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Analysis of Heavy Metals in the Human Hair to Establish the E-waste Toxicity Among the Filipino Informal Recyclers Located at Various E-waste Dumpsites in and Around Manila, Philippines

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ABSTRACT

The landfill areas of Tondo and Payatas located at the outskirts of Metro Manila are used for the dumping and dismantling of e-waste in the Philippines. The dismantling of e-waste by informal recyclers causes the leaching out of harmful substances such as heavy metals thereby contaminating the environment and the human population living in close proximity to e-waste landfills. This study was done to assess the contamination status by measuring the heavy metals in the hair of informal recyclers compared to heavy metal levels in the control group. Hair samples were collected and analysed using atomic absorption spectroscopy. Ten heavy metals were considered including essential minerals, Zn, Mg, K, Fe, Mn as well as Cd, Cu, Cr, Pb and Ni (toxic metals related to e-waste). The preliminary investigations establish the presence of heavy metals in the hair samples of e-waste recyclers, which confirms the absorption of heavy metals from e-waste into the body. The concentrations of metals (copper, lead and potassium) were significantly higher in the hair samples of the informal recyclers than the control group. Pb was significantly higher than the permissible limits in recyclers from the Payatas dumpsite and Cu, Ni and Cd were significantly higher than the permissible limits in recyclers from the Tondo dumpsite. The results prove that human scalp hair can be used as biomarker to assess the extent of heavy metal exposure to informal recyclers engaged in e-waste recycling activities.

INTRODUCTION

Philippines also known as the texting Capital of the world, like many other countries is facing a real challenge in terms of the management of its electronic waste (e-waste). E-waste is a term used to describe old, end-of-life and discarded appliances that use electricity (Puckett et al. 2002). According to an estimate, 41.8 million tons of e-waste was generated globally in 2017 and it is estimated to increase to 65.4 million tones (Breivik et al. 2014, Heacock et al. 2015). The increase in the domestic consumption of the electronic gadgets and the transboundary movement of e-waste from developing countries has also led to a tremendous increase in the volumes of e-waste generated in Philippines in the recent years (Alam 2016). With only 14 companies accredited by the Department of Environmental and Natural Resources (DENR) in the Philippines that accept e-waste and electronic scraps, the citizens of the Philippines resort to other ways of managing their waste, one of which is by informal recycling (Sanez 2010).

The lack of formal recycling facilities and the availability of cheap labour has led to the recycling of e-waste to be done by mainly the informal sector. The crude and unsafe methods used by the informal recyclers cause various toxins and harmful chemicals present in the e-waste to be released into the atmosphere, seep into the soil and into the groundwater which may then contaminate aquatic life and agricultural crops. During these often environmentally risky and unsafe processes, toxic chemicals, including heavy metals are released into the environment. Guiyu and Taizhou in China (Widmer et al. 2005, Zhang et al. 2012), Bengaluru in India (Ramesh et al. 2007), Lagos in Nigeria (Leung et al. 2008) and Accra in Ghana (Asampong et al. 2015) are the infamous e-waste dumpsites, which have witnessed the disastrous impacts of e-wastes toxicity due to informal e-waste recycling and its improper disposal. Similar to these dumpsites, besides other hazardous chemicals, a heavy metal contamination more than the permissible limits have been reported in the soil samples of the e-waste dumpsites of Tondo and Payatas in Philippines (Alam et al. 2017). The detection of heavy metals in the hair samples of the e-waste informal recyclers will confirm the exposure to the heavy metals from e-waste and their accumulation in the body of the informal recyclers working at these e-waste dumpsites. The human exposure to the heavy metals can cause damage to the body such as muscle inflammation and skin diseases

Fig. 1: Location of e-waste dumpsites in Payatas (A) and Tondo (B) near Metro Manila, Philippines.

