	0	2	2	0	0	11	6
>40,000 ≤ 50,000	3	1	4	0	0	1	0	0	1	10	6
>50,000 ≤ 60,000	2	0	2	1	0	0	3	0	1	9	5
>60,000 ≤ 70,000	4	3	0	0	0	1	0	0	1	9	5
>70,000	1	0	1	0	0	2	0	0	2	6	3
Total	**36**	**20**	**27**	**23**	**6**	**22**	**14**	**10**	**15**	**173**	**100**

NB: UoA (University of Asmara); ATS (Asmara Technical School); GPDS (Governmental Property Disposal Store); AG (ASha-Golgol); EIT (Eritrea Institute of Technology); MC (Marine College); PoM (Port of Massawa); MMR (Ministry of Marine Resource); ZA (Zoba Anseba).

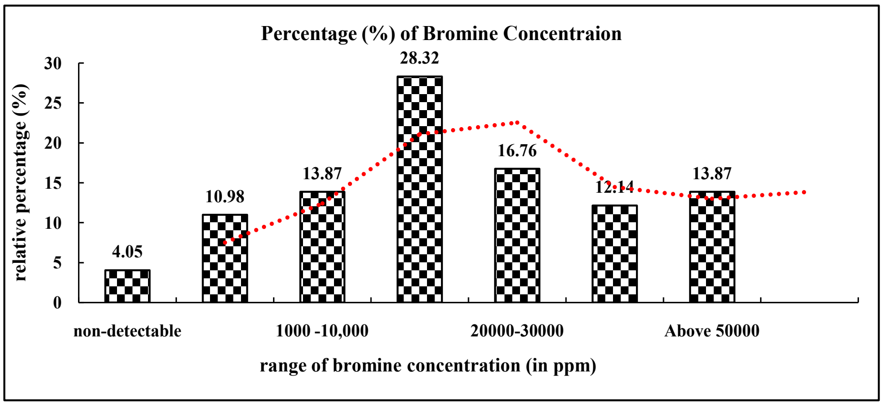

Figure 1. The percentage of bromine in computers determined using Genius 3000 XRF.

manufactured at different times was 425 (1981), 22052 (1995), 0.4006 (1996), 56,032 (2001), and 67,845 (2002). The same case was observed in DELL and the results were 28,314 (obtilex 1994), 10472 (dimension 1996), 26,463 (1997), 32,501 (2002), 15,786 (2003), and 0 (2004). Some possible reasons for the variation of Br could be due to the manufacturer's use of different levels of BFRs or the use of other types of flame retardants. Moreover, the temperature and time to which the products manufactured, the nature of the stores used, and the difference in the sample parts analysed could be additional reasons.

Based on the preliminary survey, the quantity of obsolete computers and other e-wastes temporarily stored in ordinary stores is growing at an alarming rate. Mostly, those wastes are mixed with other materials or wastes and are sometimes placed in an open area. This could be due to lack of storage facilities and

Table 2. Samples of obsolete computers screened and their bromine concentration (ppm).

Brand	Manufacturing time	Amount of Br (ppm)
DELL	#	51,542.3516
DELL dimention	1996	10,472.4833
IBM	1981	424.8742
IBM	2002	67,844.6843
Belina	1990	62,043.2443
Philips	1984	69,569.5217
Likon	1999	76,987.8613
AGC	1996	36,220.9069
Fujitsu	1993	27,869.7014
Samsung	1997	32,557.6516
NCC	2004	57,016.1862
Threei	1996	84,463.9658
RM	1998	37,685.5699
Getway	2004	73,410.3382
Adi	1997	75,410.3382

NB: # manufacturing time was not found.

inadequate infrastructure for WEEE management, and very low awareness of the users. In this study, the levels of bromine in samples of computers still functioning were also screened. As shown in Table 3, the quantity of bromine was found mainly above the level (*i.e.* 1000 ppm or <0.1 % by weight) of EU Directive (2017/2102) [25] in EEEs implemented in 2006. However, some lately manufactured products showed low levels of Br (ppm); Lenovo 2015 (134 ppm) and Dell 2013 (44 ppm) and these satisfied the RoHS directive. The analysis indicates that there is still possibility of finding computers in the market with high level of BRFs. Therefore, there should be a mechanism to scrutinize and thus monitor the importation of electronic equipments. Moreover, the Ministry in charge should implement national legislation framework related to the assembly and importation of new electrical equipment.

