



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

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## **Authors' contributions**

*This work was carried out in collaboration among all authors. All authors read and approved the final manuscript.*

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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

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**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:** It is concluded that improper disposal of incinerated BA from incinerators may pollute the environment and water bodies through leaching into ground water or being carried into water bodies through runoffs, being inhaled in dust from the dump area, and bioaccumulating in plants and animals that stray to the dump site, potentially having a negative impact on the environment and health risks like cancer and respiratory illnesses. Some of the heavy elements found in bottom ash that had been burned during this investigation were above the USEPA-permitted limits. Assuring proper BA disposal through hygienic landfills may help reduce the amount of heavy metals and other toxic elements in the environment, hence safeguarding human health. To prevent additional environmental damage and human exposure to these elements, waste management practices must be improved through BA recycling. Additionally, it is advised that waste managers in the healthcare industry receive training in safe incinerator bottom ash handling and disposal techniques. Regulatory organizations should also oversee and implement policies for bottom ash management in neighborhood healthcare facilities. In Cameroon, a developing nation that must concentrate on environmental challenges that also benefit human health, this study is fundamentally significant. Sustainable prevention of waste and heavy metals in various HCFs will result from source segregation, knowledge of the problem, and safeguards taken at every stage of the waste cycle.

*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, BMW 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 carries 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 identify 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-obtetric hospital Douala (GOHD), Laquintinie hospital (LH), and General hospital Douala (GHD) and Acha Hospital Douala (AHD) in Douala, Littoral region of Cameroon.

## 2. MATERIALS 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.

### 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 laboratoire d'analyse des contaminants Radiologiques et metaux lourds dans les produits halieutiques (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. 5 gram 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 characteristics of each element that

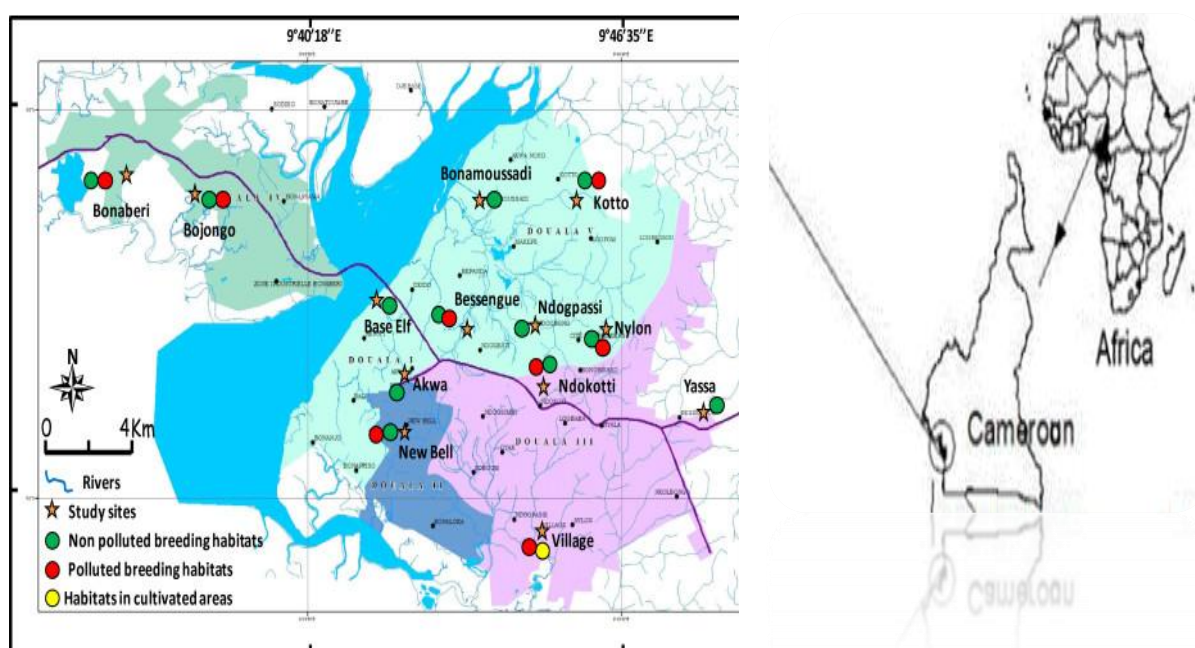


Fig. 1. Location of selected healthcare facilities in Douala

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].