Fig. 2: E-waste dumpsites located in Payatas (A, B, C) and informal e-waste recyclers (D and E).

to even more severe effects like brain damage and lung cancer (Ramachandra 2004). There is currently no data available for heavy metal exposure as a component of e-waste in Philippines. The data collected could be the baseline information for heavy metal concentration due to e-waste exposure as this study is the first of its kind in the Philippines involving the informal e-waste recyclers. Presence of a significantly high content of heavy metals in the hair of informal e-waste recyclers would be indicative of the toxicity of e-waste and the possibility that these toxins can be absorbed into the body. The results of this study can help the country to come up with effective methods to minimize the exposure to e-waste toxicity. This study also may encourage the government and the stakeholders to take necessary action and state new laws to prevent the dumping and informal recycling of e-waste in landfills, overall providing a better environment for future generations to come.

MATERIALS AND METHODS

Research and Sampling Design

The study was composed of three parts where the first part

Fig. 3: Informal e-waste recyclers in Tondo (A and B) and e-waste dumpsites located in Tondo, Manila (C and D).

involved the gathering of information about the location of e-waste dumpsites. Data from these dumpsites were obtained by visiting dumpsites located in Metro Manila specifically, Tondo and Payatas. The second part of the study involved the identification of informal e-waste recyclers located at these dumpsites, which was done for Payatas location with the help of local contacts of Ban Toxics organization (Fig. 2), and for Tondo, with the assistance of the Sustainable Management Practices officials (Fig. 3). At both the locations, the access to the e-waste dumpsites and informal recyclers was made possible through the help of the Barangay (Local Municipal Body) chief. The appropriate ethical considerations involving human volunteers were followed. A questionnaire was prepared and, a detailed survey was conducted to gather information about the medical history, involvement with e-waste, health-related problems as well as the lifestyle of each participant.

For the control group, 50 participants were selected who neither were informal e-waste recyclers nor exposed to the harmful chemicals found in e-waste dumpsites and a similar detailed survey was conducted to gather information about their lifestyle. Lastly, the third part of the study involved the processing of the hair samples collected from each participant for the atomic absorption spectroscopy (AAS) to assess the quantity of specific heavy metals in the hair samples.

Description of the Study Site

The surveys and hair samples were collected from dumpsites in Payatas and Tondo. Illustrated in Fig. 1 is an overhead map of the general area of the studied site.

Five dumpsites in close proximity to one another were visited at Payatas where scrap metal, old desktop monitors, and computer CPUs etc. were dumped (Fig. 2). The other e-waste dumpsite located at Tondo also had massive e-waste such as circuit boards, copper wires and old household appliances stored and dumped (Fig. 3). Majority of the informal recyclers did not use any protective equipment or clothing, though some wore thin gloves as a means of protection. Hair samples and survey papers from informal recyclers in dumpsites at Tondo and Payatas were collected.

Laboratory Analysis

Washing of collected hair samples: The hair samples were washed according to the hair washing protocol of the International Atomic Energy Agency (IAEA). The hair samples were cut into pieces using a pair of sterile scissors that were rinsed with ethanol. The samples were then washed with dilute non-ionic detergent (5%), de-ionized water and acetone while stirring in a beaker. Then the washing solvent was decanted off and the samples were rinsed again twice with de-ionized water to ensure that there is no remaining residue from the acetone and detergent. Lastly, the hair samples were air dried at room temperature between two filter papers in a dust-free room.

Acid digestion: Acid digestion was done to decompose the matrix of the hair samples and dissolve it into a solution in

Table 1: Heavy metal profile of male and female controls without hair products.

