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Levels of Heavy Metals in Bottom Ash from Medical Waste Incinerators in Dar es Salaam

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Abstract*—Treatment of medical healthcare waste either by incinerating or open burning in a pit produces bottom ashes which contains heavy metals and other chemicals which are toxic, persistent and accumulate in the food chain resulting in adverse health effects in human and the environment. This study assesses the level of heavy metals in the bottom ashes of thermally treated medical waste from six health care facilities in Dar es Salaam city (Muhimbili Orthopaedic Institute (MOI), Amana, Magomeni, Mwananyamala and Temeke). The samples in triplicate were collected from a pile of bottom ash, according to ASTM D6009 Standard Guide for sampling waste piles (ASTMD6009-96), digested with a 3:1 concentrated HNO_3 and $HClO_4$ then heavy metal concentrations were determined using Inductively Coupled Plasma - Optical Emission Spectrometer (ICP-OES). While As, Cd and Hg were below detection limit, incinerating healthcare waste containing mercury risks public health as it readily sublimes, appearing as vapour in the environment and can be inhaled by humans. The average concentration of other metals were in the following decreasing order Fe > Zn > Cr > Ni > Pb > Mn > Cu. Iron level from the six hospitals ranged from 758.714±253.508 to 9484.806±3148.740 mg/kg while other metals like manganese and copper varies 8.267±0.103 to 61.704±32.544 mg/kg and 13.209±1.955 to 28.873±7.917 □g/kg respectively. All the metals investigated exceeded the USEPA regulation maximum permissible levels of heavy metals in good soil quality and therefore classified as harmful and toxic and therefore proper attention should be given to the ash disposal at the landfill sites.

***Keywords*— Bottom ash, medical waste, incinerator, heavy metal**

I. INTRODUCTION

Human activities create wastes and it is the way these wastes are handled, stored, collected and disposed that constitutes risks to the environment and public health [1]. In the urban areas, especially in the rapidly urbanizing cities of the underdeveloped world like Dar es Salaam, problems and issues of solid waste management are of critical debate. This is because rapid population growth overwhelms the capacity of most municipal authorities to provide even basic services. When wastes are collected, they are disposed off in uncontrolled dumpsites and/or burnt, polluting water resources, air and soil [1]

To minimize the hazards, incineration of medical waste is a significant alternative way for disposal of this category of waste. One of the medical waste treatments methods used worldwide is medical waste incineration. Recently, waste incineration has been a preferred alternative in hazardous waste and sewage sludge management in developed countries since land filling became more difficult to site due to high costs, diminishing land availability, more strict regulations, and frequent public opposition to establishing new landfills [2]. Unfortunately, incineration is not a clean process. Emissions of heavy metals and organic pollutants from these facilities cause significant environmental harm [3].

Tanzania like other developing countries still faces the problem of healthcare waste management (HCWM). The unsafe disposal of health-care waste (for example, contaminated syringes and needles) poses public health risks [4]. Contaminated needles and syringes represent a particular threat as the failure to dispose of them safely may lead to dangerous recycling and repackaging which lead to unsafe reuse. Contaminated injection equipment may be scavenged from waste areas and dumpsites and either are reused or sold to be used again.

The use of medical waste incinerators appears to be rapidly expanding in developing countries and

Tanzania is no exception. In the past, treatment of medical waste was primarily performed on-site at hospitals in dedicated medical waste facilities through incineration [5]. All those medical wastes which are incinerated are not sorted or separated prior to treatment. The big assumption is to reduce the volume of the waste, sterilizing the waste, and eliminating the need for pre-processing the waste before treatment. The resulting incinerated waste can be disposed of in traditional methods, such as brought to a landfill. Incinerators discharge hundreds of pollutants into the atmosphere [5]. Many of these chemicals are both toxic and bio accumulative, building up over time in the body in an insidious fashion with the risk of chronic effects at much lower exposures [6]. In a developing country like Tanzania, the problem of medical healthcare waste either by incinerating or open burning in a pit has not received enough attention so as to avoid acute local toxic effects.

The exact composition of emissions from incinerators will vary with what waste being is burnt at any given time, the efficiency of the installation and the pollution control measures in place [4-6]. A municipal waste incinerator will take in a great variety of waste contaminated by heavy metals and by man-made organic chemicals. During incineration more toxic forms of some of these substances can be created. The three most important constituents of the emissions, in terms of health effects, are particulates, heavy metals and combustion products of man-made chemicals; the latter two can be adsorbed onto the smaller particulates making them especially hazardous. In Tanzania, most hospitals have low incineration capacity, with few of them having fire brick incinerators [7].

