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Contamination and Health Risk Assessment of Exposure to Heavy Metals in Soils from Informal E-Waste Recycling Site in Ghana

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Abstract

The objective of this study is first, to investigate the level of heavy metals in soils from Agbogbloshie e-waste processing site (AEPS), the degree at which these heavy metals contaminate the area and finally, to assess the carcinogenic and non-carcinogenic health risk of heavy metals on workers and residents in around the AEPS. 132 soil samples were collected from the study area and the samples analyzed for Ba, Cd, Co, Cr, Cu, Hg, Ni, Pb and Zn heavy metals after appropriate preparations were made. Results of the analysis showed mean concentrations of Cd, Cr and Ni considered as carcinogenic were lower than permissible levels of Dutch and Canadian soil standards. Mean concentrations however of Cu, Pb and Zn were between 100% and 500% higher than the permissible levels. Assessment of the degree of Contamination indicated Ni<Ba<Co<Cr<Zn<Hg<Cu<Cd<Pb in an increasing order as contributing to the degree of contamination with according to the degree of contamination index the burning, dismantling, residential and commercial considered as very highly contaminated. The health risk analysis of individual heavy metals in soil indicated non-carcinogenic risk of Cr, Hg and Pb with hazard index above the safe level of 1 in the burning and dismantling areas and as such could trigger neurological and developmental disorders in children less than six (6) years.

Keywords:

Heavy Metals;
Degree Of Contamination;
Health Risk;
Carcinogenic;
Non-Carcinogenic.

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1- Introduction

Heavy metals are ubiquitous in the environment as a result of natural and anthropogenic activities such as discharges from industries, vehicular emission, agriculture and other human induced activities. Heavy metals from these sources accumulate in soil which not only contaminate the soil but lead to uptake of elevated heavy metals by plants and thus affect food quality and safety [1–4]. The accumulation of heavy metals in soils and plants is of increasing concern as it poses potential human health risk. Food chain contamination, inhalation of contaminated soil dust and dermal contact as three possible pathways or routes by which humans can be exposed to heavy metals. Human exposure to heavy metals can have both carcinogenic and non-carcinogenic effect and can affect kidney, damage the nervous system of children, cause blood and brain disorders, irritation to the eyes and skin and can also cause permanent eye injury damage to DNA.

The Agbogbloshie scrapyard is well known for the processing end of life or discarded electrical and electronic equipment. With increasing quantities of discarded electrical and electronic equipment and its components known to contain valuable metals, avenues have been created for informal e-waste recyclers who apply extreme crude, primitive

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and rudimentary approaches such as open burning of cables and unsound dismantling to recover valuable fraction or metals from this stream of waste. The procedures of the informal recyclers and improper disposal of hazardous fractions contaminate the environment as a result of the release of heavy metals, polychlorinated biphenyls and brominated flame retardants from the open burning and unsound dismantling of e-waste in Agbogbloshie posing human health and ecological risk. Earlier studies showed significantly high levels of pollutants in soils and sediments from Agbogbloshie [5–10]. There is however very little known about the degree of contamination and health risk associated with heavy metals measured from Agbogbloshie.

Human health risk assessment models have been used to examine whether the exposure to heavy metals of any dose or amount could cause an adverse effect to human health [11–16]. Human health risk assessment consists of hazard identification, toxicity assessment, exposure assessment and characterization of risk, and involves estimating the probability of occurrence of an event (intake of heavy metals) and the probable magnitude of adverse effect of the event over a period of time [17]. With health risk especially high for children due to their low tolerance to toxins as well as the inadvertent ingestion of significant quantities of dust (or soil) through hand-to-mouth pathways [18, 19]. This research sought to fill the health risk gap by examining the degree of contamination posed by heavy metals in soil across the Agbogbloshie study site and assess both carcinogenic and non-carcinogenic health risk heavy metals in soil from the study site pose to children.