Hair samples	Cu (ppm)	Ni (ppm)	Pb (ppm)	Zn (ppm)	Fe (ppm)	Mg (ppm)	K (ppm)	Mn (ppm)	Cr (ppm)	Cd (ppm)
Male Control without hair products	0.1921 ± 0.2328	0.3604 ± 0.6330	-0.3536 ± 0.9686	1.4679 ± 1.2369	0.9213 ± 0.8190	1.2973 ± 0.7901	4.0969 ± 5.6152	0.5800 ± 0.4597	0.0131 ± 0.4156	0.7704 ± 0.4439
Female Control without hair products	0.1507 ± 0.1706	1.3456 ± 1.5361	-0.3146 ± 0.9300	2.7953 ± 3.5719	1.3378 ± 1.0387	1.8732 ± 1.8979	1.1417 ± 1.6385	0.9176 ± 0.7215	0.2028 ± 0.2090	0.9615 ± 0.6155
Permissible limits	0.1	0.2	0.1	15	N/A	N/A	N/A	N/A	0.1	0.06
*p-value	0.6453	0.0854	0.9259	0.28837	0.3891	0.4478	0.3158	0.2864	0.2747	0.7468
**p-value	0.3721	0.0427	0.1923	0.0000	N/A	N/A	N/A	N/A	0.2066	0.2863
**p-value	0.2187	0.4436	0.1514	0.0000	N/A	N/A	N/A	N/A	0.5730	0.1093

*p-value: Difference between means of male control without hair products and female control without hair products.
**p-value: Difference between means of female control without hair products and the permissible limits.
***p-value: Difference between means of male control without hair products and the permissible limits.

Table 2: Comparison of control males with hair products and no hair products.

Hair samples	Cu (ppm)	Ni (ppm)	Pb (ppm)	Zn (ppm)	Fe (ppm)	Mg (ppm)	K (ppm)	Mn (ppm)	Cr (ppm)	Cd (ppm)
Control without hair products	0.1921 ± 0.2328	0.3604 ± 0.6330	-0.3536 ± 0.9686	1.4679 ± 1.2369	0.9213 ± 0.8190	1.2973 ± 0.7901	4.0969 ± 5.6152	0.5800 ± 0.4597	0.0131 ± 0.4156	0.7704 ± 0.4439
Control with hair products	0.2073 ± 0.2176	2.3457 ± 3.2009	0.3502 ± 0.5031	-0.0295 ± 1.3258	0.3435 ± 0.6148	13.0504 ± 17.0937	0.6882 ± 0.3117	0.2315 ± 0.1353	0.3635 ± 0.0564	N/A
*p-value	0.9393	0.5410	0.2342	0.3302	0.3825	0.5089	0.2467	0.1078	0.0513	N/A

*p-value: Difference between means of control without hair products and with hair products.

Table 3: Comparison of control females with hair products and no hair products.

Hair samples	Cu (ppm)	Ni (ppm)	Pb (ppm)	Zn (ppm)	Fe (ppm)	Mg (ppm)	K (ppm)	Mn (ppm)	Cr (ppm)	Cd (ppm)
Control without hair products	0.1507 ± 0.1706	1.3456 ± 1.5361	-0.3146 ± 0.9300	2.7953 ± 3.5719	1.3378 ± 1.0387	1.8732 ± 1.8979	1.1417 ± 1.6385	0.9176 ± 0.7215	0.2028 ± 0.2090	0.9615 ± 0.6155
Control with hair products	0.2671 ± 0.3440	4.6188 ± 5.7112	0.0419 ± 1.1831	2.4098 ± 3.0016	0.7646 ± 0.7378	2.5136 ± 2.6926	3. 3453 ± 6.3871	0.2895 ± 0.2434	0.2101 ± 0.2084	0.6541 ± 0.1069
*p-value	0.2339	0.0284	0.3825	0.7746	0.1936	0.5153	0.2480	0.0444	0.9382	0.6079

*p-value: Difference between means of control without hair products and with hair products

preparation for the AAS test. For the digestion of the hair samples, the standard protocol was used (Abdulrahman et al. 2012). For the hair digestion, 1.065 g of the hair samples were then placed in a 50 mL crucible per sample and 8 mL of concentrated nitric acid was added into the crucibles. The crucibles covered with a lid were then heated on a hot plate at 75°C until the hair samples were digested completely. Afterwards, 1 mL of 30% H_2O_2 was added to the samples in the crucibles and was subjected to another round of heating until the volume of the liquid was reduced to approximately around 2.5 mL. The digested hair samples were then placed into volumetric flasks for the atomic absorption spectroscopy.