The XRF screening results displayed in Table 4 was obtained from the unassembled computer parts found in Asha-Golgol. The level of Br, from different manufacturers was much higher than the RoHS directive maximum concentration value. The result indicated that, there is a possibility to get computers having high level of Br even in new casings and thus purchasers should be aware of this matter. Besides, this result clearly indicated that BFRs are still used in some computer parts.

3.2. Televisions

The samples of televisions assessed were from private sectors such as repairing shops and vocational training centers. Most of the repairing shops are situated

Table 3. Samples of Br concentration (ppm) in computers still in use.

Functioning computers	Manufacturing time	Amount of Br (ppm)
Lenovo	2015	137.9724
HP DX2400	2008	8361.3373
HCL 2010	2010	8564.9352
DELL optiplex GX270	2003	15,726.006
Acer	2010	9752.2376
DELL India	2013	43.5646

Table 4. Samples of screened unassembled computer parts found in Asha-Golgol.

Component type	Manufacturing time	Amount of Br (ppm)
power supply	#	20,074.0372
mb. LM915	#	13,028.6725
mb.LMH61	#	11,789.3379
mb.foxconn	2010	17,278.4158
mb.elitegroup	2007	14,619.7124
mb.hasee	2007	15,130.4659
mb NCC	#	20,914.7472
HD	#	14,951.4704

NB: "#" manufacturing time was not found; "mb" motherboard.

along with other business and residential areas. The workshops are congested and thus different TV parts are kept together without proper storage conditions. Besides, the technicians are usually working without adequate personal protective equipment and others do the repairing in their living houses; thus exposing themselves, their families, local residents and the environment to the dangerous pollutants especially via dust ingestion. In this study, 50 TV samples including old and lately imported products were screened. As indicated in **Table 5** and **Figure 2**, a total of around 1.2 kilogram of Br was measured varying from lowest detectable amount (1.5793 ppm) to the highest (80,916 ppm). Due to the storage problems in the repairing shops, any material which doesn't function is usually discarded away and this increases the WEEE. E-wastes contain multiple toxic substances that are hazardous to human health and the environment; therefore even a small amount of e-waste entering the residual wastes will add up relatively high amount toxic substances.

Generally, from the screened samples, 4 TVs (8%) were found below the detection limit, and 8 (16%) had Br concentration below 1000 ppm. Majority of the samples, 22 (44%) were found with Br level between 10,000 to 30,000 ppm. Moreover, 7 (14%) TVs had concentration of 30,000 up to 50,000 ppm and 9 (18%) were found with much higher Br concentration (>50,000 ppm). Similar to the analysis of computers, the highest level of bromine in TVs was observed in

Table 5. Range of bromine concentration (ppm) measured from TVs.

Range (ppm)	Total	Percent
<detection limit	4	8
>0 ≤ 1000	8	16
>1000 ≤ 10,000	4	8
>10,000 ≤ 20,000	11	22
>20,000 ≤ 30,000	7	14
>30,000 ≤ 40,000	5	10
>40,000 ≤ 50,000	2	4
>50,000 ≤ 60,000	2	4
>60,000 ≤ 70,000	4	8
>70,000	3	6
Total	**50**	**100**