Incineration is a waste treatment process that involves the combustion of organic substances contained in waste materials. Incineration and other high-temperature waste treatment systems are described as "thermal treatment [8]. Incineration of waste materials converts the waste into ash, flue gas, and heat. The ash is mostly formed by the inorganic constituents of the waste, and may take the form of solid lumps or particulates carried by the flue gas. The flue gases must be cleaned of gaseous and particulate pollutants before they are dispersed into the atmosphere. In some cases, the heat generated by incineration can be used to generate electric power or heat the water system [8].

In several countries, there are still concerns from experts and local communities about the environmental impact of incinerators [8]. Many of these incinerators especially from poor countries were built just a few decades ago often did not include a materials separation to remove hazardous, bulky or recyclable materials before combustion [6,8]. These facilities tended to risk the health of the community around due to inadequate levels of gas cleaning and combustion process control [8].

Incineration has a number of outputs such as the ash and the emission to the atmosphere of flue gas. The flue gases may contain significant amounts of particulate matter, heavy metals, and other toxic gases [5].

Heavy metal soil contamination is particularly problematic because they are not degraded in soil. At best they can be locally reduced by redistribution in the ecosystem or removed from circulation by immobilization [9]. These heavy metals and their compounds have different physical and chemical characteristics and pose diverse toxicological characteristics. Human beings are poisoned through inhalation, ingestion and skin absorption. Acute exposures to high levels cause nausea, anorexia, vomiting, gastrointestinal abnormalities and dermatitis [8-10].

Working in or living near incinerators which sometimes are installed closer to living and working premises these metals and their compounds increases one's risk of exposure, as does living near a site where these metals have been improperly disposed. Subsistence lifestyles can also impose higher risks of exposure and health impacts because of hunting and gathering activities [5].

Many people believe that waste disappears when it is burnt. In fact the burnt waste is transformed into ashes and gas. As this happens, chemical reactions lead to the formation of hundreds of new compounds, some of which are extremely toxic. The number of substances released from a waste incinerator may run into thousands. So far, scientists have identified a few hundred substances as hazardous [3].

Metals like cadmium and cadmium compounds are known human carcinogens. Smokers get exposed to significantly higher cadmium levels than non-smokers. Severe damage to the lungs may occur through breathing high levels of cadmium. Chromium compounds are toxins and known human carcinogens. Breathing high levels of chromium can cause irritation to the lining of the nose; nose ulcers; runny nose; and breathing problems, such as asthma, cough, shortness of breath, or wheezing. Lead is a probable human carcinogen. Lead can affect every organ and system in the body [9]. Long-term exposure of adults can result in decreased performance in some tests that measure functions of the nervous system; weakness in fingers, wrists, or ankles; small increases in blood pressure and anaemia. Exposure to high lead levels can severely damage the brain and kidneys and ultimately cause death. In pregnant women, high levels of exposure to lead may cause miscarriage [10]. Its toxicity is linked with reproduction problem because it affects sperm and reduces birth weight [11]. Mercury combines with other elements to form

organic and inorganic mercury compounds. Exposure to high levels of mercury can permanently damage the brain, kidneys, and developing fetuses. Effects on brain functioning may result in irritability, shyness, tremors, changes in vision or hearing, and memory problems [6].

Numerous studies in developed countries confirm that a typical incinerator releases a cocktail of toxic chemicals, including dioxins, lead, cadmium, mercury and fine particles, into the atmosphere [12-14]. However, there has been little follow up investigation into the effects of these poisons on people near incinerators. Therefore, it is the intention of this study to determine the contamination of bottom ash from these incinerators so as to add knowledge in Africa.

The approximate chemical composition of hospital waste is 37% carbon, 18% oxygen and 4.6% hydrogen, as well as numerous other elements [15]. The toxic metals that are found in health-care waste and that are readily emitted during combustion include lead, mercury, cadmium, arsenic, chromium and zinc. In the past, elemental compositions were used to estimate the products of combustion, but this can be misleading since health-care waste varies widely.