Atomic absorption spectroscopy (AAS): AAS was performed using the atomic absorption spectrophotometer (model AA-6300 Shimadzu) and the standard procedure for hair samples was followed (Peter et al. 2012). The samples placed in the volumetric flasks were analysed using the flame photometer. First the flame spectrophotometer was prepared, and then the provided standard solutions of each of the heavy metals were utilized to create the calibration standards of 0.05, 0.1, 0.5, and 1 ppm using the concentration and absorbance data for each as basis for the content in the hair samples. These calibration standards were used due to the fact that these values are the range commonly found in hair samples. Using the data from the calibration curve of

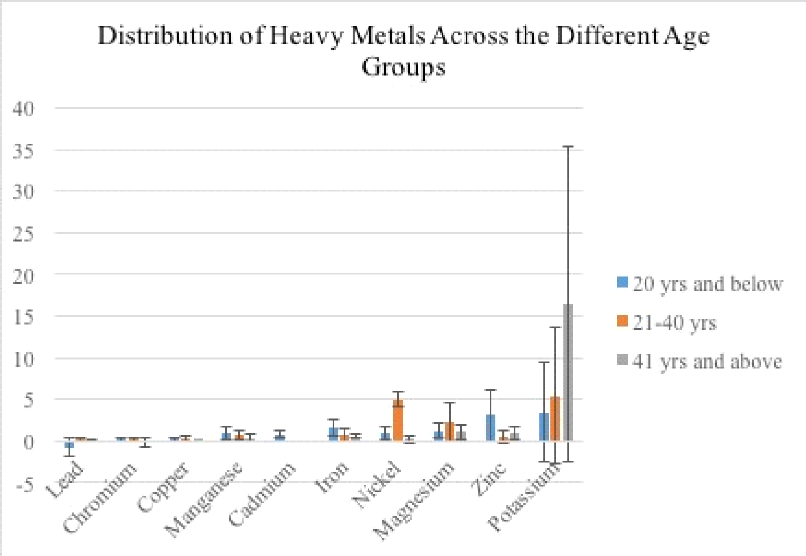

Fig. 4: Distribution of heavy metals across the different age groups.

the standard solutions, the concentration and the absorbance of the hair samples were calculated.

Data Analysis

The experimental group was composed of e-waste recyclers from Tondo and Payatas, whereas the control group, comprised of hair samples from 50 people who were not exposed to harmful conditions and live a relatively healthy lifestyle, was used as a basis of comparison in the statistical analysis. The data collected were subjected to the t-test using MS Excel to compare the heavy metals concentration in the control population and the experimental group. Any significance was determined at an alpha of at least 0.05 (95% confidence). Data were represented as mean $\pm$ SEM.

RESULTS AND DISCUSSION

Hair analysis is an accurate tool to determine the amount of heavy metals being stored in the body's fat, tissues, organs and cells (Energy Medicine Center, n.d.). Hence, in this study, heavy metal concentrations of copper, nickel, lead, zinc, cadmium, iron, magnesium, potassium, manganese, and chromium in parts per million (ppm) were taken into consideration. The information regarding their age, gender, the lifestyle and the work environment of the participants was inferred from the information collected in the survey questionnaires.

Analysis of Heavy Metal Profile of Control Population

The distribution of the heavy metals in the control female population without any hair product used on the hairs follows the series in decreasing order of Zn > Mg > Ni >Fe > K >Cd > Mn > Cr > Cu > Pb (Table 1). Zn, Fe, Mg, K, Mn, Cr and Cd were found to be higher than the male counterpart though statistically insignificant at $p<0.05$. When compared to the permissible limits, cadmium (Cd) was found to be many folds higher though, statistically insignificant. Nickel (Ni) was found to be significantly higher ($p<0.05$) than the permissible limits. The distribution of the heavy metals in the control male population follows the series in decreasing order of K > Zn > Mg > Fe Ã Cd > Mn > Ni> Cu > Cr > Pb. Cadmium (Cd) was found to be many folds higher than the permissible limits though, statistically insignificant at $p<0.05$ (Table 1). Lead was found to be absent from both cohorts. The hair products used could be the source of observed increase in the cadmium and nickel in the control population hair samples though other factors such as exposure to pollution cannot be ruled out. There is lack of any common international guidelines on the permissible limits of cadmium in the cosmetic products, however, the limits of 3 ppm and 5 ppm have been fixed by Canada and Germany respectively (Health Canada, n.d).

