

**Original Research Article**  
**Heavy Metals Identification and Detection in  
Incinerated Bottom Ash from Biomedical Solid  
Waste in Selected Healthcare Facilities in  
Douala, Cameroon.**

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**ABSTRACT**

**Aims:** To identify and detect heavy metals in incinerated bottom ash of Biomedical Solid Waste in selected healthcare facilities in Douala, Cameroon.

**Study Design:** Cross-sectional fieldwork and laboratory based study design approach that involved quantitative and qualitative data collection methods

**Place and Duration of Study:** This study was carried out in the Douala, Littoral region of Cameroon from the month of January 2023 to June 2023.

**Methodology:** 5 grams of filtered incinerated bottom ash from BSW were collected from incinerators of the selected healthcare facilities using labeled plastic polyethylene containers and transported to the laboratory for analysis. Samples were air dried and introduced on polypropylene film to the EDX 7000 spectrometer for sensitive analysis.

**Results:** Both the quantitative and qualitative concentration percentage of the heavy metals detected from Na to Uranium in each HCF was determined by the EDX 7000 spectrometer device. Zinc had a significant concentration percentage in BDH ( $7.491 \pm 0.009333\%$ ), LH ( $4.255 \pm 0.009\%$ ), GH ( $7.506 \pm 0.013\%$ ), AHD ( $6,903 \pm 0.012\%$ ) and Iron had a significant concentration percentage in GOHD ( $3.669 \pm 0.013\%$ )

**Conclusion:** From the results obtained in this study, it is concluded that improper disposal of incinerated BA from incinerators may pollute the environment and water bodies through leaching into ground water or be carried into water bodies through runoffs, be inhaled in dust from the dump area, and bioaccumulate in plants and animals that stray to the dump site, leading to possible health implications such as respiratory diseases, cancers, etc. while also negatively impacting the environment. Some heavy metals assessed by this study from incinerated bottom ash were above the permissible limits by the USEPA criteria. Ensuring proper disposal of BA through sanitary landfills may contribute to minimize the heavy metals and hazardous components in the environment, also protecting the human health. There is therefore the need to improve the waste management practice through recycling BA to avert further environmental pollution and human exposure to these elements. It is also recommended that health care waste managers be trained in safe handling of incinerator bottom ash and disposal strategies, and regulatory bodies should also monitor and enforce guidelines for bottom ash management in local health care facilities. Accordingly, this study is of fundamental importance in Cameroon, a developing country that needs to focus on environmental issues that also benefit human health. Segregation at source, awareness, and precautions at all step of the waste cycle as well as proper incineration and bioremediation will lead to sustainable prevention on waste and heavy metals in different HCFs.

*Keywords: Heavy metal, biomedical solid waste, Bottom ash, Healthcare facilities, Douala, Cameroon.*

# 1. INTRODUCTION

Biomedical Solid waste (BSW) is a relevant problem for several countries and poses serious public health threats worldwide as growing human activities in a community continuously creates waste that is mishandled in disposal [1]. Nearly 3.2 million tons of biomedical waste is generated by hospitals alone annually and the Environmental Protection Agency (EPA.2019) estimates that 10% to 15% of all biomedical waste is potentially hazardous [2].

According to the World Health Organization (WHO), nearly 85% of waste generated by the hospitals is general waste and about 15% of waste is biomedical waste, composed of 10% of infectious wastes and 5% of non-infectious wastes like radioactive and chemical wastes [3]. In developing countries, especially in Africa, BSW has not received the attention it deserves [4]. The recent population growth and the outbreak of diseases such as the Ebola virus, severe acute respiratory syndrome (SARS), coronavirus disease of 2019 (COVID-19), cancer and other illnesses [5] have significantly increased medical activities globally. Unfortunately, medical activities have also contributed to the rising generation of biomedical solid waste (BSW), making it difficult to be managed [6], especially in developing countries such as Cameroon [7]. A study by Oli et al. [8] also revealed that more than 40% of infectious BSW is generated in Southeast Nigeria health facilities. In Cameroon the waste stream is complex and heterogeneous with an average waste generation rate estimated at 44.9 kg/day equivalent to over 16 tonnes/annum comprising **49%, 16% and 14%** of general, infectious and sharps respectively for a typical Health Care Facility in Buea which is a medium densely populated town. These values are higher than the recommended 15% limit by the World Health Organization [8], [9], [10]. According to a research carried out by Nkwenti P. et al (2023), Nickel was one of the heavy metals found in surface water in Douala Bonaberi industrial zone [11]. This could adversely impact the environment and public health through uncontrollable disposals, like dumping in the open space and pit burning as seen in other researches carried in Africa [12], [13], [14], [15], [16], [17], [18], [19], [20]. The improper handling of BSW has hindered achieving of some of the sustainable development goals (SDGs) in most developing countries, specifically good health and well-being (SDG3), clean water and sanitation (SDG6) and climate action (SDG13) [21], [22]. The heavy metal concentration, which is above threshold level, could be dangerous to aquatic as well as human health. Ecosystem contamination from heavy metal pollution may damage marine organisms at the cellular level and possibly affect the ecological balance [23]. These include laryngeal cancer [24], gastric cancer [25], [26], liver cancers [27], and urinary mutagen [28]. Other research also indicate that incinerator operators can present a significant level of mercury in their hair [29], lead and cadmium in blood [30] and hexachlorobenzene in blood/urine [31]. It is the case in Cameroon. Some of the higher concentration can be of high risk to human and the environment if not disposed of properly. Heavy metals and elements such as Ca, Cl, Zn, K, Fe, Ti, Si, P, S, Pb, Br, Cu, Sr, Cr, Mn, Rb, Ni, Zr, Sn, Sb can be identified in bottom fly ash and bottom ash of incinerator. Burning in waste pits releases toxic gases into the air that could endanger the ecosystem [32]. In the Northwest region of Cameroon, poor waste management practices observed in some health care facilities has been attributed to lack of sufficient awareness on environmental and public health impacts of poor clinical waste disposal [33].