Moreover, persistent organic pollutants such as polychlorinated dioxins and furans cannot be predicted reliably from basic elemental compositions. These dioxins and furans are toxic at extremely low concentrations. However, decreasing the percentage of halogenated plastics (such as polyvinyl chloride) reduces the amounts of hydrogen chloride and other halogenated pollutants. Researchers [16], defined hospital waste as all waste generated, discarded during the patient care and not intended for further use in the hospital. Hospital waste can further categorized into seven categories namely general waste, pathological waste, infectious waste, sharps, pharmaceutical waste, chemical wastes, and radioactive waste [17]

II. Research Methodology

A. Study Area

The study was conducted in three administrative municipalities of Dar es Salaam region (Figure 1) health facilities or hospitals from within the city where incinerators were found functioning. The samples were collected from incinerators located in Magomeni Health Centre and Mwananyamala Regional Hospital in Kinondoni, Buguruni Anglican Health Centre, Amana Regional Hospital and Muhimbili Orthopaedic institute (MOI) in Ilala and Temeke Regional Hospital in Temeke

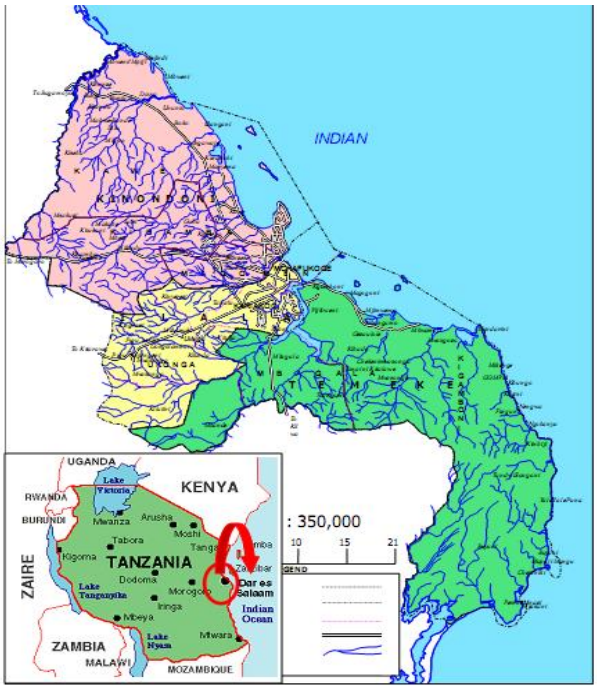

Fig. 1: Map of Dar es Salaam City Showing Three Administrative Municipalities

B. Sampling and Analysis

About 100g of bottom ash from the selected hospital incinerators was sampled. The samples were collected from a pile of bottom ash, according to ASTM D6009 Standard Guide for sampling waste piles (ASTMD6009-96), and placed in plastic packs in triplicate. The samples were transported to the laboratory of the Government Chemist Laboratory Agency (GCLA) for heavy metal analysis.
The ash samples obtained were air-dried at ambient temperature (27^{o}C) in the laboratory for five days. One gram of the dried sample was weighed and transferred into an acid washed, round bottom flask containing 10 cm^3 concentrated nitric acid. The mixture was slowly evaporated over a period of 1 h on a hot plate. Each of the solid residues obtained was digested with a 3:1 concentrated HNO_3 and $HClO_4$ mixture for 10 minutes at room temperature before heating on a hot plate. The digested mixture was placed on a hot plate and heated intermittently to ensure a steady temperature of 150°C for about 5 hours until the fumes of $HClO_4$ were completely evaporated [18]. The mixture was allowed to cool to room temperature and then filtered using Whatman No.1 filter paper into a 50 cm^3 volumetric flask and made up to the standard mark with deionized water after rinsing the reacting vessels, to recover any residual metal. The filtrate was then stored in pre-cleaned polyethylene storage bottles ready for analysis. Heavy metal concentrations were determined using Inductively Coupled Plasma - Optical Emission Spectrometer (ICP-OES).

The following metals were quantified directly: manganese, chromium, zinc, copper, lead, nickel, arsenic and cadmium. A multi-element instrument calibration standard was prepared at a concentration of 10 mg/l, matrix matched to the samples (i.e. in 15% v/v hydrochloric acid and 5% v/v nitric acid). The calibration was validated using a quality control standard (8 mg/l), prepared internally from different reagent stocks. Any sample exceeding the calibration range was diluted accordingly, in duplicate, and re-analyzed.