Since, many studies have reported the hair products such as hair pomades, hair dyes and bleaching creams to be the source of heavy metals (Amartey et al. 2011), a comparison was made between the heavy metal concentrations in the male hair samples with applied hair products and the male hair samples without the application of hair products. There was many fold increase observed in the metals nickel, lead, magnesium and chromium in the group of males with application of hair products as compared to the male group with-

Table 4: Comparison of hair samples collected from salons with hair samples of control without hair products.

Hair samples	Cu (ppm)	Ni (ppm)	Pb (ppm)	Zn (ppm)	Fe (ppm)	Mg (ppm)	K (ppm)	Mn (ppm)	Cr (ppm)	Cd (ppm)
Female Control without hair products	0.1507 ± 0.1706	1.3456 ± 1.5361	-0.3146 ± 0.9300	2.7953 ± 3.5719	1.3378 ± 1.0387	1.8732 ± 1.8979	1.1417 ± 1.6385	0.9176 ± 0.7215	0.2028 ± 0.2090	0.9615 ± 0.6155
Female Control from the salon	0.5007 ± 0.1799	12.5849 ± 2.1695	1.2272 ± 0.2731	1.7836 ± 0.9924	0.1459 ± 0.5416	2.2519 ± 1.7122	0.5356 ± 0.2584	0.1493 ± 0.2114	0.4450 ± 0.0818	NA
Permissible limits	0.1	0.2	0.1	15	NA	NA	NA	NA	0.1	0.06
*p-value	0.0073	0.0000	0.0004	0.4217	0.0206	0.7182	0.5150	0.0204	0.0151	NA
**p-value	0.0076	0.0002	0.0007	0.0000	NA	NA	NA	NA	NA	NA

*p-value: Comparison of female control without hair products and female control from the salon
**p-value: Comparison of female control from the salon and permissible limit

Table 5: Comparison of heavy metals in the hair samples of control with informal recyclers from Payatas.

Hair samples	Cu (ppm)	Ni (ppm)	Pb (ppm)	Zn (ppm)	Fe (ppm)	Mg (ppm)	K (ppm)	Mn (ppm)	Cr (ppm)	Cd (ppm)
Control without hair products	0.1724 ± 0.2016	0.8530 ± 1.2502	-0.3350 ± 0.9267	2.100 ± 2.6397	1.1295 ± 0.9288	1.5852 ± 1.4355	2.7835 ± 4.3815	0.7487 ± 0.6099	0.1080 ± 0.3325	0.8468 ± 0.4519
Experimental group (Payatas)	0.8322 ± 1.1625	0.1111 ± 0.2605	0.5140 ± 0.6020	1.1751 ± 0.6085	2.1701 ± 2.0002	0.5515 ± 0.6910	12.2363 ± 12.4046	1.1897 ± 0.6568	0.0166 ± 0.0454	-0.0083 ± 0.0111
Permissible Limits	0.1	0.2	0.1	15	NA	NA	NA	NA	0.1	0.06
*p-value	0.0763	0.0179	0.0033	0.1379	0.1143	0.0193	0.0279	0.0831	0.2939	0.0133
**p-value	0.0517	0.2620	0.0364	0.0000	NA	NA	NA	NA	0.0000	0.0000

*p-value: Comparison of the control group without hair products and the experimental group (Payatas).
**p-value: Comparison of the experimental group (Payatas) and the permissible limit

Table 6: Comparison of heavy metals in the hair samples of control with informal recyclers from Tondo.