In Cameroon, only a limited number of HCFs have incinerators. Although Cameroon have rectified the guidelines advocating for controlled disposal of biomedical waste incinerator bottom ash at landfills, some HCFs workers do not respect these regulations and guidelines put in place. The key components indicated in the guideline are: monitoring of hospital waste incinerator bottom ash quality, environmental pollution potential, and treatment strategies so as to ensure the safety of hospital incinerator bottom ash to be disposed of [34]. In most African countries where the observations made at the waste incinerator sites, continuous dumping of bottom ash in an open dump pit very close are been done. This habit can lead to high toxic heavy metal levels observed in soils around the dumping site.

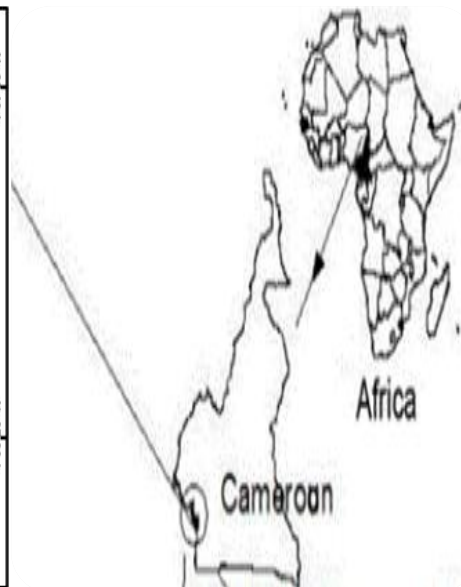
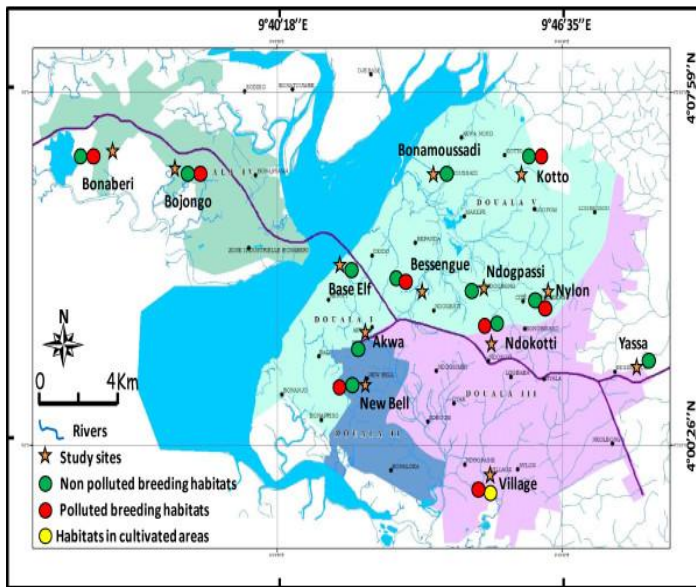
The Shimadzu EDX - 7000 spectrometer was used to analyze the heavy metals from the incinerated BA from the selected HCFs which gave us qualitative and quantitative results. Therefore, this study aims at detecting and identifying heavy metals present in incinerated bottom ash of BSW of selected health care facilities (HCFs) cases of five health care facilities: Bonassama district hospital (BDH), Gyneco-obstetric hospital Douala (GOHD), Laquintinie hospital (LH), and General hospital Douala (GHD) and Acha Hospital Douala (AHD) in Douala, Littoral region of Cameroon.

## 2. MATERIAL AND METHODS

### 2.1 Study Area

Douala is the largest city in Cameroon and its economic capital. With 5 768 400 inhabitants in 2015, Douala is the most populated city in Cameroon with about 4 063 000 inhabitants in 2023. It is situated on the Southeastern shore of the Wouri River estuary, on the Atlantic Ocean coast about 130 miles (210km) west of Yaounde, the political capital of Cameroon. [35]

In this study, the targeted populations were health personnels in the selected HCFs. 200 participants were investigated in this research. The study area comprises of selected missionary, public and private HCFs within the Douala premises which includes Bonassama district hospital (BDH), Gyneco-obstetric hospital Douala (GOHD), Laquintinie hospital (LH), General hospital Douala (GHD) and Acha Hospital Douala (AHD). These HCFs possessed incinerators for the collection of bottom ash samples from biomedical solid waste.



**Figure 1: Location of Selected Healthcare facilities in Douala**

## 2.2 Study Design and Data Sources

The study was a cross-sectional fieldwork and laboratory based study design approach that involved quantitative and qualitative data collection methods carried out from January 2023 to June 2023. Primary data were gathered from the incineration of samples of BA from BSW collected in the 5 selected HCFs. Ethical clearance was sought from the Institutional Ethics Committee for Research on Human Health of the University of Douala. Administrative authorizations for the study were acquired from the Littoral regional delegation for public health and authorizations from the different HCFs. Only waste handlers and workers/individuals who gave their consent were recruited into the study. Qualitative data on the incineration process of BSW in BDH, GOHD, LH, AH and GHD were obtained through critical observation and BA analyses using Edx 7000. The time frame for the data collection was 3 months. There was a daily check and observation of the waste type fed into the incinerators and how the BA was disposed of after incineration. In addition, the incinerated BAs were collected and sent to the laboratoired'analyse des contaminants Radiologiquesetmetauxlourdsdans les produitshalieutiques (university of Douala), for analysis.

## 2.3 Sample Collection and Preparation

### 2.3.1 Sample Collection

This involves requirements such as plastic polyethylene containers, spatula, polypropylene film, polyethylene papers, EDX 7000 machine, small wooden mortar and pistol. 5gram of incinerated BA from BSW was collected from two different areas in the incinerator and large particles were removed and the rest transported to the laboratory. This was repeated in the various selected HCFs.