2- Materials and Methods

2-1- Study Area

Agbogbloshie is a suburb of Ghana's national capital Accra and is situated on the banks of the Korle lagoon and Odaw river northwest of the central business district between latitude 5◦ 32' 30''N and 5◦ 33' 30'' N and on longitude 0◦ 13' 30''W. The e-waste processing site in Agbogbloshie scrapyard covers an area of 6.2 hectres and surrounding the site are areas such as food market, farms, schools, health centres and residential areas (Figure 1). Agbogbloshie has a population of about 40,000 inhabitants with the active age group of 11 to 35 years involved in e-waste recycling [6]. Agbogbloshie e-waste processing site (AEPS) nick named "graveyard" for electronic waste is the largest in Ghana with activities estimated to bring in about 105 million dollars in revenue per annum to the economy. With lack of strict legislation and regulation, the brisk and primitive approaches such as burning used in Agbogbloshie, heavy metals, Copper (Cu), zinc (Zn), lead (Pb), cadmium (Cd), mercury (Hg), chromium (Cr), nickel (Ni) and other contaminants are emitted in to the environment in large quantities.

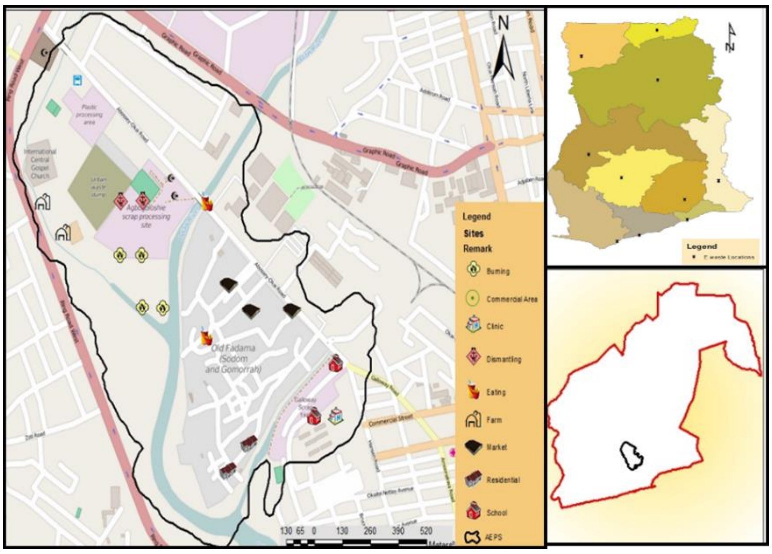

Figure 1. Location map of Agbogbloshie e-waste processing site

2-2- Sample Collection, Preparation and Analysis

132 soil samples were collected from 9 clusters in Agbogbloshie based on grid sampling system at a 100 m interval with the help of a handheld GPS. The samples were air dried in the laboratory at room temperature for a week. The samples were then pulverized using 100 µm nylon mesh to remove debris. Using a 10 ton hydraulic press 10 grams of the pulverized samples were pressed into 2.5 cm diameter pellet. An x-ray fluorescence spectrometer operating at 1000w (40kV and 20mA) was used to analyzed for heavy metals in the 2.5cm pellet. The pellet samples were placed on a disk 45° to the primary beam for a 10 minute irradiation using a silicon lithium Si(Li) detector at a resolution of 160eV with Mn and Kα peak. To validate the procedure used for analysis, IAEA soil 7 reference standard material was irradiated 5

times and the mean concentration of the elements obtained compared with certified values. The results felt within acceptable ratio of 5 to 10% indicating the results of the XRF conforms to certified values of the IAEA standard reference material. Validation procedure was repeated to ensure the calibration prior to the analysis was still intact. R 3.2.1 software and Microsoft excel were used to conduct basic statistical analysis of the results obtained in the study

2-3- Data Analysis

2-3-1- Contamination Assessment

With the possibility to utilize background or continental crustal averages and provide comprehensive assessment of contamination, this study utilized the contamination factor (Equation 1) to evaluate the pollution of the environment by single substances and complimented by the degree of contamination (Equation 2) which is defined as the sum of contamination factors was used to describe the contamination of the environment by all examined heavy metals.

$$C_f^i = \frac{C_{0-1}^i}{C_n^i} \tag{1}$$

$$C_{deg} = \sum C_f^i \tag{2}$$

where C_f^i is the contamination factor of the element of interest, C_{0-1}^i is the concentration of the element in the sample, and C_n^i is the background concentration or the continental crustal average as was used by [20]. C_f^i is defined by the following criteria < 1 low contamination, 1< $C_f^i \leq 3$ moderate contamination, 3< $C_f^i \leq 6$ Considerable contamination, and C_f^i>6 very high contamination. C_{deg} is the degree of contamination defined by Cdeg < 8 as low degree of contamination, 8 ≤ Cdeg < 16 as moderate degree of contamination, 16 ≤ Cdeg < 32 as considerable degree of contamination and Cdeg ≥ 32 as very high degree of contamination.