#### 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 spectrometer shown in Fig. 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(surphur), Br (Bromine), Cr(Chromium), Sr(Strontium), Cu(Coper), Ni(Nickel), Zr(Zirconium), Mn (Manganese), Rb(Rubidium), Al(Aluminium), Pb(Lead), Sn(Tin), Sb(Antimony)

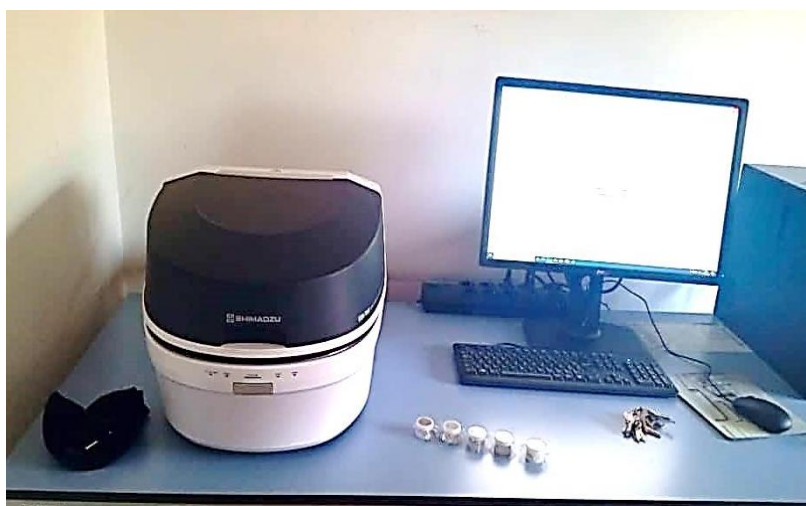


Fig. 2. Shimadzu EDX-7000 analysis device

### 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 1.

### 4. DISCUSSION

Heavy metal concentrations for the five hospitals' burned bottom ash samples (Cu, Fe, Zr, Zn, Mn, Cr, Pb, Al, Sn, Rb, Ni, Sb, and Ti) were measured. Along with the heavy metals, other elements like calcium, potassium, sulfur, bromine, and others were also found. The

majority of these harmful heavy metals are needed by the human body and can be found as trace elements in all bodily tissues. Because problematic human organs like placentas are always burned in waste products from these chosen HCFs, it is not surprising to find significant levels of these harmful metals.

Although this burning method decreases the volume and weight of BSW, it also creates BAs that are harmful to the environment and humans because they include heavy metals and oxides. If adequate segregation is addressed prior to incineration, these values can be decreased. Most HCF incinerators included high percentage values of heavy metals, specifically Fe, Zn, Pb, Cu, and Mn, beyond USEPA acceptable 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.

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

Metals	Acha Hospital (AH) %	Laquintinie hospital (LH) %	Gyneco-obstetric hospital Douala (GOHD) %	Bonassama District Hospital (BDH) %	General hospital Douala (GHD) %	USEP A 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	NA	0.152±0.004667	0.615±0.007	0.5