Na-U qualitative/quantitative analysis of the EDX 7000 machine is the standard method for powder/ fine particles analysis. Performing measurements in a vacuum achieved sensitive measurements of light elements. The machine then read and gives all the concentration quantitatively and qualitatively and their various percentages as well as graphical results were obtained. Incinerated BAs (0.27 tons and 0.07 tons) were produced every week after the incineration of BSW from BDH, GOHD, LH, AHD and GH incinerators.

### 2.3.2 Sample Preparation

The powdered samples were dried using the sun rays for 4hours and then ground in a mortar to be uniform. The sample was placed in a sample container lined with a 5um-thick polypropylene film and lightly pressed down for measurement. A pre-treatment of the metal sample is done by polishing the sample surface with lathe and rotary polishing machine which will enhance the quantitation precision for the metal samples or eliminate the effects of contamination or oxidation on the sample surface. Ground sample of at most 12mm of diameter was used and the bottom of the cell is covered with a film before adding the sample. The sample is later covered with film.

## 2.4 Procedure and Technique

### 2.4.1 Technique

When a sample is irradiated with X-rays from an X-ray tube, the atoms in the sample generate unique X-rays that are emitted from the sample. Such X-rays are known as 'fluorescent X-rays' and they have a unique wavelength and energy that is characteristic of each element that generates them. Consequently, qualitative analysis can be performed by investigating the wavelengths of the X-rays. As the fluorescent X-ray intensity is a function of the concentration, quantitative analysis is also possible by measuring the amount of X-rays at the wavelength specific to each element [36].

### 2.4.2 Procedure

Prepared samples of bottom ash were transported to the Laboratoire D'analyse Des Contaminants Radiologiques et Metaux Lourds dans Les Produits Haleutiques, University of Douala. The samples were quantified using energy dispersive X-ray fluorescence spectrometer (EDX-7000, Na-U, Shimadzu, Japan) with loose powder method, calibration with Al-Cu standard [37–40]. Five-gram powder from the samples of bottom ash in replication of three were placed over a thick film lined a 10 mL Polypropylene cup and then mounted inside the EDX-7000 spectrometer [41]. The instrument is equipped with an X-ray tube using Rhodium (Rh) target and a high-performance silicon drift detector (SDD), operated with a maximum of 50 kV and 1000  $\mu$ A and a PCEDX-Navi software. The elemental composition of all samples was detected under an air based atmosphere. The analytes were then assessed with a collimator of 10 mm in diameter with a live acquisition time of 60s [42].



Figure 2: Shimadzu EDX-7000 analysis device

## 2.5 Data Analysis

The standard limits of heavy metals and other substances in BSW in the different HCFs according to USEPA and WHO were recorded from the literature review. The determined levels of heavy metal in the samples were then compared to this standard limits in order to establish whether the levels of pollution in the environment and health was above the local and internationally acceptable standards. In addition to make reliable conclusions, they were used to conduct the analysis of the data. Descriptive statistics involved computing mean and standard deviation (SD) for the different variables measure in BA in the selected HCFs samples.

To identify and determine the concentration of heavy metals; measurements were determined using EDXRF on a Shimadzu EDX-7000 spectrometers shown in Figure 2. Indeed, a given amount of powder of our samples was put into the bottom of cell; and covered with plastic film. Then, the cells were placed in the X-ray chamber and analyzed. The EDX-7000 incorporates a new high-performance solid state detector, which offers excellent sensitivity, resolution and throughput for a wide range of applications, from general screening analysis to advanced materials research in areas such as chemistry. These tools allow the analysis of the various heavy metals in any sample between Sodium (Na) and Uranium (U). Some of the heavy metals detected are as follows;

Ca (Calcium), Cl (Chlorine), Zn (Zinc), Ti (Titanium), Si (Silicon), Fe (Iron), K (Potassium), S (Sulphur), Br (Bromine), Cr (Chromium), Sr (Strontium), Cu (Copper), Ni (Nickel), Zr (Zirconium), Mn (Manganese), Rb (Rubidium), Al (Aluminium), Pb (Lead), Sn (Tin), Sb (Antimony)

### 3. RESULTS

All heavy metals assessed in bottom ash were within detectable limits. Table 1 below shows the mean of heavy metals detected in incinerated bottom ash. In a descending order of concentration  $Ca > K > Cl > Zn > Ti > Si > Fe > Al > Pb > S > Br > Cr > Sr > Cu > Ni > Zr > Rb > Sn > Sn$ , some were all found to be above USEPA allowable limits for safe disposal to a landfill site. Our findings were similar to studies conducted in Kenya [43, 44]. The heavy metals found in the bottom ash are usually associated with the waste feed stock (thermometers, blood pressure cuffs, laboratory chemicals, plastics, syringes, etc.) or construction material of the incinerators [45]. The non-metal and heavy metal concentrations from BA of BSW with the USEPA standard in the various HCFs are presented in the table below;

Metals	Acha Hospital (AH) %	Laquintinie hospital (LH) %	Gyneco-obstetric hospital Douala (GOHD) %	Bonassama District Hospital (BDH) %	General hospital Douala (GHD) %	USEPA Std
Ca	70,090±0.069	75.727±0.073	66.972±0.075	70.423±0.068667	61.912±0.070	
Cl	7,602±0.040	12.527±0.047	NA	NA	10.187±0.051	
Zn	6,903±0.012	4.255±0.009	NA	7.491±0.009333	7.506±0.013	
Ti	6,780±0.033	2.941±0.020	0.341±0.012	5.813±0.029	4.004±0.025	
Si	3,257±0.042	1.452±0.043	0.634±0.034	6.723±0.06	2.918±0.038	
Fe	1,856±0.009	1.515±0.007	3.669±0.013	5.927±0.015333	4.492±0.014	0.3
K	1,300±0.008	0.693±0.010	26.356±0.041333	1.284±0.008	5.193±0.020	
S	1,160±0.008	0.55±0.010	0.738±0.006	1.43±0.010667	0.8±0.013	
Br	0.762±0.003	0.074±0.002	NA	NA	0.239±0.003	
Cr	0.105±0.005	NA	NA	0.061±0.004667	0.08±0.005	0.005
Sr	0.093±0.002	0.115±0.002	0.598±0.002	0.139±0.001667	0.084±0.002	
Cu	0.09±0.002	0.12±0.002	0.096±0.003	0.205±0.003	0.187±0.003	0.5
Ni	0.002±0.002	0.002±0.002	NA	0.002±0.002333	0.058±0.003	0.1
Zr	NA	0.028±0.001	NA	0.152±0.001667	0.052±0.002	
Mn	NA	NA	0.29±0.005667	0.435±0.004	0.061±0.004	1,0
Rb	NA	NA	0.24±0.002333	0.023±0.001333	0.058±0.002	
Sn	NA	NA	NA	0.137±0.005667	NA	
Sb	NA	NA	NA	0.123±0.006667	NA	
Al	NA	NA	NA	2.478±0.171333	NA	
Pb	NA	NA		0.152±0.004667	0.615±0.007	0.5