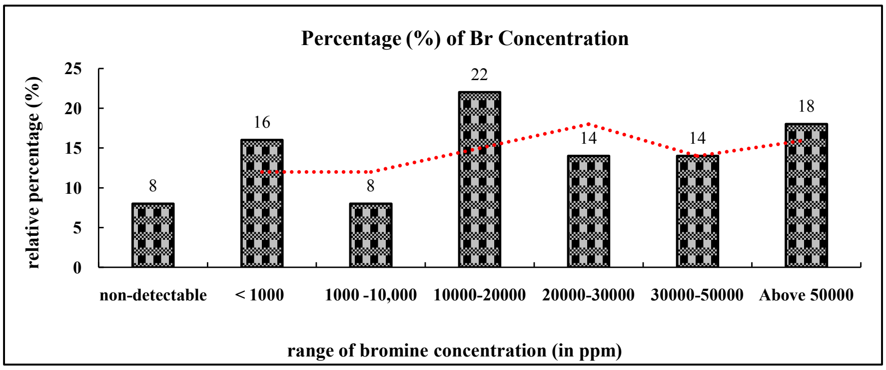

Figure 2. The percentage of bromine in TVs determined using Genius 3000 XRF.

the range of 10,000 - 20,000 ppm. Relatively, the trend shows that there were large percentage of TVS with extreme level (>50,000 ppm) of Bromine and thus large portion of the highly toxic polybrominated flame retardants. According to Korcz, *et al.* (2014) [26], heating the electrical devices during operation as well as UV irradiation are the main factors to the release of PBDEs from TVs. A 5˚C rise in temperature has been shown to increase the emission of PBDEs from television casings to the environment from 40% to 70%. From this it can be suggested that every user is exposed to those chemicals even at low amounts; children and individuals in which their daily life are related to repairing and indoor activities are highly exposed. The results of the XRF screening (Table 6) clearly indicates that BFRs are highly employed in different brands of TVs including the lately manufacture products. However, like the case of computers, the amount of Br didn't show any consistency regarding to either product type or manufacturing time. For example, the amount of Br (inppm) was found to be 30,143 in Sony wega, 35,582 in Sony tritron (both CRTs), and 68,591 in Sony (LCD). Similar results were obtained in Sharp 2004 (12,809), Zenith 1995 (65,397), Samsung 2011 (35,326), Samsung 2013 (19,981), and LG 2012 (16,683).

Table 6. Samples of televisions screened for bromine.

TV name	Manufacturing time	Amount of Br (ppm)
Sanyo*	#	574.0035
Philps*	#	824.3209
RMC*	#	1552.5406
Aiwa*	#	80,916.4919
LG*	#	54,690.8849
Samsung*	#	71,729.7516
Sony Tritron*	#	35,582.8421
SHARP*	2004	12,809.6396
ZENITH*	1995	65,397.7278
SONY*	#	64,779.6055
LED Samsungmalasia	2013	19,981.5015
LCD Samsung china	2011	35,326.4404
Plasma Samsung china	2012	24,776.6682
Plasma HCT	2009	9707.4004
LG Korea	2012	16,683.3133
Changhong	2012	13,836.8859
LCD Sony	#	68,519.2829
LG universal	2015	5137.8747

NB: * CRT TVs, # manufacturing time was not found.

4. Conclusion

In Eritrea, the current lack of e-waste management framework and extremely low awareness has resulted into institutions and individuals storing their wastes in offices, homes and/or along with other types of materials. This preliminary XRF data for brominated flame retardants and the survey conducted related to e-waste management clearly indicated that there is high potential of environmental pollution as well as human exposure in the country. Sustainable management of e-waste stream not only safeguards the environment and human health from the hazards posed by the hazardous chemicals available in the e-wastes, but can also serve as an avenue to create employment and investment opportunities. Unless urgent suitable safety measures both for handling and disposing in a sustainable manner are taken, the growth of E-wastes will have significant economic, environmental as well as social impacts. To evaluate the environmental as well as health hazardous of PBDEs and other toxic materials of e-waste, further study using advanced analytical methods is mandatory.

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Conflicts of Interest

The authors declare that there is no conflict of interest in the overall project and publication of this manuscript.

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