Hair samples	Cu (ppm)	Ni (ppm)	Pb (ppm)	Zn (ppm)	Fe (ppm)	Mg (ppm)	K (ppm)	Mn (ppm)	Cr (ppm)	Cd (ppm)
Control without hair products	0.1724 ± 0.2016	0.8530 ± 1.2502	-0.3350 ± 0.9267	2.100 ± 2.6397	1.1295 ± 0.9288	1.5852 ± 1.4355	2.7835 ± 4.3815	0.7487 ± 0.6099	0.1080 ± 0.3325	0.8468 ± 0.4519
Experimental group (Tondo)	0.3692 ± 0.1721	0.9953 ± 0.1178	-1.2624 ± 0.1178	3.3121 ± 1.2666	NA	NA	NA	NA	NA	0.9749 ± 0.1474
Permissible Limits	0.1	0.2	0.1	15	NA	NA	NA	NA	0.1	0.06
*p-value	0.0276	0.6207	0.2453	0.1198	NA	NA	NA	NA	NA	0.5700
**p-value	0.0061	0.0000	0.1007	0.0000	NA	NA	NA	NA	NA	0.0000

*p-value: Comparison of the control group without hair products and the experimental group (Tondo).
**p-value: Comparison of the experimental group (Tondo) and the permissible limit.

out hair products though the results were statistically insignificant at $p<0.05$ (Table 2).

In case of females, the metals copper, nickel, lead, iron, magnesium and potassium were found to be many folds higher than the control female hair samples without the hair products (Table 2). Nickel was found to be significantly higher ($p<0.05$) in the female's hair samples with hair products than the female's hair samples without the hair products. Manganese was significantly higher ($p<0.05$) in the control group without the hair products than the group with the hair products (Table 3). The results suggest that for relatively more accurate comparison of the heavy metal concentration in the control and experimental group, the hair samples without the application of hair products should be used.

Review of literature related to heavy metal studies reveal that in many studies the hair samples were collected from salons for the experiments (Wei et al. 2008). In the present study, a comparison was made between the heavy metal concentration in the hair samples of females collected from hair salons and the scalp hair samples obtained from respondents individually. The hair samples from salon showed significant increase in the heavy metal concentration of Cu, Ni, Pb and Cr at $p<0.05$ (Table 4). Cu, Ni and Pb were found to be significantly higher than the permissible limits ($p<0.05$) (Table 4). One of the probable reasons could be the presence of heavy metals in the hair products used at salons, which can be absorbed into the hair and scalp of the participants. High concentrations of heavy metals have been reported in the cosmetic products of spurious nature (Ullah et al. 2017). Hair dyes have been reported to contribute to the increase in the levels of certain heavy metals particularly manganese, iron, copper, cadmium and antimony (Wei et al. 2008, Hussain et al. 2013). Since, the presence of heavy metals in the hair samples can lead to high control values due to contamination, these samples were excluded from our studies. Many participants also reported that the regular use of hair dye and bleaching products on their hair can also lead to higher concentrations of heavy metals in the control group. These results clearly suggest that for any studies related to comparison of heavy metal concentrations, the collection of hair samples from the hair salons should be avoided, as the possibility of the hair products being the source of heavy metals could not be ruled out.