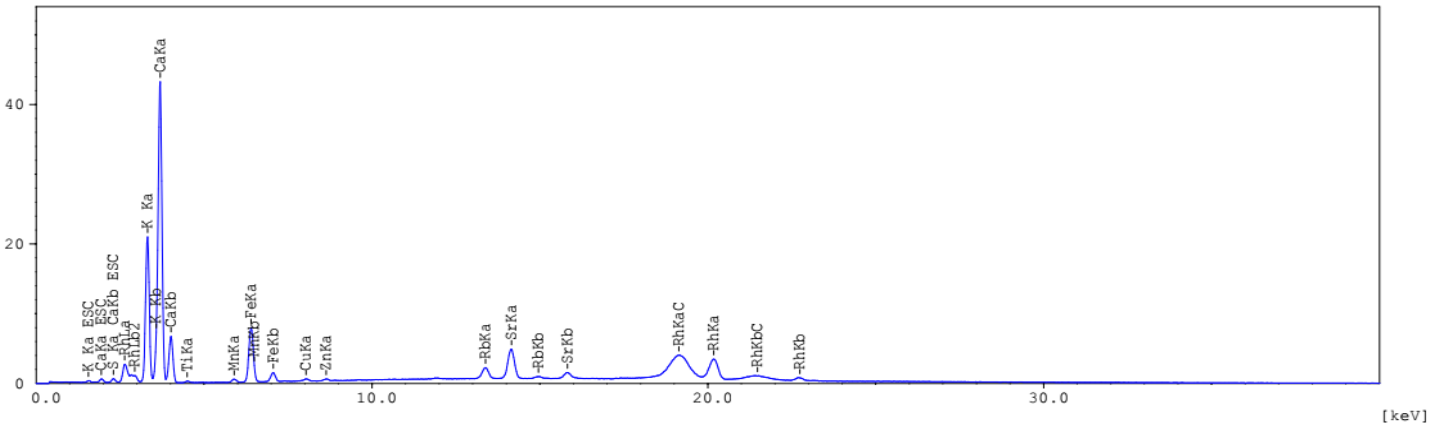
**Table 1: Heavy and trace metal concentration in the selected Health care incinerators**

NA: not available

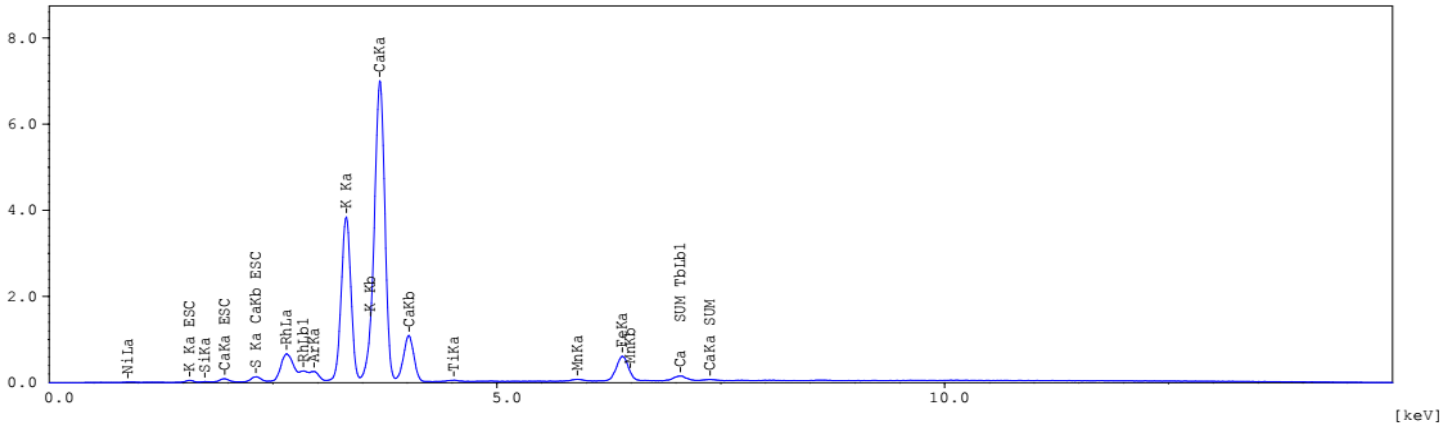
### Figure 3: Gyneco-Obstetric Hospital Douala