NA: not available

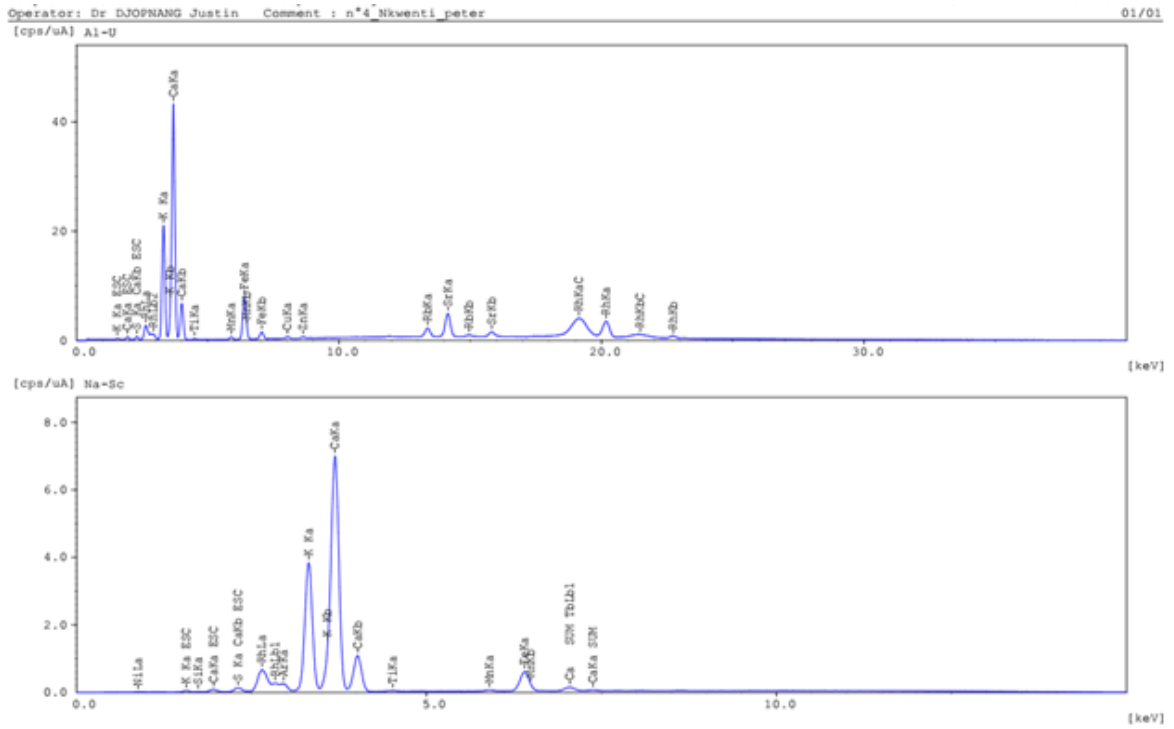


Fig. 3. Gyneco-Obstetric hospital Douala