2-3-2- Determination of health risk from heavy metals

Health risk assessment is defined as the process of estimating the probability of occurrence of an event (exposure to heavy metals) and probable magnitude of its adverse effect over a specified time period.[21, 22] The assessment of human health risk in this study consisted of three phases; the hazard identification which involves the selection of chemicals or heavy metals of concern, exposure and dose intake assessment where the possible average daily dosage (ADD) for the three exposure pathways by which humans can be contaminated estimated and then finally the characterization of the human health risk either as carcinogenic or non-carcinogenic. The ADD which is the quantity of heavy metal concentration ingested, inhaled or absorbed through the skin were estimated based on exposure to heavy metal assessment model [23]. The equations of the exposure assessment models are as follows:

Ingestion

$$ADD_{ing} = C(mg/kg) \times \frac{IngR \times EF \times ED}{BW \times AT} \times 10^{-6} \tag{2}$$

Dermal contact

$$ADD_{derm} = C(mg/kg) \times \frac{SA \times SL \times ABS \times EF \times ED}{BW \times AT} \times 10^{-6} \tag{3}$$

Inhalation

$$ADD_{inh} = C(mg\ /kg) \times \frac{InhR \times EF \times ED}{PEF \times BW \times AT} \tag{4}$$

The characterization of the human health risk is expressed by the hazard index (Equation 7) and hazard quotient (Equation 6), with the hazard quotient defined as a ratio between exposure, i.e, the ADD for per exposure pathway of the heavy metal and the reference dose of the heavy metal. The sum of the hazard quotient for all the three exposure pathways defined the non-carcinogenic health risk.

$$HQ = \frac{DI}{RfD} \tag{5}$$

$$HI = HQ(inh) + HQ(ing) + HQ(derm) \tag{6}$$

Where the parameters in the Equations 3-7 are defined as follows for children less than 6 years; IngR: ingestion rate given as 200 mg day−1; InhR: inhalation rate 7.6 m3day−1; EF: exposure frequency as 350 day year−1; ED: exposure duration as 6 years; SA: Skin area exposed as 2800 cm2; SL: skin adherence factor as 0.2 mg cm−2h−1; ABS: dermal absorption factor as 0.001 for all heavy metals; PEF: particle emission factor as 1.36×109m3kg−1; BW: average body weight as 15kg for Ghanaian children and AT: averaging time; for non-carcinogens, ED×365 days; for carcinogens, 70×365=25,550 days. For carcinogens, the lifetime average daily dose (LADD) (Equation 8) for inhalation exposure was used in the assessment of the cancer risk [24,25]. The LADD is expressed as:

$$LADD = \frac{C \times EF}{AT \times PEF} \times [\left(\frac{InhR_{child} \times ED_{child}}{BW_{child}}\right) + \left(\frac{InhR_{adult} \times ED_{adult}}{BW_{adult}}\right)] \tag{7}$$

The potential cancer health risk was obtained by the product of the lifetime average daily dose and the inhalation slope factors for each of the heavy metals.

3- Results and Discussion

3-1- Heavy Metal Concentration in Soils

Concentrations of heavy metals measured in soils from AEPS are summarized in Table 1. Results indicate that the mean concentrations of Ba in the burning, dismantling, residential and areas close to worship centres, as well as mean concentrations of Cu and Pb in the burning, dismantling, residential and recreational areas and that of Zn levels in burning, dismantling and residential areas were above action required limits of Dutch and Canadian soil regulatory standards. Mean concentrations of heavy metals considered as carcinogenic, Cd, Co, Cr and Ni as well as Hg (which is non-carcinogenic) measured in soil from all sites in the AEPS were however below the Dutch and Canadian soil regulatory limits. Further, the results reveal a high variation in the distribution heavy metal concentration within AEPS and also show that the highest concentration of the heavy metals alternating between the burning and dismantling site which could indicate variability and intensity of activities that are conducted within the study area. At the burning site, Cu, Pb and Zn concentrations recorded 15, 5 and 3 times respectively more than concentrations for which action should be taken per the Dutch and Canadian soil standards. Similar trend is seen at the dismantling site where the mean concentration of Cu, Pb and Zn are 8, 2 and 3 times respectively more than concentrations for which action should be taken.