Operator: Dr DJOPNANG Justin    Comment : n°4\_Nkventi peter  
[cps/uA] Al-U

01/01



[cps/uA] Na-Sc

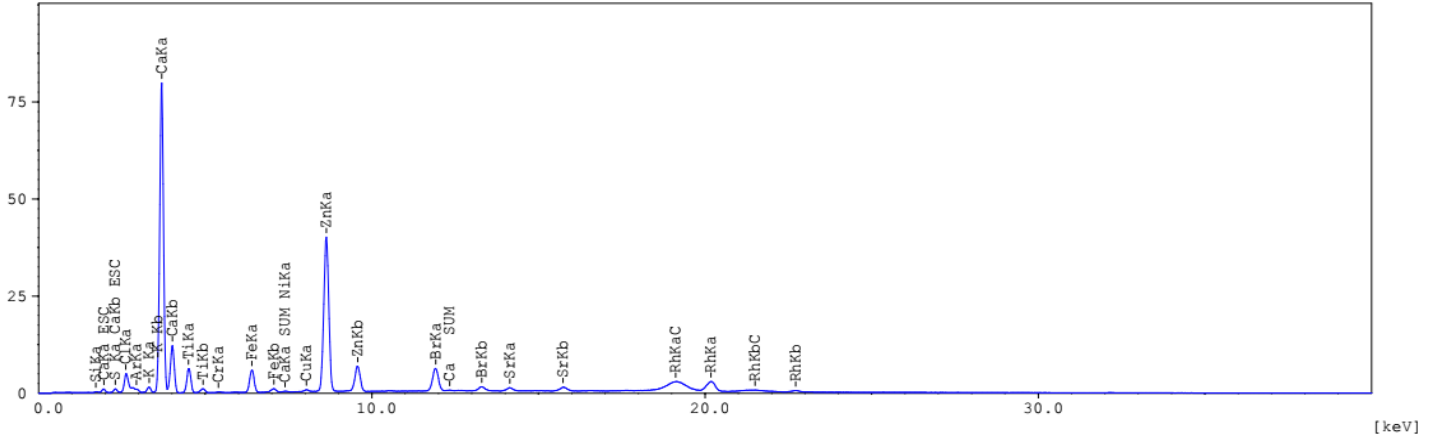


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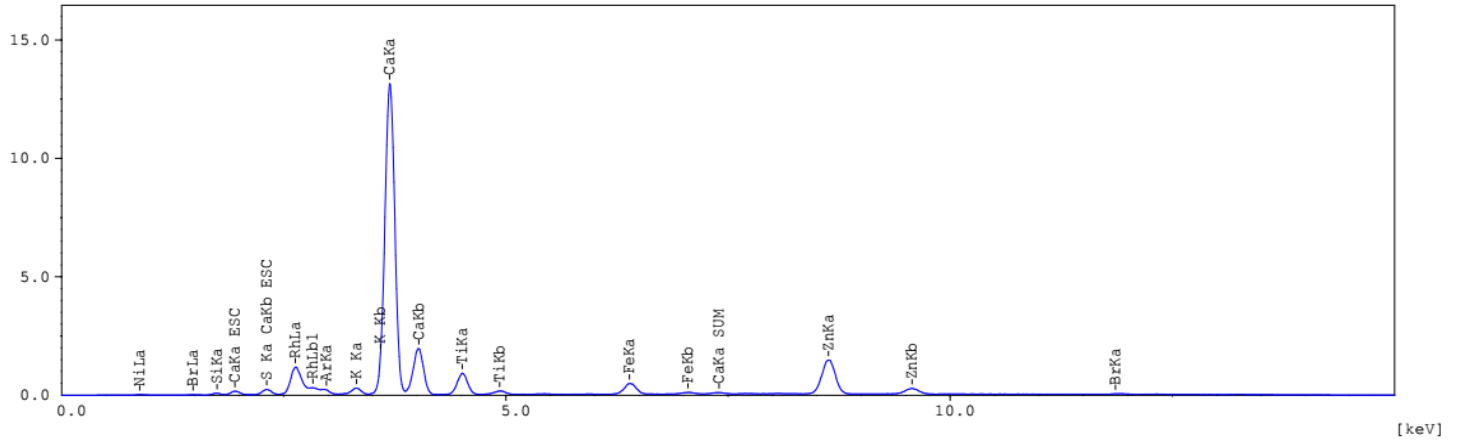
# FIGURE 4: ACHA HOSPITAL

Sample : Acha                      Group : easy                      Date : 2023-05-30 19:35:35  
 Operator: Dr DJOPNANG Justin    Comment : n°2 Nkwenti peter                      01/01