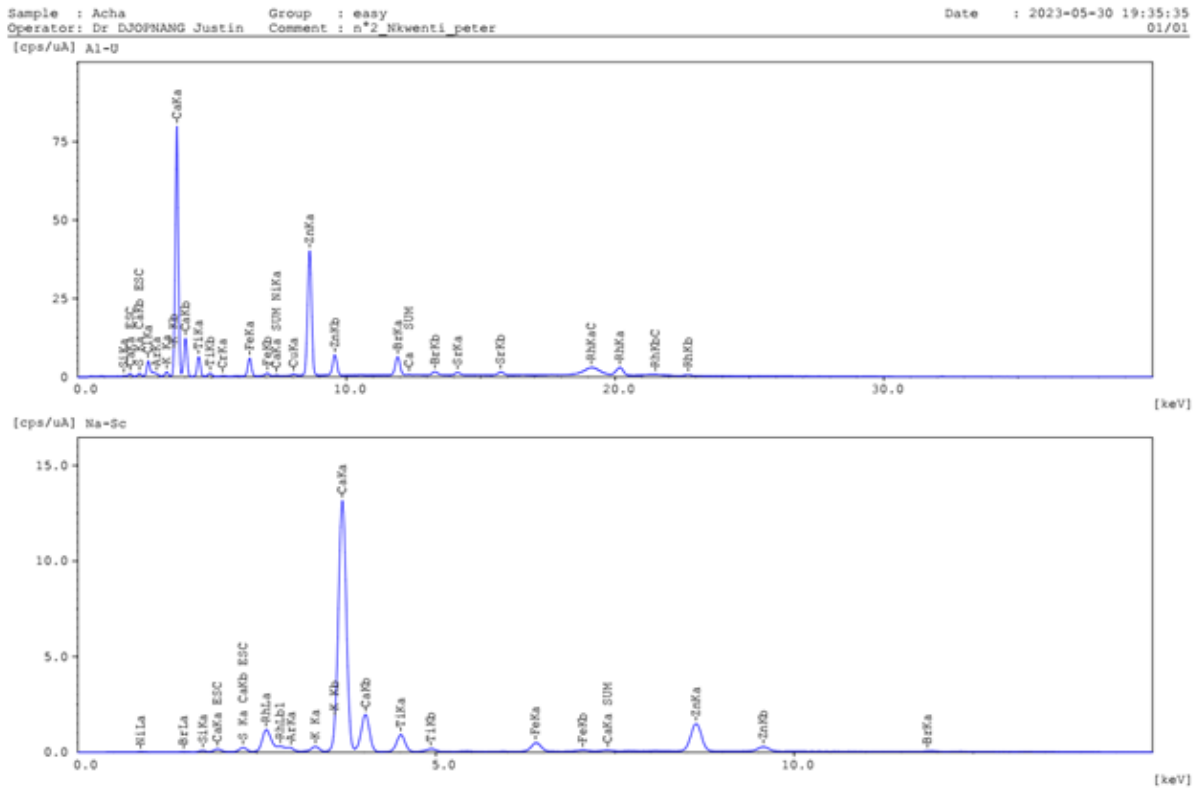


Fig. 4. Acha hospital

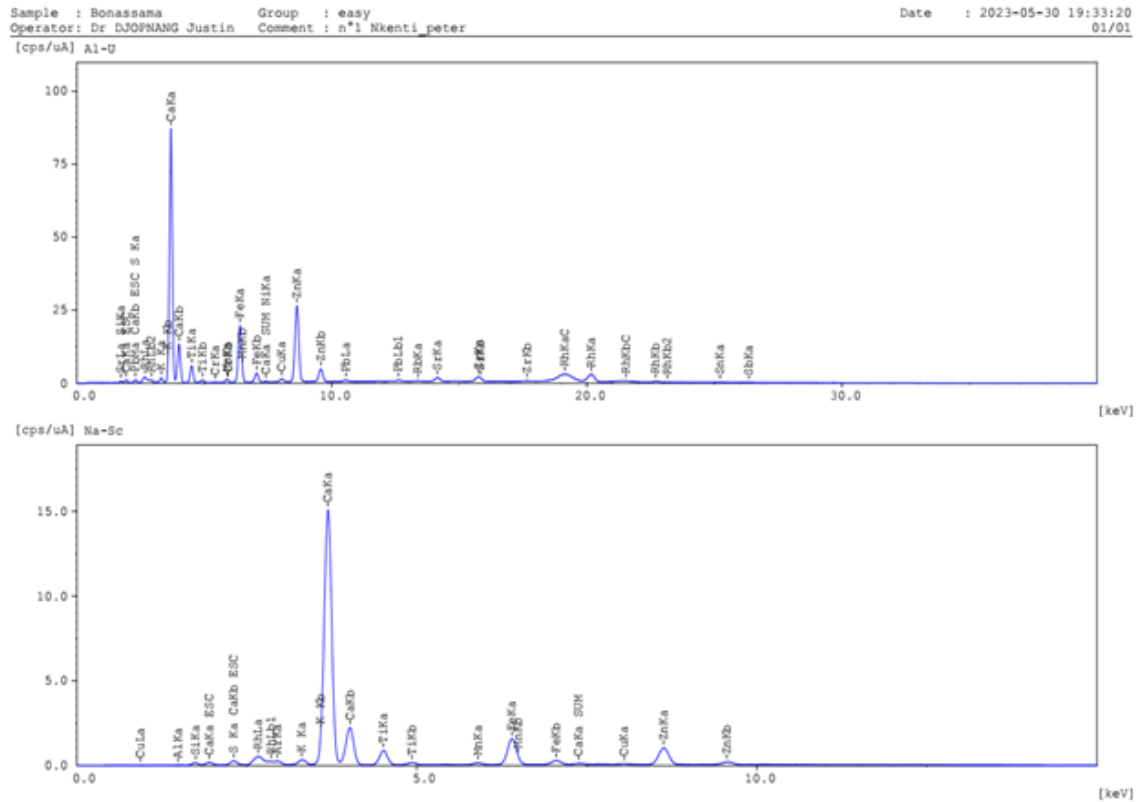