Table 1. Concentrations of heavy metals in soil at AEPS

Site	Ba	Cd	Co	Cr	Cu	Hg	Ni	Pb	Zn
				Burning					
Mean	641.5	10.1	43.8	171.5	2967.8	3.5	21.8	2666.4	1887.2
Range	270.5-1279.0	0.5-26.5	19.6-95.05	58.6-439.2	72.2-8254.0	0.9-9.9	3.2-85.0	81.2-5903.0	158.2-5398.0
Commercial Area									
Mean	493.6	0.6	29.6	290.9	157.7	0.35	6.2	163.9	516.9
Range	281.8-973.7	0.5-6.1	16.1-107.4	36.9-881.0	9.4-930.4	0.5-2.2	0.7-34.2	14.2-865.3	48.9-5398.0
Clinic									
Mean	581.1	-	28.5	119.3	40.7	-	-	55.8	220.5
Range	370.4-791.8	-	14.3-42.6	109.2-129.3	39.4-42.0	-	-	53.6-57.9	181.1-259.9
Dismantling									
Mean	785.7	7.8	66.1	419.2	1643.5	1.6	44.6	846.8	1939.2
Range	120.6-1469.0	0.5-26.1	10.8-129.0	53.2-1099.0	27.0-5615.0	0.7-9.9	0.6-106.1	30.2-2714.0	53.1-5398.0
Farm									
Mean	315.4	0.2	23.7	319.2	91.4	0.5	4.9	143.5	271.2
Range	226.3-399.0	0.9	11.2-32.4	70.3-1007.0	42.4-213.1	1.0-1.5	1.6-9.6	52.1-397.6	41.9-633.9
Recreational									
Mean	443.7	1.87	36.5	338.6	762.9	0.5	14.8	355.2	700.3
Range	157.2-739.7	0.4-11.1	8.8-77.6	53.7-737.6	44.1-8254.0	0.4-3.2	1.0-49.2	36.8-1441.0	75.3-2540.0
Residential									
Mean	658.08	2.63	51.5	153.9	1354.6	1.6	27.2	896.1	1170.4
Range	391.0-1045.0	0.9-9.6	13.5-129.0	21.1-380.6	38.3-6510.0	1.0-9.9	1.1-106.1	48.1-5903.0	194.5-4407.0
School									
Mean	394.35	0.3	42.3	118.8	47.6	0.6	2.2	111.3	293.2
Range	269.4-519.3	0.5	39.4-45.10	97.0-140.5	29.3-65.8	0.6	2.2	48.4-174.2	137.5-448.8
Worship									
Mean	783.9	0.3	30.5	184.6	118.2	0.4	4.9	117.0	419.9
Range	374.0-1306.0	0.3	11.8-41.2	59.9-372.7	57.7-230.5	0.6-0.7	1.9-12.9	64.3-218.9	178.4-881.9
Optimal (DSQGV)	200	0.8	20	100	36	0.3	35	85	140
Action (DSQGV)	625	12	240	380	190	10	210	530	720
Canadian (SQGV)	500	10	-	64	63	7	50	140	200

*Heavy metal concentration measured in (mgL^{-1})

3-2- Contamination Assessment of Heavy Metals

Contamination factor was used to evaluate the contribution of respective heavy metals to the sum of toxic units. Figure 2 shows results of contamination factors from the analyzed soil samples. On the average Ni<Ba<Co<Cr<Zn<Hg<Cu<Cd<Pb in an increasing contributed to the degree of contamination with Pb observed to have the highest contamination factor, while contamination factor of Ni is categorized as low, Ba, Co and Cr categorized as moderate contamination factor with Zn, Hg and Cu categorized as having very high contamination factor. Since individual metals can cause significant contamination to soil and ecosystem, it becomes more imperative to access their additive nature so as to examine or assess the cumulative risks [26]. The results of the cumulative risk represented by the degree of contamination is shown in Figure 2. The degree of contamination of the sites were largely driven by Pb, Cd and Hg. The commercial, recreational, residential, dismantling and burning sites are all classified as very highly contaminated with degree of contamination greater than 32, while premises close to worship, farms and school sites classified as having considerable contamination with degree of contamination within the range of 16 and 32 and areas close to the community clinics classified as having moderate contamination with degree of contamination within the range of 8 and 16 (Figure 3). The problem of contamination to soil by heavy metals within the AEPS may become prominent when steps are to be taken to remediate the site for the ecological restoration project and more importantly the health risk these contaminated site could pose to children who play and live in these areas.