[cps/uA] Al-U



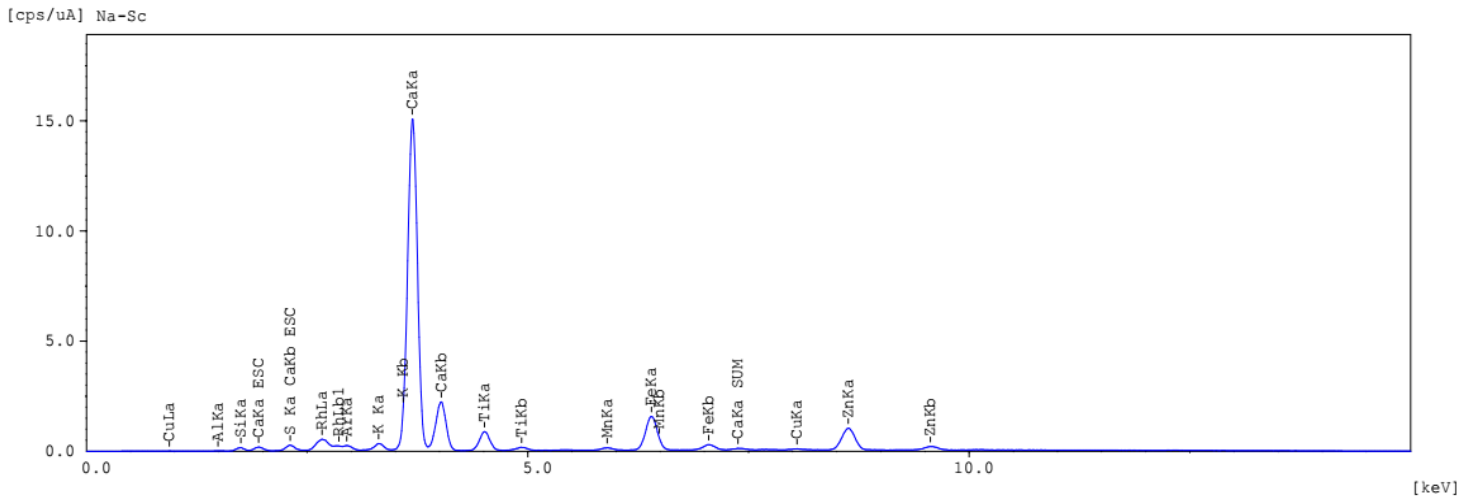
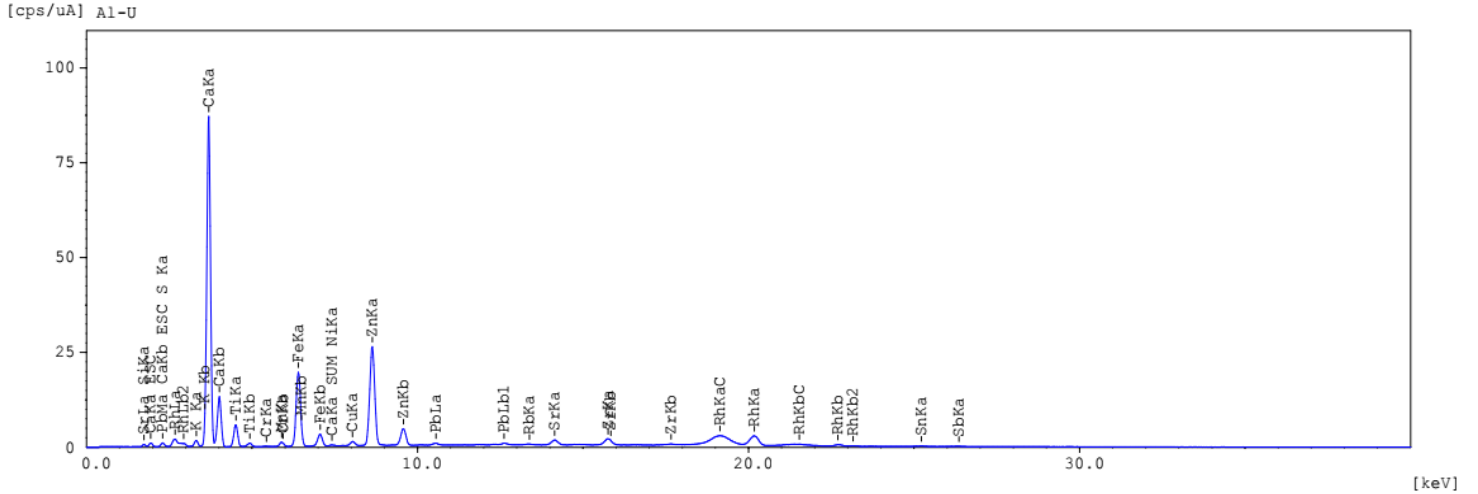
[cps/uA] Na-Sc



UNDEF

# FIGURE 5: BONAMASSA DISTRICT HOSPITAL

Sample : Bonassama      Group : easy      Date : 2023-05-30 19:33:20  
 Operator: Dr DJOPNANG Justin      Comment : n°1 Nkenti peter      01/01

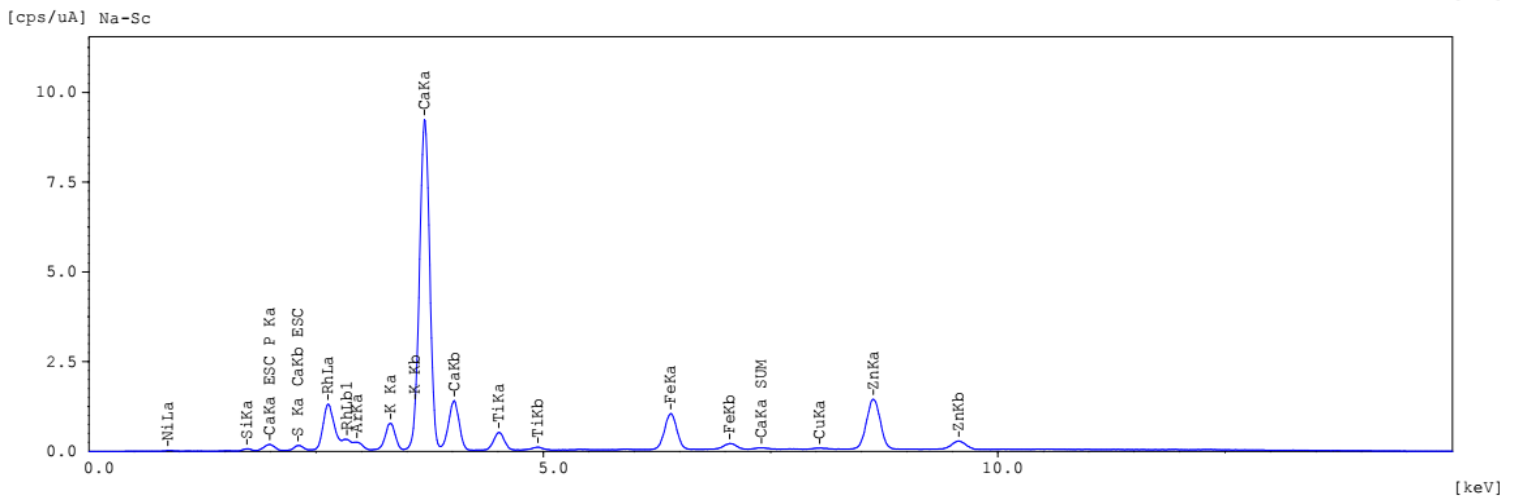
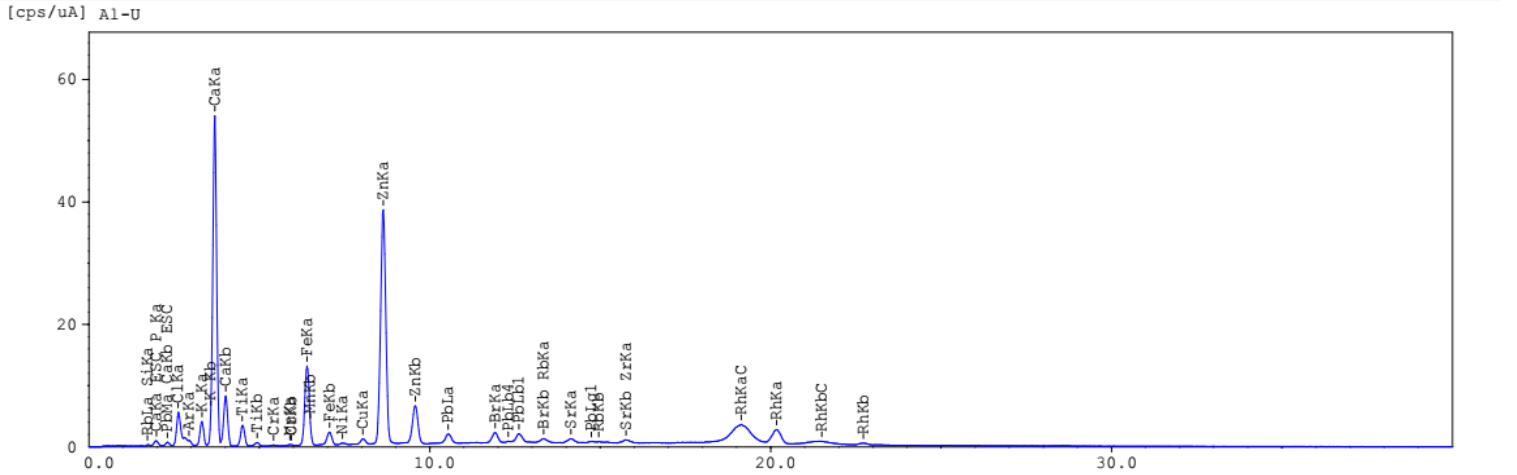