Besides hair dyes, age and the type of food, which comprises the diet and nutrition status, can also influence the heavy metal profile of an individual which was evident as the control group included people with unusual levels of certain heavy metals when compared to the other samples. In general, heavy metals show no significant relationship in terms of age groups, although it can be said that in general the levels of heavy metals increase with increase in the age (Sani 2017). In the present study also like other studies, no significant association between the age and heavy metal concentration was observed though an overall increase in the metal concentration was detected in the age group of 21-40 year with respect to Pb, Cr, Cu, Ni, Mg. However, a decrease in these heavy metals was observed in the age group of 41 year and above with the exception of K concentration, which was the highest in this age group (Fig. 4). Lemos et al. (2005) have also reported that individual's deviation of elemental concentrations reflect the degree of environmental pollutants exposure to the human body, intake of food and metabolism. It is noteworthy to mention that heavy elements also play an important role in assisting the body to perform important functions. Potassium for example, aids in heart function and muscle contraction while magnesium aids in nerve and immune function (Wills 1986). Nonetheless, consumption of foods rich in potassium such as bananas may contribute to high levels of potassium (Stone et al. 2016). Similarly, foods such as nuts, leafy vegetables and soy are rich source of magnesium. Bananas and soy in the form of soya sauce are common components of the Filipino diet; it is possible that excessive consumption of foods high in these elements can lead to a build-up of these metals in the body. High levels of potassium can lead to hyperkalemia, which causes abnormal heart rhythms and muscle paralysis (Mushiyakh et al. 2012). High levels of magnesium on the other hand can cause hypermagnesemia which cause problems in the nervous system wherein it can cause neuromuscular hyper excitability that may range from tremors, fasciculation, convulsions, and even neuropsychiatric disturbances (apathy, delirium, and even coma) (Phuong-Chi et al. 2014). Those who consume fish in their diets can also show increased levels of heavy metals due to their habitat being in bodies of water that contain presence of heavy metals that come from nearby factories or in the case of the one in Tondo, near e-waste dumpsites. Fish can also accumulate high levels of heavy metals in their tissue through the food they eat as well as sediments that pass through the gills. A study showed that heavy metals such as Cu, Zn, and Fe accumulate highest in the livers of fish (El-Moselhy et al. 2014). Pb and Mn accumulate highest in the gills of fishes. Fish with high levels of heavy metals can increase the risk of problems (renal failure, liver damage, cardiovascular disease) to people who include them in their diet (El-Moselhy 2014). From this we are compelled to assume that the diet and nutrition of the participants may affect the heavy metal concentration in the body, hence these important factors need to be considered for any future analysis involving heavy metal accumulation in humans.

Analysis of Heavy Metal Profile of E-waste Recyclers (Payatas E-waste Dumpsite)

The heavy metal concentration analysis in the informal recyclers located at Payatas, demonstrate K, Mn, Pb and Cu to be many folds higher than the control population (Table 5). The distribution of the heavy metals in the experimental group at Payatas follows the series in decreasing order of K > Fe > Mn > Zn > Cu > Mg > Pb > Ni > Cr > Cd (Table 5). Pb, and K were found to be significantly higher than the control group at $p<0.05$. Pb was significantly higher in the Payatas recyclers when compared to the permissible limits at $p<0.05$ (Table 5).

Analysis of Heavy Metal Profile of E-waste Recyclers (Tondo E-waste Dumpsite)

The concentration of heavy metals found in the hair samples of the informal e-waste recyclers located at Tondo were comparable to the concentrations in the hair samples of e-waste recyclers reported in other studies (Wang et al. 2009). With the exception of Pb, all metals compared (Zn, Ni, Cd, Cu) were found to be many folds higher in the experimental group of informal e-waste recyclers located at Tondo than the control population though statistically insignificant at $p<0.05$ (Table 6). This increase in the metal concentration could be due to the exposure to e-waste while engaging in dismantling and recycling practices. Cu was found to be significantly higher in the informal recyclers as compared to the control group at $p<0.05$. High dosages of this metal absorbed into the body beyond the permissible limit of 0.1 ppm may lead to vomiting, diarrhoea, liver damage and skin disease (Minnesota Department of Health 2005). Cu, Ni and Cd were found to be significantly higher than the permissible limits at $p<0.05$ (Table 6). Batteries, pigments, metal coatings, televisions phosphors are the source of cadmium (ACGIH 2007). Short-term exposure to cadmium can lead to shortness of breath, cough, chest pain and the long-term exposure can result in emphysema, kidney damage and increased risk of cancer (Thun et al. 1991).