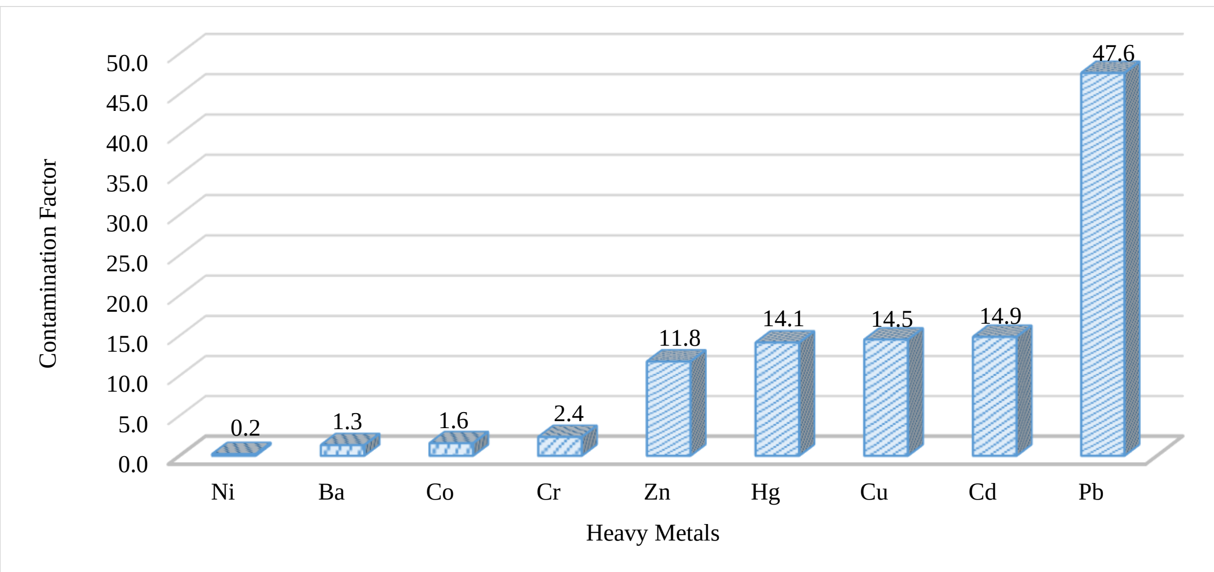

Figure 2. Contributions of respective heavy metal to the degree of contamination

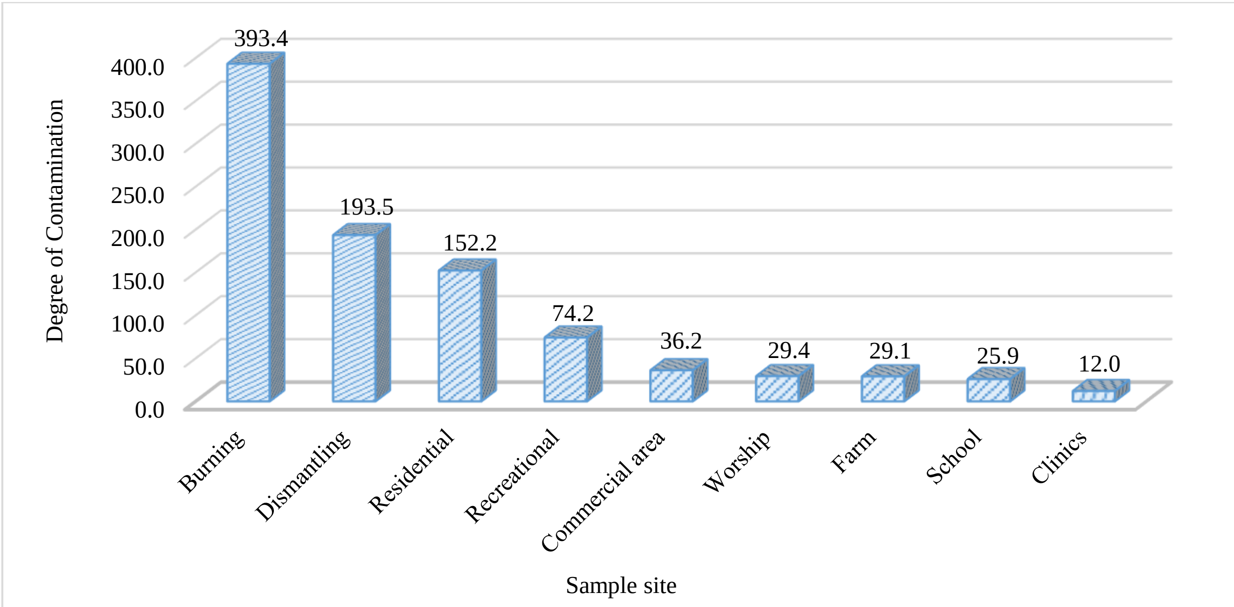

Figure 3. **Degree of contamination of heavy metals from the AEPS**

3-3- Health Risk of Heavy Metals

3-3-1- Exposure Pathways of Heavy Metals

The results of the health risk assessment are summarized in Table 2. The results reveal ingestion of heavy metals from soil dust as the highest exposure pathway followed by dermal intake and inhalation of heavy metals from soils. For the ingestion pathway, Cr, Pb and Ba (order Cr>Pb>Ba) were the three heavy metals with the highest hazard quotients, and a similar trend was also seen for the dermal pathway. The heavy metal Cr showed the highest hazard quotient through inhalation, followed by Ba and Pb. It is also however worth noting that Ni and Zn had the lowest hazard quotient in all three exposure pathways. Similar exposure pathway trend of inhalation<dermal contact<ingestion have also been reported by [11,12]. Further, it is also worth noting that the highest exposure or possible intake of heavy metals alternate between the burning and dismantling sites indicating the activities at these sites contribute to the heavy metals measured in soil and the danger it present to children in the area.

Table 2. **Hazard quotient and heavy metal intake of each element and exposure pathway**