Fig.5. Bonamassa district hospital

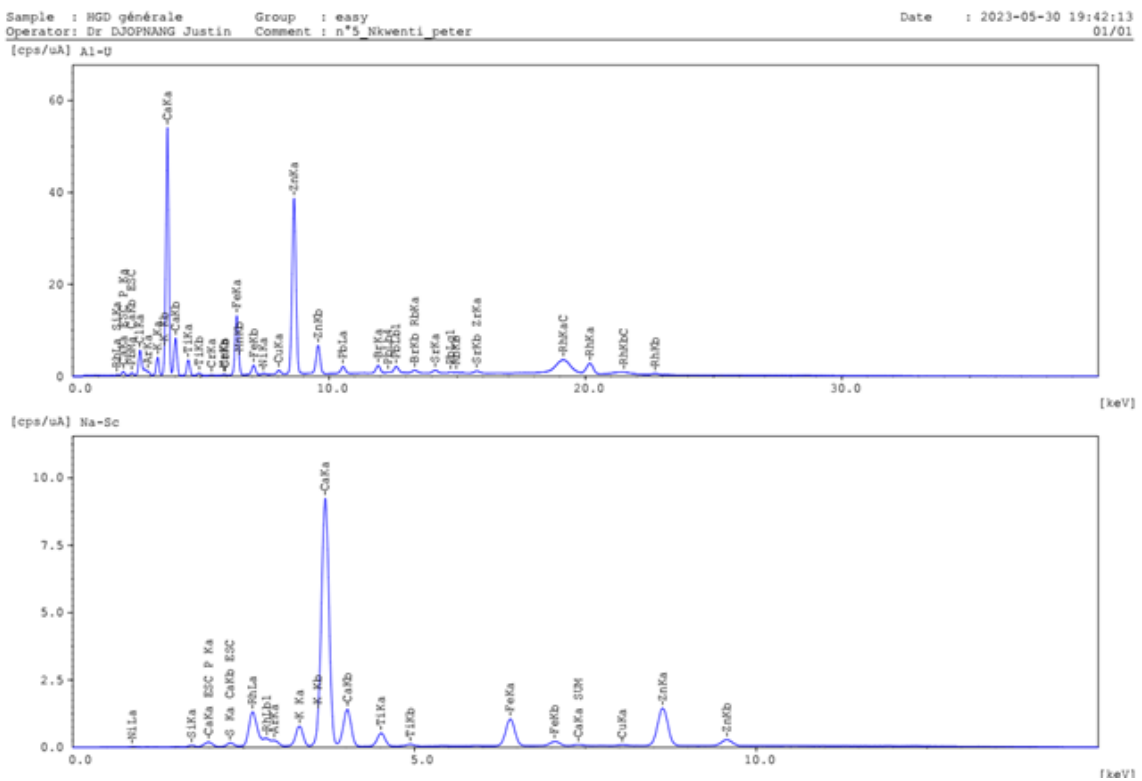
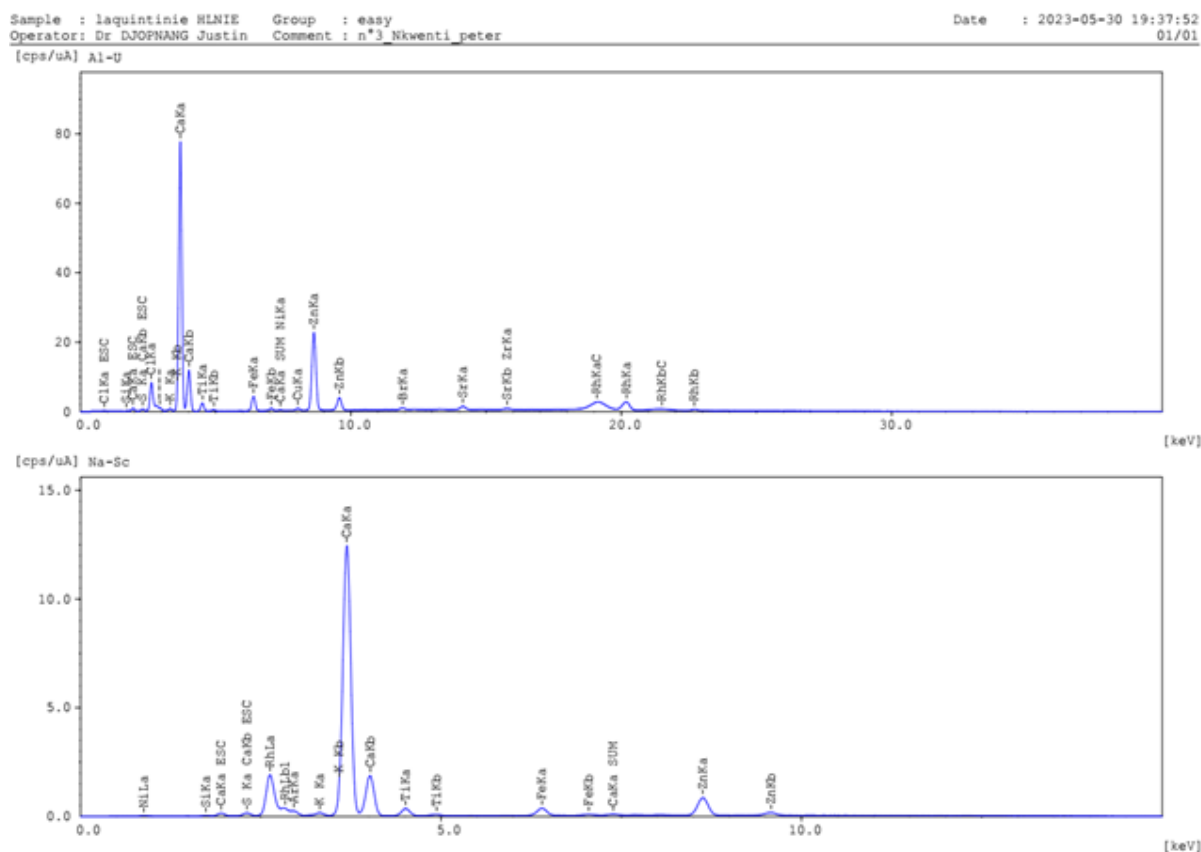