UNDEF

# FIGURE 6: GENERAL HOSPITAL

Sample : HGD générale      Group : easy  
 Operator: Dr DJOPNANG Justin      Comment : n°5 Nkwenti peter

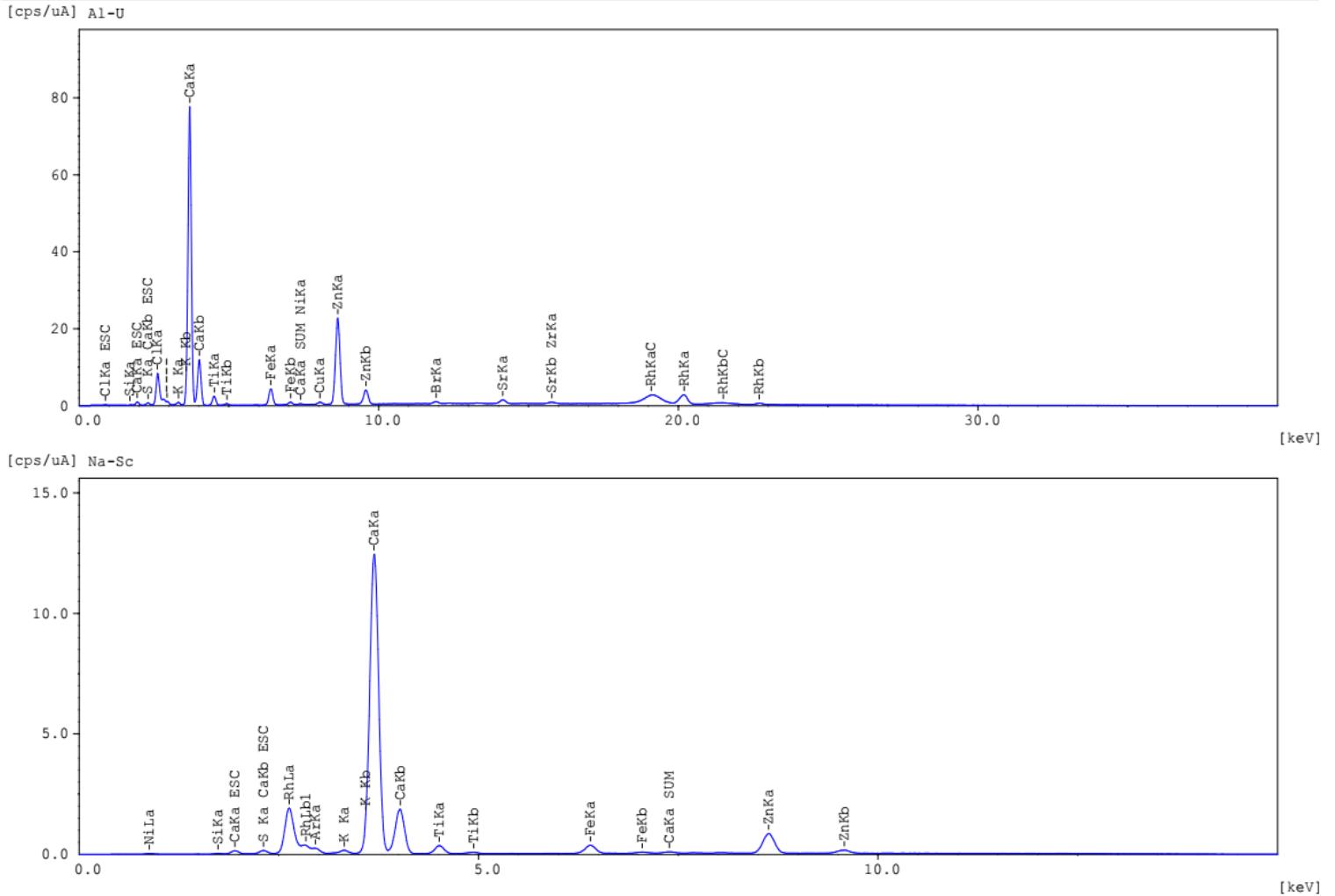
Date : 2023-05-30 19:42:13  
 01/01



UNDER

## FIGURE 7: LAQUINTINIE HOSPITAL

Sample : laquintinie HLNIE Group : easy Date : 2023-05-30 19:37:52  
 Operator: Dr DJOPNANG Justin Comment : n°3 Nkwenti peter 01/01



## 4. DISCUSSION

The incinerated bottom ash samples from the five hospitals were tested for heavy metal concentration (Cu, Fe, Zr, Zn, Mn, Cr, Pb, Al, Sn, Rb, Ni, Sb, and Ti). Other elements were also detected alongside the heavy metals such as Calcium, Potassium, Sulphur, Bromine etc. Most of these toxic heavy metals are required in human body and they can be present in all tissues of the body as trace elements. Therefore, it is not surprising to find high level of these toxic metals because waste materials from these selected HCFs contain pathological human parts such as placentas which are always incinerated.