Site	Ba	Cd	Co	Cr	Cu	Hg	Ni	Pb	Zn
Ingestion RfD	0.07	0.001	0.02	0.003	0.04	0.0004	0.02	0.0035	0.3
Dermal RfD	0.0049	0.00001	0.016	0.00006	0.012	0.000021	0.0054	0.000525	0.06
Inhalation RfD	0.000143		5.71E-06	0.0000286					
Inhalation SF		6.3	9.8	4.2			0.84		
Burning									
HQ_{Ing}	6.03E-02	6.64E-02	1.44E-02	3.76E-01	4.88E-01	5.70E-02	7.18E-03	5.01E+00	4.14E-02
HQ_{Derm}	2.41E-03	1.86E-02	5.04E-05	5.26E-02	4.55E-03	3.04E-03	7.45E-05	9.35E-02	5.79E-04
HQ_{Inh}	8.24E-04	1.86E-04	1.41E-03	1.10E-03	4.54E-05	3.03E-05	7.43E-07	9.33E-04	5.78E-06
LADD		5.18E-10		8.79E-09			1.12E-09		
Commercial Area									
HQ_{Ing}	4.64E-02	4.10E-03	9.73E-03	6.38E-01	2.59E-02	5.75E-03	2.04E-03	3.08E-01	1.13E-02
HQ_{Derm}	1.85E-03	1.15E-03	3.41E-05	8.93E-02	2.42E-04	3.07E-04	2.12E-05	5.75E-03	1.59E-04
HQ_{Inh}	6.34E-04	1.14E-05	9.52E-04	1.87E-03	2.41E-06	3.06E-06	2.11E-07	5.74E-05	1.58E-06
LADD		3.19E-11		1.49E-08			2.67E-10		
Clinic									
HQ_{Ing}	5.46E-02	_	9.35E-03	2.61E-01	6.69E-03	_	_	1.05E-01	4.83E-03
HQ_{Derm}	2.18E-03	_	3.27E-05	3.66E-02	6.24E-05	_	_	1.96E-03	6.77E-05
HQ_{Inh}	7.47E-04	_	9.15E-04	7.66E-04	6.23E-07	_	_	1.95E-05	6.75E-07
LADD				6.11E-09					
Dismantling									
HQ_{Ing}	7.38E-02	5.13E-02	2.17E-02	9.19E-01	2.70E-01	2.61E-02	1.47E-02	1.59E+00	4.25E-02
HQ_{Derm}	2.95E-03	1.44E-02	7.61E-05	1.29E-01	2.52E-03	1.39E-03	1.52E-04	2.97E-02	5.95E-04
HQ_{Inh}	1.01E-03	1.43E-04	2.13E-03	2.69E-03	2.52E-05	1.39E-05	1.52E-06	2.96E-04	5.94E-06
LADD		4.00E-10		2.15E-08			1.92E-09		
Farm									
HQ_{Ing}	2.96E-02	1.18E-03	7.80E-03	7.00E-01	1.50E-02	8.22E-03	1.60E-03	2.70E-01	5.94E-03
HQ_{Derm}	1.19E-03	3.31E-04	2.73E-05	9.80E-02	1.40E-04	4.38E-04	1.66E-05	5.03E-03	8.32E-05
HQ_{Inh}	4.05E-04	3.31E-06	7.64E-04	2.05E-03	1.40E-06	4.37E-06	1.66E-07	5.02E-05	8.30E-07
LADD		9.23E-12		1.64E-08			2.10E-10		
Recreational									
HQ_{Ing}	4.17E-02	1.23E-02	1.20E-02	7.42E-01	1.25E-01	8.51E-03	4.85E-03	6.67E-01	1.53E-02
HQ_{Derm}	1.67E-03	3.44E-03	4.20E-05	1.04E-01	1.17E-03	4.54E-04	5.03E-05	1.25E-02	2.15E-04
HQ_{Inh}	5.70E-04	3.44E-05	1.17E-03	2.18E-03	1.17E-05	4.53E-06	5.02E-07	1.24E-04	2.14E-06