Fig. 6. General hospital





**Fig. 7. Laquintinie hospital**

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].

The results show that safe disposal of burned BA from BSW incineration is necessary since the resultant BA can endanger both humans and ecosystems. “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].

According to the findings of the study, inappropriate disposal of BA from incinerators may contaminate the environment and water sources through leachate, potentially causing cancer and respiratory illnesses as well as having a harmful influence on the environment.

Assuring proper BA disposal through hygienic landfills may help reduce the amount of heavy metals and other toxic elements in the environment, hence safeguarding human health. The advancement of particular Sustainable Development Goals (SDGs), such as SDG3, 6, and 13, depends significantly on initiatives targeted at improving waste management in Africa. In Cameroon, a developing nation that must concentrate on environmental challenges that also benefit human health, this study is fundamentally significant. It is an accomplishment.

#### 4. CONCLUSION

BSW produced by diagnostic centers, HCFs, blood banks, research institutions, and laboratories is dangerous and has a detrimental impact on the environment and public health when inappropriately managed and improperly disposed of. BSW is largely burnt in Sub-Saharan African nations, as well as in Cameroon. This study found that several heavy metals in incinerator bottom ash were beyond the USEPA-permitted limits. The levels found in the hospital incinerator BA suggest that ash needs to be processed before being disposed of safely. Unfortunately, this isn't the case, as burned BA is instead thrown nearby in an open pit. Our research also showed that soils near the incinerator and the nearby landfill could be contaminated with heavy metals. These metals may corrode.

To prevent additional environmental damage and human exposure to these elements, it is therefore necessary to recycle the BA and/or enhance the waste management practices at the incineration site. Additionally, it is advised that waste managers in the healthcare industry receive training in safe incinerator bottom ash handling and disposal techniques. Regulatory organizations should also oversee and implement policies for bottom ash management in neighborhood healthcare facilities. Sustainable prevention of waste and heavy metals in various HCFs will result from source segregation, knowledge of the problem, and safeguards taken at every stage of the waste cycle.

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#### 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.

#### COMPETING INTERESTS

Authors have declared that no competing interests exist.

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