Although this incineration process reduces the volume and weight of BSW, it also produces BAs that contains heavy metals and oxides, toxic to human health and the environment. These values can be reduced if proper segregation is addressed prior to incineration. High concentrations percentage values of heavy metals, specifically Fe, Zn, Pb, Cu, Mn were found in most HCFs incinerators above USEPA permissible soil limits.

This study helped to obtain higher mean concentrations of Ti, Fe and Zn in BDH, GOH, AH and GH, similar to a study conducted in China on pollutants of BMW BA [46]. The higher concentration of Ti, Fe and Zn in BA is because they are

widely used as metal alloys in medical equipment [47, 48, 49]. However, due to their high melting point, above the temperature used in incinerators, Ti and Fe tend to be present in BA.

Some metals found in BA could contain toxic contaminants that can be persistent in the environment (such as Pb, Ni, Cu and Cr) [50], negatively impacting it [51]. The mean concentration of Ti, Cr, Cu, Mn and Pb released from BDH, GOHD, AH and GH BA exceeded the USEPA standard limits of heavy metals in soil, including Fe from GOH BA, as shown in Table 1 above. Due to its high content of heavy metals concentration value, the improper disposal of this incinerated BA could negatively impact the environment and public health. Each heavy metal has different properties and impacts, in terms of human health effects. As example, the exposure to high concentrations of Zn corresponding to  $6,903 \pm 0.012\%$ ,  $4,255 \pm 0.009\%$ ,  $7,491 \pm 0.009333\%$  and  $7,506 \pm 0.013\%$  respectively, in AHD, LH, BDH, and GOHD. Zinc is one of the essential elements to human beings and also one of the toxic heavy metal that is present in medical waste as large amounts of zinc may cause stomach cramps, nausea and vomiting to health. 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. This is also due to the fact that Zn forms many metallic alloys used in the HCFs e.g. Al/Zn alloys. [52] Ti is one of the most hazardous heavy metals, negatively impacting the environment and human health, Ti contained in incinerated BA samples could cause coughing, tightness and chest pains [53]. Zn and Fe present in the BA may cause nausea, vomiting and anaemia [54].

As seen by the results being presented, the disposal of incinerated BA resulting from BSW incineration needs to be properly addressed since the resulting BA can threaten ecosystems and humans. The heavy metal component in the BA can leach out into water bodies, groundwater and soil, polluting the environment and possibly causing cancer, respiratory and other issues severely affecting human health [55].

From the results obtained in this study, it is concluded that improper disposal of BA from incinerators may pollute the environment and water bodies through leachate, leading to possible health implications such as respiratory diseases and cancers, while also negatively impacting the environment. Ensuring proper disposal of BA through sanitary landfills may contribute to minimize the heavy metals and hazardous components in the environment, also protecting the human health. The advance of specific Sustainable Development Goals (SDGs), such as SDG3, 6, and 13, strongly depend on actions aimed at contributing to better handling of waste in Africa. Accordingly, this study is of fundamental importance in Cameroon, a developing country that needs to focus on environmental issues that also benefit human health. It represents a contribution to fulfill the gap of knowledge at this respect and the scarcity of studies in the Central African region.

#### 4. CONCLUSION

When incinerated BA are improperly handled and inadequately disposed, BSW generated from diagnostics centres, HCFs, blood banks, research institutions and laboratories are hazardous and negatively impact the environment and public health. In Sub-Saharan African countries in particular, and also in Cameroon, BSW is primarily incinerated. Some heavy metals assessed by this study in incinerator bottom ash were above the permissible limits by the USEPA criteria. The levels observed in the hospital incinerator BA imply the need for ash to be treated before safe disposal. Unfortunately, this is not the situation and incinerated BA is dumped in an open pit close to the incinerator. Our study also revealed the surrounding landfill and soils from the incinerator can be polluted with heavy metals. These metals can leach into ground water or be carried into water bodies through runoffs, be inhaled in dust from the dump area, and bioaccumulate in plants and animals that stray to the dump site. We anticipate that continuous exposure to heavy metals in BA and soil may pose direct health risk to waste workers at the incinerator site and the public in general and remotely through the consumption of exposed plants and animals that may have accumulated heavy metals in their tissues and water sources contaminated with heavy metals or by the inhalation of heavy metal laden dust from polluted soils or ash.

There is therefore the need to recycle the BA and/or improve the waste management practice at the incinerator site to avert further environmental pollution and human exposure to these elements. It is also recommended that health care waste managers be trained in safe handling of incinerator bottom ash and disposal strategies, and regulatory bodies should also monitor and enforce guidelines for bottom ash management in local health care facilities. Segregation at source, awareness, and precautions at all step of the waste cycle as well as proper incineration and bioremediation will lead to sustainable prevention on waste and heavy metals in different HCFs.

## CONSENT

Written informed consent was obtained from each participant before their enrollment into the study.

## ETHICAL APPROVAL

All authors hereby declare that all experiments have been examined and approved by the Institutional Ethics Committee for Research on Human Health of the University of Douala, regional ethical committee approvals. The Institutional Ethics Committee for Research on Human Health of the University of Douala Project number is 3491/IEC-UD/01/2023/T.

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