LADD		9.59E-11		1.74E-08			6.35E-10		
Residential									
HQ_{Ing}	6.18E-02	1.73E-02	1.69E-02	3.37E-01	2.23E-01	2.69E-02	8.94E-03	1.68E+00	2.57E-02
HQ_{Derm}	2.47E-03	4.83E-03	5.93E-05	4.72E-02	2.08E-03	1.44E-03	9.27E-05	3.14E-02	3.59E-04
HQ_{Inh}	8.45E-04	4.82E-05	1.66E-03	9.88E-04	2.07E-05	1.43E-05	9.25E-07	3.14E-04	3.58E-06
LADD		1.35E-10		7.89E-09			1.17E-09		
School									
HQ_{Ing}	3.70E-02	1.64E-03	1.39E-02	2.60E-01	7.82E-03	9.04E-03	7.23E-04	2.09E-01	6.43E-03
HQ_{Derm}	1.48E-03	4.60E-04	4.86E-05	3.64E-02	7.30E-05	4.82E-04	7.50E-06	3.90E-03	9.00E-05
HQ_{Inh}	5.07E-04	4.59E-06	1.36E-03	7.63E-04	7.28E-07	4.81E-06	7.49E-08	3.89E-05	8.98E-07
LADD		1.28E-11		6.09E-09			9.47E-11		
Worship									
HQ_{Ing}	7.36E-02	1.97E-03	1.00E-02	4.05E-01	1.94E-02	7.12E-03	1.62E-03	2.20E-01	9.20E-03
HQ_{Derm}	2.95E-03	5.52E-04	3.51E-05	5.67E-02	1.81E-04	3.80E-04	1.68E-05	4.10E-03	1.29E-04
HQ_{Inh}	1.01E-03	5.51E-06	9.82E-04	1.19E-03	1.81E-06	3.79E-06	1.68E-07	4.09E-05	1.29E-06
LADD		1.54E-11		9.47E-09			2.12E-10		

3-3-2- Non-Carcinogenic Health Risk of Heavy Metals

The hazard indices for the non-carcinogenic risk obtained from a total of the hazard quotients are summarized in Table 3. The non-carcinogenic health hazard indices of Ba, Cd, Co, Ni and Zn for children under 6 years in all study areas within the AEPS were below the 1 reference limit of environmental and regulatory agencies below which hazards are considered acceptable for children. The values however of Cr and Hg in some areas (Burning, Dismantling and Residential) were above the 1 regulatory limit and considered unacceptable by environmental and healthcare managers. For instance hazard index for Pb in the burning was 500% above the reference limit for which exposure if contacted by children in high doses, can trigger neurological and developmental disorders [11,12]. Further, despite the low health hazard indices of Ba, Cd, Co, Ni and Zn in all AEPS sites, these heavy metals can be cumulative and can affect the kidney and other vital human organs, and as such their exposure to children must be avoided [27].