Mercury (Hg) was determined using Cold Vapour Generation ICP-OES. Hg (II) was reduced to Hg (0) i.e. a vapour, following reduction of the samples with sodium borohydride (0.6% w/v), sodium hydroxide (0.5% w/v) and hydrochloric acid (10 molar). The vapour was carried in a stream of argon into the spectrometer. Two calibration standards were prepared, at 10 ug/l and 100 ug/l, matrix matched to the samples (i.e. in 15% v/v hydrochloric acid and 5% v/v nitric acid). The calibration was validated using a quality control standard (80 ug/l), prepared internally from different reagent stock.

III. Results and Discussion

Taken together, these results are indicative of the hazardous nature of the ash residues generated by the incineration process, resulting from the presence of large quantities of heavy metals in the ash which is carried over from the material incinerated at the hospitals plant. Iron, manganese, lead, cadmium and copper are used in a wide range of consumer products. For example, lead and lead compounds are used extensively as additives in paints, plastics (particularly as stabilizers in PVC), glazes and solder preparations. Cadmium is also used as a PVC stabilizer and as a pigment in other plastics, as well as in nickel cadmium batteries and in some metal plating applications [19]. Iron is fourth most common element found in the Earth's crust and it is one of the components of stainless steel which is an alloy of metal Iron**,** carbon, chromium, silicon, molybdenum, and nickel. Stainless steel has the strength to withstand high pressure and temperature. Stainless steel is corrosion-resistant steel used extensively used to produce surgical appliances.

Heavy metals are not destroyed in the incineration process but are simply concentrated up to high levels in the ash residues or dispersed over the surrounding environment from the incinerator stack. Emissions of metals from the stack were not covered in the current study, but may be highly significant nevertheless. Both lead and cadmium are highly toxic metals. For example, exposure to elevated levels of lead has been associated with numerous adverse effects on renal function, development and reproduction in animals and humans [20,21].

Table 1: Mean Concentration (mgkg-1) of Heavy Metals in Bottom Ash

Metals	Bugu runi	MOI	Amana	Magomeni	Mwanyamala	Temeke
As	BD	BD	BD	BD	BD	BD
Cd	BD	BD	BD	BD	BD	0.017±0.847
Cu	28.873±23.747	21.328±5.470	13.209±1.955	15.539±5.121	16.010±0.403	23.521±7.917
Fe	4091.709±5359.609	1260.027±702.989	758.714±253.508	3530.665±2927.157	3048.971±2013.462	9484.806±3148.740
Hg	BD	BD	BD	BD	BD	BD
Pb	27.537±4.373	51.571±27.330	67.413±11.064	66.315±7.773	27.772±3.406	22.607±3.907
Cr	97.848±39.150	60.328±38.396	61.477±16.742	507.805±855.061	743.750±693.762	293.209±265.879
Mn	52.574±23.527	17.130±7.918	8.267±0.103	36.297±30.552	33.915±11.722	61.704±32.544
Ni	7.506±3.608	18.013±19.034	32.858±51.716	596.906±625.913	212.298±140.305	393.615±208.951
Zn	2067.344±482.422	3047.588±1303.801	1853.374±1108.560	1369.911±847.663	349.367±10.053	1082.434±719.721

BD Means Below Detection Limit

From the results (Table 1), while As, Cd and Hg were not detected in the instrument, incinerating healthcare waste containing mercury risks public health as it readily sublimes, appearing as vapour in the environment and can be inhaled by humans. The positions of most of incinerators under study by virtue of their situation make render the heavy metals they discharge a public health risk. This is an obvious threat because when mercury in unacceptable concentration was traceable in bottom ash of incinerator, it implies that much of it had undergone sublimation and was discharged as mercury vapour in the environment in the medical hospitals under study. The healthcare waste likely to emit mercury during incineration, a heavy metal isolated from the bottom ash, includes dental amalgam from dental clinics which has 50% mercury [22], thermometers, blood pressure cuffs, laboratory chemicals, certain electrical switches, paints, fluorescent lumps and bulbs [23].

The analysis shows the concentration of heavy metals in ascending order of content was Fe > Zn > Cr > Ni > Pb > Mn > Cu. Other studies [24.25], identified range of different levels of heavy metals from bottom ash of municipal solid waste (Table 2).