In addition to Payatas and Tondo informal recyclers with higher levels of heavy metals compared to the control population, it was also observed that the heavy metal concentrations of lead was significantly higher in the scalp hair of the informal recyclers from Payatas (Table 5) and the copper, nickel and cadmium were significantly higher in the scalp hair of informal recyclers of Tondo when compared to the permissible limits (Table 6). This indicates that informal recyclers of e-waste are absorbing heavy metals into their body in dangerous quantities which puts them in greater risk for certain diseases such as muscle inflammation, neurological diseases as well as lung cancer. This is an alarming fact that must be made known to the people living near e-waste dumpsites, especially for those who work as informal e-waste recyclers.

The comparison of heavy metal profile of the recyclers of the two locations is in tandem with the difference in the recycling style of the informal recyclers. At Paytaas, each recycler was tasked with handling a specific electronic appliance such as one specifically dismantling car battery, another one computers etc. However, at Tondo, the recyclers were dealing with general e-waste including motherboards and circuit boards. The health survey conducted in this study using the questionnaire also confirmed the higher prevalence of work related respiratory, dermatological and overall compromised health among the e-waste recyclers as compared to the control population. Since, e-waste pollutants including the heavy metals are released as mixtures, the effects of exposure to a specific compound or element cannot be considered in isolation. Hence, a more detailed understanding of the complex interactions between the heavy metals and other chemical components is needed. Just like any other study related to hair samples analysis for heavy metals, the results obtained in this study is also influenced by the lack of differentiation between the endogenous and exogenous deposition of pollutants and the exact metabolic state of an individual. Despite these limitations, the results confirm that the scalp hair can be used for biomonitoring of heavy metal contamination due to e-waste exposure.

CONCLUSION

The atomic absorption spectroscopy results confirm the presence of heavy metals in the hair samples of the control as well as the informal e-waste recyclers. Hence, the human scalp hair can be used as biomarker to assess the extent of heavy metal exposure to informal recyclers engaged in e-waste recycling activities. The presence of heavy metals in the hair samples establishes the occupational hazards and the possibility of long-term effects of toxicity of these heavy metals on the health of the e-waste recyclers. The results demonstrate that heavy metals such as copper, lead, potassium, nickel and cadmium were statistically higher in e-waste recyclers when compared to the control group. The results of the control group in the present study can be used in elaboration of reference values in the Filipino population for the heavy metal concentrations with the consideration of age, sex and their general health. Since, the heavy metals contribute to the genotoxic potential of the e-waste it is critical and of vital importance to carry out further investigations at other e-waste landfill areas in the Philippines and more e-waste informal recycler cohorts are identified for heavy metal hair analysis to understand the e-waste toxicity.

Recommendations

The results from this study establish the increase in certain heavy metals concentration in the informal recyclers due to exposure to the e-waste, therefore, it is important to minimize the e-waste toxicity by its proper management. In Philippines, there are no specific laws against e-waste, and discarded electronics fall under the “special waste” category of Republic Act No. 9003 also known as the Ecological Solid Waste Management Act of 2000. In addition to RA 9003, there is RA 6969, the Toxic Substance and Hazardous and Nuclear Waste Act of 1990, which seeks to regulate or prohibit the importing, manufacturing, processing, sale, distribution, use and disposal of these dangerous wastes. These laws do not cover the explicit problem of e-waste management. Since, e-waste is still considered within the solid waste category, there will always be a lacuna in terms of strict legislation needed to manage e-waste unless there is an amendment in these laws. Hence, the government, stakeholders and other agencies should formulate proper guidelines, legislature and policies to manage e-waste effectively and efficiently. It is also important to carry out more investigation by increasing the sample size of the experimental group by including more informal e-waste recyclers located at e-waste dumpsites outside Metro Manila. Since the high levels of heavy metal exposure is linked to many health hazards, regular biomonitoring and health checkup of the informal recyclers is recommended. In addition to hair, other body tissues such as nails can be included to get more comprehensive information.

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