Table 3. Non-carcinogenic hazard indices

Area	Ba	Cd	Co	Cr	Cu	Hg	Ni	Pb	Zn
Burning	0.063	0.085	0.016	0.430	0.492	1.323	0.007	5.104	0.042
Commercial Area	0.049	0.005	0.011	0.729	0.026	0.134	0.002	0.314	0.011
Clinic	0.058	_	0.01	0.299	0.007	_	_	0.107	0.005
Dismantling	0.078	0.066	0.024	1.050	0.273	0.605	0.150	1.621	0.043
Farm	0.081	0.002	0.009	0.800	0.015	0.191	0.002	0.275	0.006
Recreational	0.044	0.016	0.013	0.848	0.127	0.197	0.005	0.68	0.016
Residential	0.065	0.022	0.019	0.385	0.225	0.625	0.009	1.715	0.026
School	0.039	0.002	0.015	0.297	0.008	0.210	0.001	0.213	0.007
Worship	0.078	0.003	0.011	0.463	0.020	0.165	0.002	0.224	0.009

3-3-3- Carcinogenic Health Risk of Heavy Metals

The carcinogenic risk was calculated as product of inhalation slope factor and the life average daily dosage based on the risk through inhalation for four carcinogenic heavy metals (Cd, Cr and Ni) using the model as expressed in Equation 8. The carcinogenic risk of these heavy metals due to activities within the AEPS is low, as it is below the threshold range of values 10^{-4} and 10^{-6}(Table 4. The cancer hazard index of these metals is in the order Cr> Cd>Ni with risk indices of Cd and Ni alternating depending on the site. Although hazard indices for the 3 carcinogenic heavy metals of Cd, Cr and Ni were all below the threshold range for which the hazard is acceptable, the risk index for Cr in all areas cannot be overlooked as is the closest to the threshold value and further accumulation without an intervention can be detrimental to health of children and adults.

Table 4. Carcinogenic hazard indices of heavy metals

Area	Cd	Cr	Ni
Burning	3.26E-09	3.69E-07	9.41E-10
Commercial Area	2.01E-10	6.26E-07	2.67E-10
Clinics	_	2.57E-07	_
Dismantling	2.52E-09	9.03E-07	1.92E-09
Farm	5.81E-11	6.87E-07	2.1E-10
Recreational	6.04E-10	7.29E-07	6.35E-10
Residential	8.48E-10	3.31E-07	1.17E-09
School	8.07E-11	2.56E-07	9.47E-11
Worship	9.69E-11	3.98E-07	2.12E-10

4- Conclusion

Heavy metal contamination as a result of e-waste recycling presents a significant threat to the environment, workers and residents of the Agbogbloshie e-waste processing site. This paper assessed the extent of contamination and health risk posed by Ba, Cd, Co, Cr, Cu, Hg, Ni, Pb and Zn heavy metals within the AEPS. From 132 soil sample locations, heavy metal concentrations were measured, contamination factor of each heavy metal estimated, degree of contamination calculated and the health risk evaluated.

In general, heavy metal concentrations in soils from the study area were highest in the main working areas burning and dismantling sites of informal e-waste recyclers and mean concentrations of Cd, Cr and Ni considered as carcinogenic and Hg from all sites within the AEPS were lower than the Dutch and Canadian soil regulatory limit but those of Cu, Pb and Zn considered non-carcinogenic had mean concentrations between 100-500% higher than regulatory limits of Dutch and Canadian soil standards. Analysis of contamination factor of individual heavy metal in soil from AEPS showed Ni<Ba<Co<Cr<Zn<Hg<Cu<Cd<Pb in an increasing order as contributing to the degree of contamination. According to the degree of contamination index classification, the burning, dismantling, residential, recreational and commercial areas within the AEPS represented highly contaminated sites.

Further analysis of possible health risk due to exposure of heavy metals to children under 6 years suggests children are not at significant potential carcinogenic health risk from intake of Cd, Cr and Ni but there is significant potential non-carcinogenic health risk due to exposure of Cr, Cu, Hg and Pb with hazard indexes in the burning and dismantling areas above reference value of 1 and can cause developmental and neurological disorders in children.

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6- Conflict of Interest

The authors declare no conflict of interest.

7- References

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