Table 2: Heavy Metal Found in MSW Bottom Ash (mg/kg)

Metal	[24]	[25]	US EPA Std
As	31-95	1.3 - 45	1.5
Cd	250-450	0.3 - 61	0.005
Cu	860-1,400	80 - 10700	1.3
Fe	nd	nd	4.0
Hg	0.8-7	0.003 – 2	0.005
Pb	7,400 – 19,000	98 – 6,500	0.015
Cr	230-600	21 – 1,901	0.1
Mn	0.8-1.7	171 – 8,500	1.0
Ni	95-240	10 – 1,970	0.7
Zn	19,000-41,000	2,800 – 152,000	5.0

The highest concentration of Fe from the six hospitals ranged from 758.714±253.508 to 9484.806±3148.740 mg/kg. This is lower than other study [26], who find concentration of iron in bottom ash to be in the range of 193,462.14-581,002.34 mg/kg. However, the highest concentration of iron could be due to highest melting point of iron (1,493°C) means the larger amount of its residues due to the fact that the main component of medical equipment such as needles, hypodermic needles, scalpel, blades and others, is iron.

Zinc is one of the toxic heavy metal that is present in medical waste as large amounts of zinc may cause stomach cramps, nausea and vomiting. It can also cause anemia, pancreas damage, and lower levels of high density lipoprotein cholesterol (beneficial cholesterol). Breathing large amounts of Zn can cause a specific short-term disease called metal fume fever, especially found in bandages or needles. The concentration of zinc ranged between 349.367±10.053 to 3047.588±1303.801 mg/kg. The maximum level detected is three times lower than the amount detected by other researcher 41,000 mg/kg and 51 times lower than the amount shown in Table 2 by other researcher [25].

Nickel is another toxic heavy metal that has been detected in our experiment. Nickel sulfide fume and dust is recognized as being potentially carcinogenic. The concentration of nickel ranges from 7.506±3.608 to 596.906±625.913 mg/kg. The different research [25] detected highest value 1,970 mg/kg which is three times higher but the highest concentration detected in this research is 2 times higher than the value detected by different researcher [24]. When compared with USEPA regulation limits all these concentrations are above the acceptable limit.

Chromium concentrations ranged from 60.328±38.396 to 743.750±693.762 mg/kg. The highest level detected is approximately equal to levels detected by other [24], but half the amount detected somewhere else [25]. Basically, chromium is used in tanning, wood conservation and pigments and dyes for plastics, paint and textiles and in some instances Cr alloys [27]. This may mean that the presence of Cr in the incinerated hospital waste ash residue may be due to the presence of plastics in the incinerated waste.

Other metals like lead ranges from 22.607±3.907 to 67.413±11.064 mg/kg while in another research [28] ranges between 7,400 – 19,000 mg/kg. Hospitals mostly incinerated sharps which consisted of needles and plastic syringes and therefore it was not surprising that the Pb content was high. Even though sharps are also burnt in incinerators, they were normally mixed with other combustible waste which probably contributed to the level of Pb in the ash residue. Another reason for high level of lead could be due to lower melting point of lead (328°C) than incineration temperature (550-950°C). Therefore, lead compounds might have melted during incineration process and adsorbed on surface area of bottom ash. Other metals manganese and copper varies 8.267±0.103 to 61.704±32.544 mg/kg and 13.209±1.955 to 28.873±7.917 respectively. These amounts are extremely lower compared to amount detected somewhere else [25].

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IV. Conclusion

The study revealed varied heavy metals concentrations in the bottom ashes from the incinerated medical hospitals waste. From the

incinerators, the studied heavy metals were found to be present in the decreasing order (Fe > Zn > Cr > Ni > Pb > Mn > Cu) of concentration. As most of these pollutants are persistent, probably lasting for centuries, they will sooner or later threaten the environment where their removal would be near impossible and they are known to have high leachability [29]. Allowing this to take place is an abdication of our responsibility to future generations. Except for mercury, the heavy metals do not naturally occur in the environment in metallic form. Heavy metals in the waste will sooner or later - dependent on the treatment method are transformed into other chemical or physical forms. All the heavy metals can exist in a wide variety of physical and chemical forms and several forms will coexist in a certain media. The distribution on the different forms (speciation) is important for the transport and the bioavailability of the metals. Surprisingly there is no regular monitoring of heavy metal concentrations in the bottom ashes of the incinerators in the medical institutions to quality to ensure for safe disposal of bottom ashes in the environment. Also TBS do not specify the standard of permissible levels of these heavy metals from the incinerators.

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